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Review Article

A Systematic Literature Review on Integrating VANETs, VDTNs, 5G, and IoT for Smart Cities: Current Approaches, Challenges, and Future Directions

Orjola Jaupi, Evjola Spaho*

Department of Electronics and Telecommunications, Faculty of Information Technology, Polytechnic University of Tirana
***espaho@fti.edu.al**

Abstract

Nowadays smart cities have become a necessity for rapidly changing and transforming urban environments and the core technologies enabling this development are Vehicular Ad Hoc Networks (VANETs), Vehicular Delay Tolerant Networks (VDTNs), 5G networks, and Internet of Things (IoT). These technologies alone offer an important contribution, but when integrated effectively, they offer the opportunity of uninterrupted connectivity, real-time data sharing and management of urban resources. This paper conducts a comprehensive literature review to study existing techniques/approaches and challenges for integrating VANET, VDTN, 5G, and IoT within smart cities based on three research questions. Recent articles from databases such as Google Scholar, ResearchGate and MDPI, were reviewed to examine this integration, to identify recent advancements in this topic with focus on innovative methodologies proposed in an international context and to highlight the research gaps, challenges and solutions. The VOSviewer software was used to build the keyword co-occurrence network and to cluster the relevant literature. Our findings reveal that although promising solutions exist, issues such as high mobility, heterogeneous network architecture, and resource constraints remain critical barriers to large-scale deployment of smart city applications. Furthermore, this review proposes a conceptual framework for intelligent and adaptive network integration of VANET, VDTN, IoT, and 5G for future smart city applications.

Keywords: Smart Cities; VANET; VDTN; 5G; IoT; Integration, Challenges

INTRODUCTION

The concentration of population in urban areas has led to dense traffic, complex urban infrastructure, increased demand for housing, higher energy consumption, greater waste generation, environmental pollution, rising living costs, and heightened pressure on public services such as healthcare, education, and transportation. To address these challenges, it is necessary that every traditional city starts the transformation into Smart Cities, to make the urban environment more sustainable and more efficient.

New developments in vehicular communication, network resilience, ultra reliable 5G connectivity, and continuous expansion of Internet of Things (IoT) are reshaping the way urban mobility, public services and infrastructure management are conceptualized and deployed [1].

The key technologies that enable the transformation from a normal city to a smart city include Vehicular Ad-hoc Networks (VANET), Vehicular Delay Tolerant Networks (VDTNs), the Internet of Things (IoT) and the Fifth Generation (5G) of cellular networks [2]. Research has increasingly focused on the fifth-generation broadband networking (5G) and investigating its role in supporting smart city applications [3]. Smart cities use different technological solutions to improve the management and efficiency of the urban environment [4, 5]. To better understand the capabilities of each technology for smart cities purposes and services we have reviewed their main functions. VANETs support real time communication between vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). Smart city development can leverage public transportation networks to enhance IoT connectivity and reduce infrastructure costs [6]. IoT technology and sensors help with real time infrastructure monitoring and data gathering. VDTN enhances reliability in areas with interrupted network communication but also helps with network resources management regarding the information that is not crucial to send in real time [7, 8]. 5G enables low-latency communication, massive device connectivity, and high-bandwidth data transfer, which are crucial for smart cities and IoT applications, however, these capabilities also introduce new security challenges that require advanced solutions such as ML-based intrusion detection systems [9, 10]. 5G offers the right capabilities to handle the growing number of humans in urban areas, number of devices, number of sensors and big amounts of data provided by them.

After conducting systematic research on articles and contributions that are related to the integration of 5G, IoT, VANET, VDTN for smart cities and after valuing the increasing academic interest in this domain, we see a lack of comprehensive and systematic exploration of these four technologies for smart city development. We have seen that both architectural and functional integration of all these technologies is missing. Most existing studies tend to examine one or two technologies, often neglecting the architectural and operational challenges that arise when integrating heterogeneous systems under real-world urban constraints.

Taking into consideration all mentioned above the integration of all these technologies together may unlock the full potential in supporting smart cities in many applications such as intelligent transport systems, emergency response coordination and autonomous vehicle routing etc.

This review focuses on current challenges faced during the integration of these four technologies, current architecture design principles and integration patterns. Through this review, we aim to provide a consolidated reference point for understanding and advancing the convergence of intelligent communication systems in Smart City ecosystem.

The main contributions of this study are:

- Evaluate the individual and combined roles of 5G, VANET, VDTN, and IoT in the context of smart cities.
- Identify key research gaps and challenges and provide highlighting unresolved issues such as scalability, interoperability, latency, and cost, and providing concrete directions for future studies.
- Provide a comparative synthesis of existing architectures and communication frameworks, assessing their feasibility, scalability, and limitations.
- Propose a conceptual multi-layered framework that addresses scalability, latency, interoperability, and reliability.

This paper is structured as follows. The paper begins by outlining the methodology employed for conducting the systematic literature review. It then presents a detailed overview of the individual roles and applications of VANET, VDTN, IoT, and 5G technologies in the context of smart cities. Following this, a comparative analysis of existing literature is provided, addressing the integration of these technologies along with their main approaches and limitations. The study also reviews relevant works and introduces a proposed multi-layered conceptual architecture for integrating VANET, VDTN, IoT, and 5G within smart city environments. Finally, the discussion answers the research questions, outlines future research directions, and concludes by summarizing key findings while highlighting remaining challenges and opportunities for advancing smart city technology integration.

METHODOLOGY

Our research work is based on a Systematic Literature Review which purpose is to offer a full and deep panorama for the integration of the four important technologies VANET, VDTN, IoT and 5G in the context of smart cities. The reason why we have chosen this methodology is that it is very effective in critical analyses of the current existing sources and identification of current research gaps.

The SLR is reported in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [11]. The PRISMA framework provides a transparent and reproducible process for identifying, screening, and including relevant studies, while documenting the reasons for exclusion.

Research Questions

Technological Roles and Integration Motivations

RQ1: What are the individual and combined roles of VANET, VDTN, IoT, and 5G in enhancing smart city functions, and how has their integration been addressed in the literature?

Integration Challenges and Performance Optimization

RQ2: What are the key challenges and optimization strategies in integrating these technologies under high-mobility and high-data-volume smart city scenarios?

Research Gaps and Architectural Innovation

RQ3: What research gaps remain, and how can a multi-layered conceptual architecture contribute to overcoming integration challenges in smart cities?

In Fig. 1 the literature review steps are presented. The first step is the identification of the technological roles of VANET, VDTN, IoT, and 5G and integration motivation. The second step is identification of integration challenges and performance optimization. The last step is to identify the research gaps and architectural innovation.

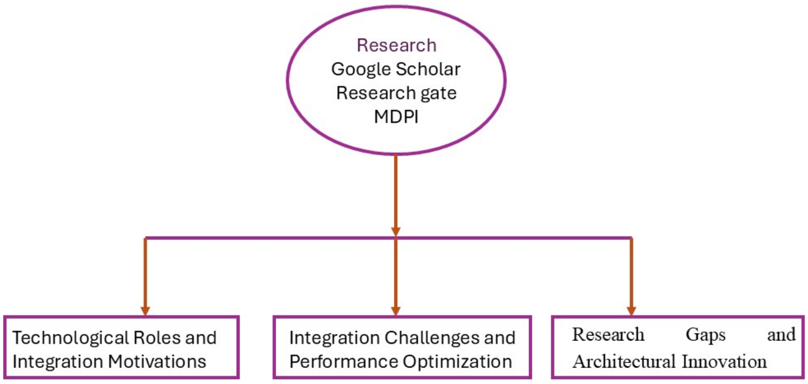

Figure 1. Literature Review steps

The literature review is structured around three research questions designed to treat the aspects of the most important technological integration, importance and performance, resource management, costs, scalability and actual challenges. Questions help with thematic literature separation and its critical analysis. After that was the selection of the most trusted research databases and well known internationally such as Google Scholar, Research Gate and MDPI (accessed on: 10-30 July 2025). It is important to note that most of the peer-reviewed journal articles retrieved through Google Scholar and MDPI are also indexed in established bibliographic databases such as Scopus and IEEE Xplore. Therefore, although this study did not directly query these subscription-based databases, the overlap ensures that the review maintains strong coverage of the scientific literature.

ResearchGate was used primarily to access preprints and author-uploaded versions of already published articles, many of which are likewise indexed in Scopus or IEEE Xplore. This helped in retrieving full texts where publisher access was limited.

In these big databases we have searched for combined terms of "VANET", "5G", "IoT", "Smart Cities", "VDTN", "Integration", "Challenges", "Latency", "Mobility", "Scalability", etc. and we made a first screening on what researchers had studied for this fields.

Then we executed the search strings in each of the selected databases, and we obtained 109 scientific papers in total.

Query Strings as below were used to find important articles:

1. VANET' AND 'IoT' AND '5G' AND 'SMART CITIES'
2. VANET' AND 'SMART CITIES' AND '5G'
3. VANET' AND 'SMART CITIES' AND 'IoT'
4. '5G' AND 'IoT' AND 'SMART CITIES'
5. '5G' AND 'VDTN' AND 'SMART CITIES'
6. Smart cities' AND 'VANET'
7. Smart cities' AND 'VDTN'
8. "Smart Cities" AND 'IoT'
9. "Smart Cities" AND '5G'

These combinations make possible the inclusion of all technologies while addressing the role and interconnection in Smart Cities.

Prisma Phases

The study selection followed the four PRISMA phases:

1. Identification: Initial search retrieved a total of 109 articles across the three databases.
2. Screening: After removing duplicates, studies were screened by titles and abstracts, excluding papers published before 2019, non-English works, and non-peer-reviewed sources.
3. Eligibility: Full-text articles were assessed using predefined inclusion/exclusion criteria (see below).
4. Included: A final set of 52 studies was retained for in-depth review and analysis.

Inclusion Criteria:

- Articles published in between 2019 - 2025 to ensure up to date research
- Articles that integrate at least two technologies: VANET, VDTN, IoT, 5G in the context of Smart Cities.
- Articles that offer methodological, architectural or experimental approach for the integration of these technologies but without excluding articles.

Exclusion Criteria:

- The subject of the paper is not written in English language.
- We excluded generalist articles that did not conclude in an outcome or studies that were not published in scientific journals or international indexed conferences (Scopus, IEEE Xplore, Springer, MDPI etj.).
- Articles that had studied only one technology standalone without integration

Finally, the papers were scanned through full paper reading by considering some quality criteria to ensure their relation to our study.

Articles filtering and selection are based on the main purpose: integration of any of these technologies: VANET, 5G, IoT, VDTN for smart cities. We also logically mapped the articles based on the relevance of the research questions, time of publication (most of them published in the last 6 years 2019-2025), their focus on technical challenges of integration, and how well studied this integration was, how innovative the proposals and the integrated architectures were. After reading the content of these articles, we selected only 53, which were related utmost to our systematic review. Table 1 represents the results of our research, number of the identified articles for every group of key words based on the relevant sources.

A thematic and comparative analysis has been done on the chosen articles based on the main topics that relate to each technology and the way they interact in the architecture of smart cities. The main advantages and challenges of each approach are analysed.

The final part of our research identifies remaining gaps and develops a conceptual framework. We propose a layered architectural framework that integrates the four main technologies with a flexible and scalable approach.

The VOSviewer software [12] was used to build the keyword co-occurrence network and to cluster the relevant literature.

Table 1. Literature review keyword search results

Keywords	Number of papers found	Number of the papers after filtering
“VANET” “5G” “IoT” “Smart Cities”	6	5
“VANET” “5G” “Smart Cities”	30	20
“VANET” “IoT” “Smart Cities”	10	2
“5G” “IoT” “Smart Cities”	25	11
“5G” “Smart Cities”	10	3
“5G” “VANET”	14	4
“VANET” “Smart Cities”	8	4
“5G” “VDTN” “Smart Cities”	1	1
“IoT” “Smart Cities”	1	0
“VDTN” “Smart Cities”	2	2
“DTN” “IoT” “Smart Cities”	1	0
VDTN	1	0

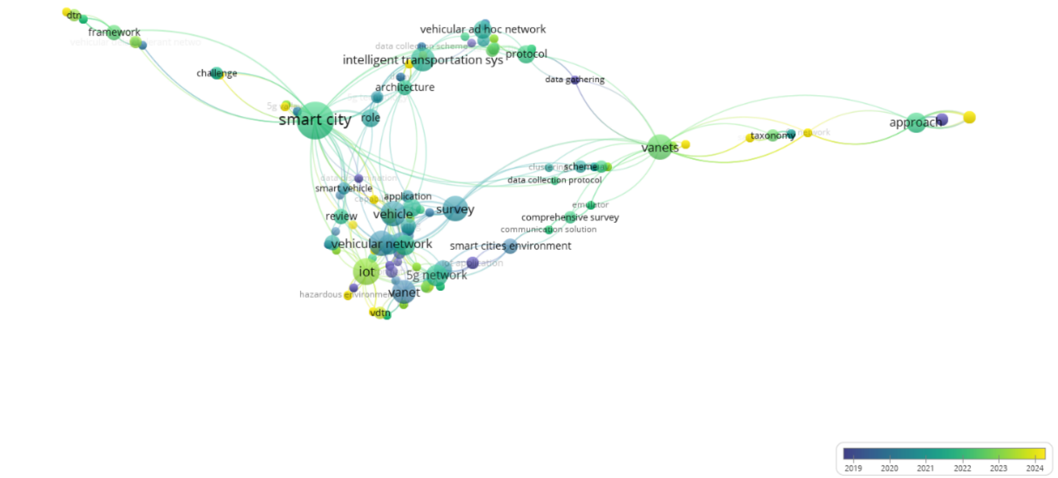

Figure 2. Keyword co-occurrence network of VANET-related literature generated with VOSviewer

Figure 2 presents the keyword co-occurrence map generated with VOSviewer. The clusters (distinguished by colours) represent major thematic concentrations within vehicular networks research. Earlier studies (2019-2020, in blue) emphasized fundamental aspects such as data gathering, dissemination, and protocols. Over time, research focus expanded toward emerging technologies including IoT and 5G (green-yellow, 2022-2025), as well as broader applications in smart cities, VANETs, and intelligent transportation systems.

THE IMPORTANCE OF INTEGRATING VANET AND VDTN WITH 5G AND IOT FOR SMART CITIES

VANET, VDTN, IoT and 5G main applications for smart cities

Since smart cities are evolving, it is essential to analyse their key components and explore how they can be integrated effectively. The primary technologies that contribute to making cities "smart" include VANETs, VDTNs, IoT and 5G

The role of VANETs in smart cities

The number of vehicles in the world is growing daily, and we can refer here to the growing number of autonomous vehicles also. Vehicles can communicate with each other, with physical infrastructure and with pedestrians so they can form the network of vehicles, the so-called Vehicular Ad-hoc Network. They are part of Intelligent Transportation Systems (ITS) which are crucial in smart cities for mobility, safety and efficiency for urban transport systems [4].

Some VANET capabilities, which are very useful for smart cities, are achieved by using different sensors that are installed inside the car to gather continues data or information [13] regarding the environment or other vehicles where the vehicle moves. Information that could be gathered could be motion of vehicles, temperature, sound, pressure etc. The main applications of VANET such as V2V, V2I [5, 14] help this network to coordinate with each other and send the needed information for smart cities such as safety and emergency (collision warning, emergency braking alerts, blind spot detections etc.), traffic and road information (road surface condition, roadwork and construction warnings, traffic congestions alerts), environmental and vehicle status (weather updates, air quality monitoring, fuel battery status sharing, vehicle diagnosis, data sending directly to the services), energy related information.

Beyond these applications, VANET relies on V2X communications for advanced traffic management functions such as virtual traffic lights, navigation support, and fleet management, where security challenges and countermeasures remain a central research focus [15]. Security is also very important for VANET applications in smart cities, with recent work proposing a chaotic secure multi-verse optimization approach to mitigate MITM attacks [16]. Recent work also shows that combining VANET with edge computing can reduce latency and improve efficiency in smart urban transportation, for example through hybrid optimization models that enhance resource management and Quality of Service (QoS) [17].

The role of VDTN in smart cities

VDTNs have been created because VANET networks have faced challenges for transmitting information in areas where traffic is low, and number of vehicles is small [7]. VDTNs can play a key role in smart city data collection, as demonstrated by the DC4LED scheme, which leverages vehicle mobility patterns to provide low-cost, scalable, and energy-efficient data delivery services [18]. VDTN have shown improvements by making sure that the information is transmitted in an end-to-end communication form. From VANETs, in smart cities we can collect data from vehicles because they communicate with other vehicles or infrastructure near them V2I. The data generated from applications, which are delay tolerant, can be transmitted using VDTNs [19]. On the other hand, smart cities are facing the need to process large amounts of data not only from vehicles but also from different wireless sensors with low energy capabilities and for various applications. Smart city applications data such as temperature, smart metering, photos reporting road infrastructure changing etc. that are delay tolerant can be transmitted using VDTN.

The role of IoT in smart cities

Would a smart city really exist without the presence of IoT? IoT is like fuel for smart cities that continuously feed them with data in real time making it possible for smart cities to maintain and process a lot of services. IoT is the main contributor to smart city applications including smart homes, smart infrastructure, smart health, etc. [20]. IoT allows interaction between different devices and different technologies, making possible an increased capacity for smart cities and making a more comfortable life for the citizens. IoT-enabled 5G vehicular networks with edge computing [21] have shown high accuracy in short-term traffic flow prediction, aiding smart city traffic management [22]. The Internet of Vehicles (IoV), as an extension of IoT, connects vehicles with infrastructure, networks, and other devices, enabling intelligent transportation services in smart cities [23].

The role of 5G in smart cities

Even though smart cities have always taken advantage of cellular communications technologies such as 4G, LTE etc. for transmitting useful information in urban areas, the deployment of 5G cellular network has changed the way smart cities operate [24]. Deployment of 5G has grown in different countries in the world and so its applications and benefits are increased [2, 25]. 5G networks capabilities relate to low latency data transmission, faster data rates, network scalability, availability and reliability which are very important in the context of smart city applications. Some of these applications include smart transportation [26, 27], healthcare and emergency services, environment monitoring, smart infrastructure and buildings, public safety, digital services for citizens etc. [3]. 5G NR V2X is considered vital for smart city applications, though challenges like access and attenuation remain, with AI/ML offering potential solutions [28].

Usage of VANET, VDTN, IoT and 5G in different smart city applications

Various applications in Smart Cities are reviewed, and for each application, we provide an updated analysis of how each technology (VANETs, VDTNs, IoT, and 5G) contributes individually to improving urban life. Table 2 presents the usage of these technologies across different Smart City applications. This comparative table highlights that while VANETs and 5G are essential for ultra-reliable communication, IoT ensures pervasive sensing across applications, and VDTNs uniquely fill the gap in disrupted environments, underscoring the complementary nature of these technologies and the need for integrated frameworks.

Table 2: Smart city application and usage of VANET, VDTN, IoT and 5G

Smart City application	VANET	VDTN	IoT	5G
Autonomous Vehicles (V2X)	V2V, V2I, V2P communication	Store-carry-forward in areas without coverage	Sensors in vehicles and in streets	Ultra-reliable low-latency communication (URLLC)
Intelligent Traffic Management	Traffic data exchange between vehicles in real time	Traffic messages stored and forwarded in areas with limited connectivity	Traffic camera and road sensors for monitoring and data collection	High bandwidth and low latency communication, real time analysis

Smart Parking Systems	V2I for parking navigation	Not typically used, but it can carry information in areas with intermittent connectivity	Sensors for finding free parking spaces	Massive Machine-Type Communication (mMTC) for massive sensor connection.
Infrastructure Monitoring	Mobile data reporting from vehicles (e.g., road condition detection)	Can buffer and forward critical data (e.g., from isolated zones or in case of link failure)	Sensor networks embedded in roads, bridges, tunnels to monitor vibration, stress, cracks, etc.	mMTC for massive device connections; URLLC for real-time fault alerts
Emergency Vehicle Prioritization	Real time message transmission	Back up for sending messages when the network connection is lost	Sensors for emergency detection	URLLC for critical signalling
Connected Ambulances	V2V for the already free roads	Back up for connection in remote areas	Biometric devices for patient monitoring	Ultra-low latency for monitoring
Air Quality Monitoring	N/A	N/A	IoT sensors distributed in the city	mMTC for a large number of devices
Smart Grids (Energy)	N/A	N/A	Smart meters & sensor networks	mMTC for connection and URLLC for critical control
Public Safety & Surveillance	Security messages in between vehicles	Back up signalization when the connectivity is lost	Camera and moving sensors	High bandwidth communication for HD video and AI analysis
Crowd Management & Events	Emergency messages V2P	Message back up for signalization in critical situations	IoT wearables & sensors	URLLC for massive

				signalization in real time
Smart Street Lighting	N/A	N/A	Sensors for detection/usage	mMTC for controlling and energy optimization.
Smart Waste Management	N/A	N/A	Sensors for garbage fullness	mMTC for massive connections and sustainable networks
Smart Lighting Systems	N/A	N/A	Lightning and moving sensors	mMTC for automatization and energy saving
Smart Water Management	N/A	N/A	Water flow sensors and consumption measurements	mMTC & URLLC for real time action in water supply networks
Smart Buildings / Home Automation	N/A	N/A	Connected devices, and environment sensors	mMTC & URLLC for security and control in real time
Smart Tourism & Navigation	Navigation for tourists in vehicles	Information services in case of network loss	IoT for information and touristic guides	Broadband for augmented reality and virtual reality and translation in real time
Edge AI for smart cities	Data exchange from vehicles for local inference	Data transmission for later analysis	Cameras, sensors, edge devices for local inference	URLLC & broadband for real-time AI

Mobility-as-a-Service (MaaS)	V2X messages for coordination with public transport	Support for transport for areas without coverage	Connected devices for booking	Sustainable connection and coordination for many platforms
Digital Twins for the city	Real time data from vehicle network	Store-carry for sending updates in isolated areas	Urban, traffic, energy sensors for digital models	High Bandwidth for continues modelling
Climate Resilience Systems	Alarms for atmospheric conditions of vehicles	Communication back up for disaster cases	Humidity, rain, temperature sensors	URLLC for emergency response, mMTC for a massive network of sensors
Vehicle Platooning	Ultra-fast communication V2V for vehicle formations	N/A	Sensors for distance and follow up on the lane	URLLC for synchronization control
Smart School Zones	V2I messages for warning near schools	Back up signalization when network is lost	Sensors for moving and camera near schools	Ultra-low latency communication
Disaster Recovery Networks	Mesh and ad-hoc networks for communication between vehicles	Saved communication in extreme conditions.	IoT fume monitoring, shaking etc.	5G for fast coordination of emergency services.
Smart Logistics / Supply Chains	V2X messages for transport and fleets	Back up for transmission when there is no network.	IoT for ware investigation	mMTC for millions of devices and URLLC for critical control
Micromobility Integration	V2X messages for interconnection between vehicles	N/A	IoT in bicycles/scooters for location and battery	Broadband for follow up in real time

As shown in Table 2, many Smart City applications rely on the integration of all four technologies: VANETs, VDTNs, IoT, and 5G. We have focused on these four main technologies because they represent the main components for communication and data gathering in smart cities. New intelligent techniques are important for integrating these technologies together because none of these technologies alone can offer all the characteristics that are required for an optimal function of smart cities. Other technologies such as Wireless Network Sensors (WSN), Mobile Ad hoc Networks (MANETs), Unmanned Aerial Vehicles (UAVs), Software Defined Networking (SDN), Network Function Virtualization (NFV), Cloud, Fog and Edge Computing, as well as Big Data, machine learning and deep learning are supportive and complementary for the integration.

SDN and NFV: they are integrated with 5G, providing flexibility, programmability, and virtualization of network functions to enable network slicing and efficient service management. For this reason, they are considered a natural part of the 5G ecosystem. Similarly, in the context of VANETs, SDN has been applied together with cloud-fog-edge architectures to enhance resource management and support flexible, programmable, and scalable communication [29].

Cloud, Fog, and Edge Computing: Although these technologies play a key role in data processing in smart cities, they are considered to support architecture for IoT and 5G. Edge/Fog computing is essential for low-latency applications, while Cloud provides massive storage and analysis capabilities [30]. The main function of this technology is not communication itself, but the processing of data collected through IoT and 5G networks, hence they are not taken as the focus.

Big Data, Machine Learning, and Deep Learning: These technologies build analytical mechanisms with the data generated by IoT, VANETs, VDTNs and 5G. Their use is essential for applications such as smart grid, emergency management, and healthcare. However, these technologies are considered as methods of processing and interpreting data, not as technologies of communication or information transport, and for this reason, they have not been treated separately.

LITERATURE REVIEW OF INTEGRATION OF VANET, VDTN, IOT AND 5G FOR SMART CITIES

This literature review is based on analysing and searching on existing literatures that include the integration of VANET, VDTN, IoT and 5G for smart cities.

In Table 3, 4 and 5 we have shown the main approach to each considered paper and their limitations.

Table 3. Literature review of integration of VANET and 5G for smart cities

Article	Integrated technologies	Main approach	Limitations
[31]	VANET + 5G + Edge/Fog + Big Data	This article is a comprehensive survey on the use of 5G, edge/fog computing, and big data for applications in intelligent transportation systems. It proposes hybrid architecture (vehicular cloud + vehicular edge computing) to support safety, infotainment, and real-time traffic management	The article is a survey and not a direct architectural proposal, so the main limitation is the lack of practical implementation. It also emphasizes challenges in data heterogeneity, network topology volatility, and high costs for large-scale edge/fog deployment.
[32]	VANET + 5G + Fog Computing	This article proposes architecture based on priority- based fog computing and it uses 5G MEC (Multi-access Edge Computing) to manage traffic in smart cities. The technique used achieves data processing at low latency and network load. This approach is very important for V2X systems and autonomous transport in smart cities.	The proposed approach improves the QoS in smart transport, but it requires big investments in MEC infrastructure and maintenance.
[33]	VANET + 5G + Clustering	This article analyses clustering techniques to enhance performance and scalability in VANETs in smart cities. It groups all static and mobile, with cluster head or without cluster head. Authors identify three class metrics, network specific, application specific and topology-based noting that topology based are the most used metric in VANETs. Clustering has the potential to play an important role in the 5G-VANET enabled solutions in smart cities.	This study does not offer a new algorithm to address VANET+ 5G + clustering and lack of empirical validation with prototypes and realistic traffic models.
[34]	C-V2X + AI + 5G	The article analyzes the impact of C-V2X on road safety and traffic efficiency using SUMO simulations. It shows that C-V2X	Limitations include packet loss, communication delays, potential cyberattacks,

		reduces latency by >99% compared to DSRC and decreases traffic conflicts by up to 38% at high AV penetration levels.	and reliance on high AV penetration rates to achieve maximum benefits.
[35]	IoV + IoT + AI + Cloud/Fog	This article provides a survey on the Internet of Vehicles (IoV) with layered architecture and applications for smart cities. It integrates IoT, V2X, and deep learning for safety and sustainable transport management.	Limitations include security and privacy challenges, lack of uniform standards for IoT/IoV integration, and difficulties in managing large volumes of data.
[36]	5G + V2X + MEC + AI	This study proposes architecture for ITS based on 5G V2X, including the use cases for emergency vehicles, V2V, V2I, and V2P communication. It discusses the use of MIMO, beamforming, and MEC for ultra-low latency and improved safety.	Limitations include high costs of 5G/MEC deployment, complexity of 3GPP standards, and interoperability challenges among heterogeneous devices.
[37]	VANET + 5G + Blockchain + SDN/NFV	The article reviews emerging technologies in VANET (5G, SDN/NFV, Blockchain, Edge). It proposes blockchain for security and SDN for flexible traffic management.	The main limitation is the lack of practical studies; most works remain conceptual. Integrating blockchain into VANET also introduces latency and additional overhead.
[38]	5G + VANET	This paper focuses on the role of 5G for smart vehicles in smart cities. It argues that 5G enables reliable communication for safety and real-time traffic management.	Limitations include limited 5G coverage in rural areas, infrastructure costs, and uncertainty about interoperability with existing technologies (DSRC, LTE).

This analysis shows that while many studies integrate 5G with VANETs and complementary technologies (AI, MEC, Blockchain, Fog/Edge), most remain conceptual, lacking empirical validation, cost-effectiveness analysis, and standardized interoperability, highlighting a clear research gap that our proposed multi-layered framework addresses.

Table 4. Literature review of integration of IoT and 5G for smart cities

Article	Integrated technologies	Main Approach	Limitations
[39]	5G + IoT	In this article the authors propose a new approach for urban traffic management through IoT sensors and 5G for smart cities. The proposed system allows data collection and analyses from different sources to enhance traffic movement in real time.	The proposed technique contributes to latency reduction but needs strong architecture for security and trust in data delivery. Besides that, it is very expensive because of 5G infrastructure deployments and signal constraints.
[40]	5G/6G, MIMO, multiband RF, perovskite photovoltaic	This article proposes a system for power supply for IoT devices in smart cities by combining RF power and perovskite photovoltaic. The method proposed has an efficacity of 90 % and its purpose is to replace the battery necessity for IoT devices concluding in a sustainable energy solution for these devices.	Challenges in system complexity and performance in different environments.
[9]	5G, 6G, Machine Learning, WIDA, EU AI Act	This article presents a security framework for 5G and 6G networks by using advanced machine learning techniques for preventing network attacks. The author presents a new algorithm called Wida which uses reinforcement learning and real time analysis to identify anomalies in areas with IoT devices.	WIDA algorithm is a prototype and has not been tested practically yet.
[41]	5G, AI, blockchain, digital twins, smart grids	Technology trends for energy management in smart cities are analyzed. It emphasizes the role of technologies such as 5G, IoT, AI, blockchain and digital twins. The main solution is system automation based on IoT and smart grids.	The proposed solution searches for investments in infrastructure and public policies regulations.

[42]	5G, AI, federated learning, edge AI, CNN, LSTM	In this article AI driven solutions for anomalies detections in real time in 5G enabled IoT devices in smart cities are studied. Authors combine different models such as autoencoders, LSTM, and CNN federate learning, and Edge AI for real time security and privacy. Different scenarios offer 97% accuracy.	The main challenges remain are devices heterogeneity, scalability and privacy
[43]	5G, IoT, edge computing, network slicing	Authors analyze the integration of IoT with 5G networks while including technologies like edge computing and network slicing. This article gives a very clear summary of capacities, integration challenges for critical applications such as autonomous vehicles and industrial systems.	Limitations on energy management, security and device interoperability are encountered.
[44]	5G, LPWAN, SDN, NFV, LEO satellites	This paper considers hybrid architecture for 5G- LPWAN IoT (Low Power Wide Area Network) for smart cities and remote areas. The proposed architecture includes SDN, NFV and endogenous security for addressing universal connections requests. This article describes usage of LEO satellite networks as a support for remote connections.	Challenges include costly infrastructure and problems related to interference and resource management.
[45]	5G, IoT, smart city infrastructure	This article analyses 5G in collaboration with IoT devices for climatic changes in smart cities like Singapore. It has been acknowledged that a smart management of energy, water, waste and risk management for sustainability purposes. Authors identify all the fields where 5G can make a very good impact on energy and resource management.	The main limitation of this article is the absence of deep analyses of implementation costs and scalability in other countries.

[46]	5G, satellite, IoT, two-ray propagation model	Authors have analyzed the performance of the integrated 5G-satellite while using two-way propagation model for IoT applications in smart cities. Results show that lower altitude satellites and low frequencies raise the power of the signal and decrease connection loss probability. This model has shown very good results for distance monitoring and emergency responses.	In high frequencies this model faces signal losses and lower capacity.
[47]	Hybrid cloud, MEC, fog-to-cloud, PaaS	The authors in this article propose a decentralized architecture for IoT in smart cities with Platform as a service by integrating hybrid cloud and multi-access edge computing (MEC). This platform offers good management of sources for real time data processing in smart cities, mobile health etc.	Challenges are foreseen in sources dynamic management, devices movement and energy consumption.

Table 4, reveals that although diverse integrations of 5G with IoT expand smart city capabilities, most approaches remain limited by high infrastructure costs, scalability, heterogeneity, and lack of practical validation reinforcing the need for inclusive frameworks like ours that balance performance and sustainability.

Table 5. Literature review of integration of VANET or VDTN, IoT and 5G for smart cities

Reference	Integrated Technologies	Main Approach	Limitations
[48]	VANET + IoT + 5G + Cloud	This paper proposes an end-to-end communication system for VANET/IoT using XMPP, mDNS, and IEEE1451 protocols, contributing to integration importance, latency minimization, and performance improvements. Focuses on robust and scalable V2I/V2C communication with real-time traffic monitoring, while emphasizing IoT	Scalability and robustness of VANET infrastructures remain underdeveloped for long-term urban deployment. Security concerns in open IoT environments expose the system to potential cyberattacks. Ensuring high throughput and reliability in large-scale urban networks is still challenging, particularly

		harmonization for cost-efficient deployment and maintenance.	for critical services requiring ultra-low latency.
[49]	VANET + IoT +5G	This paper offers a detailed analysis for transforming traditional VANET networks into an advanced form called IoV while integrating other technologies such as IoT, 5G, AI and Fog Computing to make smart communications in smart cities. A 5 layered architecture is proposed which includes perception, network, artificial intelligence, application, and business layer to raise the scalability, security and efficacity in IoV networks.	There is a lack of real-life environment and limited support for unpredictable dynamics in urban areas.
[50]	VANET + IoT +5G	This paper proposes a new authentication protocol A-MAC (Authentication-based Medium Access Control) for secure communications in 5G Enabled VANET, and a five layer architecture in Internet of Vehicles (IoV). This approach aims to increase security, privacy and efficacity in data transmission in between vehicles and infrastructure.	The use of MD5 (not sufficiently secure), lack of real urban testing, reliance on RSUs with powerful CPUs, challenges in real-world application.
[8]	VDTN + IoT +5G	This paper analyzes the integration of VANETs with cloud computing and Internet of Things (IoT) for building smart communication infrastructure in smart cities. Authors introduce an architecture based on cloud- VANET where vehicles, RSU-s and sensors relate to cloud with intermediary platforms which manage data in real time.	The provided solution brings latency in critical situations, bottleneck in publish/subscribe for scalability and hardships in harmonization of protocols IoT-VANET.

[51]	5G + IoT + ITS	This paper studies how 5G will impact smart cities and ITSs while it is integrated with IoT. Authors include practical challenges for integration of 5G and ITS and IoT for smart cities analyzing each application step by step. This paper makes contributions to making possible real time communication and traffic monitoring.	It analyses the presence of massive devices connecting in real time, but it does not address details regarding energy management, infrastructure costs and load balancing.

This table analysis shows that while recent works attempt to integrate VANET, IoT, and 5G, recently also VDTN through layered architectures, authentication protocols, and cloud-based solutions, most remain limited by scalability, and lack of real-world validation, emphasizing the gap our multi-layered framework aims to bridge with a more robust, interoperable, and future-proof approach.

As can be seen from all the tables, most of the reviewed works integrate only some of these technologies, while the full integration of VANET, VDTN, IoT, and 5G remains largely unexplored. This highlights a significant research gap, as the convergence of these four technologies has the potential to combine the delay-tolerant features of VDTNs with the ultra-low latency and high bandwidth of 5G, while also leveraging IoT's pervasive sensing and VANET's mobility support. Such integration could address many of the scalability, reliability, and coverage issues identified in current studies.

ARCHITECTURE FOR LOGICAL INTEGRATION OF VANET, VDTN, IOT AND 5G FOR SMART CITIES

Architecture models with multiple layers are known for communication systems and data processing. This model usually is created based on OSI model where each level, for example physical, network, transport layer etc., enables modularity, interoperability and complexity management. In the context of smart cities architecture layers are widely used to integrate heterogenic technologies such as IoT, 5G, cloud and edge/fog computing. The main advantage of this model is that every layer has a clear function, for example the layer for access in data collection, layer for local processing and fast communication and the layer for analysis and long-term storage.

Many studies have proposed architecture with different layers to integrate technologies in smart cities.

Table 6 summarizes previous studies that have proposed layered architecture for the integration of VANET, IoT, and 5G, highlighting their focus areas and their limitations.

Table 6. Literature review of layered architectures for integration of VANET, IoT and 5G for smart cities

Article	Integrated Technologies	Layers number	Focus	Limitations
[49]	IoV (VANET + IoT + 5G + Fog + AI)	5 layers	Scalability, intelligence, IoV	Practical testing limitations
[50]	IoV (VANET + 5G)	5 layers	Security, authentication V2X	Weak protocols, not real testing
[43]	IoT + 5G	3 layers	Edge computing, network slicing	Energy, device interoperability
[47]	IoT + 5G + Cloud/Edge	Multi-layer	Source management, data-intensive apps	Energy, devices dynamic
Our proposed architecture	VANET + VDTN + IoT + 5G	3 layers (Access, Edge/Fog, Core/Cloud)	Full integration, scalability, lower latency	Needs practical validation

In [49], a 5-layer architecture is proposed for Internet of Vehicles (IoV) which combinates IoT, 5G, AI and fog computing to increase the capabilities and security in transport.

Authors in [50] have proposed a five-layer architecture for IoV with focus on security and authentication in communications V2V and V2I.

In [43], is analyzed integration of IoT with 5G using edge computing and network slicing while building a three-layer architecture for critical applications like autonomous vehicles.

In [47], authors propose a decentralized multi-layered architecture (cloud + edge+ IoT) for data intensive applications with focus in source management and efficacity.

Based on related works mentioned above the main purpose is the usage of architecture models with different layers to bring a decreased latency, scalability and interoperability. As we can see all current works integrate two or three technologies and they have not proposed a complete architecture with VANET, VDTN, IoT and 5G.

For the integration of VANET, VDTN, IoT, and 5G technologies in smart cities, we propose a multi-layered architectural approach shown in Figure 3, where each technology plays a specialized yet complementary role.

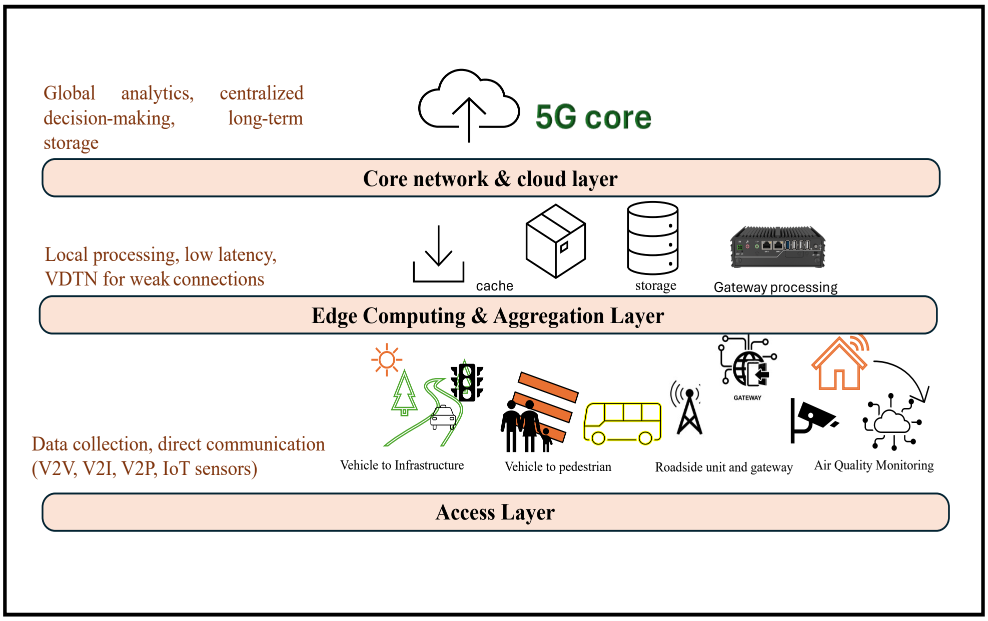

Figure 3. Proposed layered architecture for the integration of VANET, VDTN, IoT and 5G for smart cities.

At the lowest level the Access Layer direct communications between vehicles, pedestrians, and infrastructure are established primarily through VANET and IoT devices. This layer enables vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), and roadside unit (RSU) communications, as well as data collection from IoT-based monitoring systems such as air quality sensors.

In the intermediate layer, Edge Computing and Aggregation 5G and IoT technologies are utilized for fast, localized data processing, while VDTN is employed to store and forward messages in cases of weak or absent network connectivity. This ensures reliability in highly dynamic urban environments.

The central layer, the Core Network and Cloud serve for large-scale data analytics, centralized decision-making, and long-term information storage, using the scalability and high throughput of 5G infrastructures [51, 52].

The purpose of the integrated platform is to achieve fast communication, low latency, sustainability, tolerance for a weak network or if the network is lost (VDTN), collection and data analysis from environment (IoT), high capacity and massive connections in real time (5G). Each technology has its own powers, but it also has its own limitations. For example, in VANET we have direct communication between vehicles (V2V, V2I, V2X, V2P) but it depends on the density of the vehicles and local network. VDTN on the other hand uses a store-carry-forward protocol in networks with a weak connection but it has a high latency, and it is not for critical situations. IoT is used for data collection from the environment in real time, but it does not allow real time and critical communication. 5G offers secure, fast connections with low latency. To have a functional smart city in practice we need to get data from IoT devices, to analyze and save this data with VDTN and to act in real time using 5G and VANET.

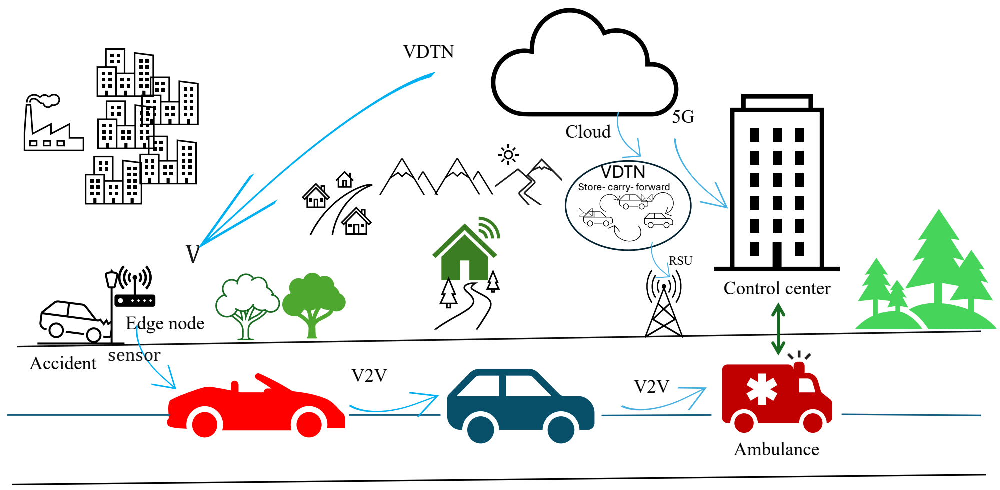

Figure 4. Example of communication between IoT, VDTN, VANET and 5G in a smart city

Figure 4 illustrates an example of how the integration of 5G, VANET, VDTN, and the IoT can enable resilient and adaptive architecture for smart cities. An IoT sensor deployed along the road detects a traffic accident and immediately transmits data to nearby vehicles and roadside infrastructure through V2V and V2I communication. This ensures that critical alerts reach drivers in the vicinity without delay.

Then, the accident data is processed in an edge node (fast decision-making without passing it in the cloud). If the network is present 5G sends signals to the control center. If there is no network connection, VDTN are used to save and transmit messages. At the same time, V2V communication allows nearby cars to exchange critical information in real time and notify emergency vehicles, such as ambulances, to reduce response times. The ambulance that is connected takes priority notifications through V2I and URLLC communication.

DISCUSSION

This paper is concepted as a systematic literature review with the main objective to explore the ways that VANET, IoT, 5G and VDTN can be integrated to support the smart cities applications. The systematic analysis was focused on related research work by applying classification and selection criteria to identify the current research gaps and for potential technological synergy. Research findings showed that most of the current existing literature explores only IoT and 5G to manage sensors and urban data collection. Another group focuses on VANET and 5G for communication between vehicles and to enhance road security and only few studies include VDTN in the context of emergencies and for areas where the fixed infrastructure is missing. It shows a lack of comprehensive framework that will unify the four main technologies for smart cities.

In relation to RQ1, the review highlights that each technology plays a distinct role: IoT provides pervasive data collection, VANET enables dynamic mobility-based communication, 5G ensures high speed and ultra-low latency, while VDTN contributes delay-tolerant delivery in connectivity-challenged areas. However, the literature demonstrates only partial integrations, such as VANET + IoT + 5G, or VANET + IoT + Cloud, without a complete synergy of all four.

This study does not only offer a literature synthesis, but it uses systematic analyses as a basis for building new architecture. The organization of the proposed architecture in access layer, edge/fog layer and core/cloud layer offer a modular structure where each technology (VANET, VDTN, IoT, 5G) contributes with its own strengths. IoT transmits data from urban environment while VANET offers dynamic communication between vehicles, 5G assures high velocity and low latency meanwhile VDTN covers gaps in unexpected situations and can be used to transmit data that are not critical time. This layered design helps to address precisely the gaps identified in the literature, creating an integrated framework that has been lacking until now.

Addressing RQ2, the review identified that integration in high-mobility and high-data-volume scenarios faces challenges such as scalability, latency, security, interoperability, and cost. The proposed architecture responds to these challenges by leveraging edge/fog computing for localized processing, VDTN for resilience under network failures, and 5G features like URLLC and network slicing for resource efficiency. Furthermore, enabling technologies such as AI for predictive analytics and blockchain for security can strengthen the framework's performance and trustworthiness.

The main contribution of this work is that the proposed architecture is not an isolated theoretical idea, but the result of a structured systematic review. The analysis shows that existing literature is weak in addressing technological interoperability and does not sufficiently cover challenges such as scalability, latency, and costs in urban environments.

In relation to RQ3, this study highlights research gaps such as the absence of real-world validation, limited exploration of full VANET-VDTN-IoT-5G convergence, and insufficient resilience mechanisms. The proposed multi-layered architecture offers a structured solution to these issues by unifying the four technologies into a resilient and scalable framework adaptable to multiple smart city scenarios.

The proposed architecture uses this element and puts them in a standard structure which can be adopted and adapted in different scenarios of smart cites. Traffic management can use data exchange in real time between vehicles and infrastructure by reducing congestion and improving security. Emergency systems will function also in the conditions of network failure by using VDTN and guaranteeing that critical information arrives at the required destination. Urban data collection from IoT sensors and their processing in edge layer will offer faster analysis and smarter decisions for the relevant authorities.

However, it should be emphasized that this architecture currently remains at a conceptual level and needs experimental validation. Testing through simulations, digital twins and real prototypes will be essential to evaluate its performance under various urban conditions. Such methods will help measure the impact on latency, throughput, reliability, and energy consumption, providing clear evidence of the advantages or limitations of architecture.

At the access layer, simulators like SUMO can be employed to generate realistic urban mobility scenarios, while network simulators like NS-3 can simulate 5G and V2X communications under different network conditions. To capture delay-tolerant scenarios, such as disrupted connectivity or intermittent RSU availability, the ONE Simulator can be used to model store-carry-forward mechanisms.

At the edge layer, digital twins of smart cities can be utilized to model large-scale urban dynamics and assess the real-world impact of communication strategies. This will enable realistic validation of latency reduction and decision-making efficiency at the edge.

At the core/cloud layer, validation can focus on the ability of the architecture to handle the growing number of devices, sensors, and data expected in future smart cities.

Finally, validation can be extended to a physical testbed composed of RSUs, IoT sensors, 5G modems, and VDTN/VANET devices. This real-world setup bridges the gap between simulation and deployment, allowing measurement of latency, reliability, and scalability under real conditions.

Looking ahead, while this study focuses on the integration of VANET, IoT, VDTN, and 5G, the rapid development of 6G networks offers an important perspective for future research. 6G is expected to deliver ultra-high data rates, sub-millisecond latency, and AI-native communication capabilities, while also integrating terrestrial and non-terrestrial infrastructures such as UAVs and satellites [53]. In the context of our proposed layered architecture, 6G can enhance each layer: at the access layer by providing more reliable V2X and IoT connectivity, at the edge layer through embedded AI-driven processing and semantic communication, and at the core/cloud layer with advanced network slicing and quantum-resilient communication.

In this way, our work opens a new research path: on one hand, showcasing the power of a systematic literature review to generate knowledge and identify gaps, and on the other hand, proposing a concrete solution that can serve as a basis for further research and practical developments in the field of smart cities. By considering 6G as a natural evolution of the proposed framework, the architecture is not only relevant for today's deployments but also for the next generation of smart urban systems.

CONCLUSIONS

This study offers a systematically structured analysis of the existing literature related to the integration of four main technologies VANET, VDTN, 5G and IoT in the context of smart cities. After analyzing the existing related works was evidenced that actual research is focused on partial combinations of these technologies rather than their full integration. For this reason, we proposed a new architecture of integration based on three main layers. The proposed architecture aims to unify the strengths of each technology in a modular and integrated structure, capable of supporting critical applications such as traffic management, emergency services and real time data processing. This contribution is not just in a conceptual form, but it represents a big step for creating a comprehensive framework for future smart cities. In this way, this study, does not only offer a synthesis of the current literature but also opens new research perspectives by putting the base for other advanced research works in the technological integration for smart cities.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest associated with the publication of this study.

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