Future smart cities requirements, emerging technologies, applications, challenges, and future aspects

Abdul Rehman Javed [a,b,*], Faisal Shahzad [b], Saif ur Rehman [b], Yousaf Bin Zikria [c,*], Imran Razzak [d], Zunera Jalil [b], Guandong Xu [a,*]

[a] School of Computer Science & Advanced Analytics Institute Faculty of Engineering & IT, University of Technology Sydney, Australia
[b] Department of Cyber Security, Air University, PAF Complex, E-9, Islamabad, Pakistan
[c] Department of Information and Communication Engineering, College of Engineering, Yeungnam University, Gyeongsan 38541, South Korea
[d] School of Computer Science and Engineering, University of New South Wales, Sydney, Australia

ARTICLE INFO

Keywords:
Survey
State-of-the-art
Future cities
Smart cities
Internet of Things
Big data
Cloud computing
Intelligent sensors
Transportation
Data mining
Smart education
Smart health
Smart mobility
Urban modeling
Real-time systems
Technologies
Applications
Challenges
Best practices

ABSTRACT

Future smart cities are the key to fulfilling the ever-growing demands of citizens. Information and communication advancements will empower better administration of accessible resources. The eventual fate of the world's betterment lies in its urban environment advancement. The fast influx of individuals creates possibility, yet it additionally causes challenges. Creating sustainable, reasonable space in the world's steadily extending cities is tested confronting governments worldwide. The model of the smart cities rise, where the rights and well-being of the smart city citizens are assured, the industry is in action, and the assessment of urban planning from an environmental point of view. This paper presents a survey on analyzing future technologies and requirements for future smart cities. We provide extensive research to identify and inspect the latest technology advancements, the foundation of the upcoming robust era. Such technologies include deep learning (DL), machine learning (ML), internet of things (IoT), mobile computing, big data, blockchain, sixth-generation (6G) networks, WiFi-7, industry 5.0, robotic systems, heating ventilation, and air conditioning (HVAC), digital forensic, industrial control systems, connected and automated vehicles (CAVs), electric vehicles, product recycling, flying Cars, pantry backup, calamity backup and vital integration of cybersecurity to keep the user concerns secured. We provide a detailed review of the existing future smart cities application frameworks. Furthermore, we discuss various technological challenges of future smart cities. Finally, we identify the future dimensions of smart cities to develop smart cities with the precedence of smart living.

1. Introduction

Internet and its allied technologies are duly penetrating every field. The benefits of technology incorporation in everyday life have now surpassed from impacting the individual level and benefiting the masses at the community and metropolitan level. The critical component of these new internet-enabled technologies is IoT devices which made reality to make us live in smart cities (Perera et al., 2017). These IoT devices revolutionize human-computer interaction (HCI) to bring the paradigm shift and open new technology integration methods within everyday life. Now the HCI technology is more human-centric than computer-centric as in the past (Liu, 2018). The sustainability and coherence in the HCI in the past decade resulted in increased dimensions where HCI is now utilized in a more effective way (Knowles et al., 2018).

To reap the benefits of smart governance and management, countries started incorporating innovative techniques and technologies to manage better and govern the affairs of their cities (Okai et al., 2018). For having a truly smart city, almost all required aspects of management and governance of that city need to incorporate these technical advancements within the allied processes. A city transformation is required at the design level to make a city truly smart which is a substantially primary task and can positively impact socially, economically, humanly,

* Corresponding authors.
E-mail addresses: abdulrehmanjaved@ieee.org (A.R. Javed), faisal.shahzad@ieee.org (F. Shahzad), 181065@students.au.edu.pk (S. Rehman), yousafbinzikria@ynu.ac.kr (Y.B. Zikria), imran.razzak@unsw.edu.au (I. Razzak), zunera.jalil@mail.au.edu.pk (Z. Jalil), guandong.xu@uts.edu.au (G. Xu).

and environmentally.

Many cities in the developed world are already moving to smart cities technology implementation. These cities include (but are not limited to) London, Stockholm, Dubai, New York, Barcelona, Hong Kong, Amsterdam, Singapore, Tokyo, Paris, and Copenhagen (Lai et al., 2021). A conceptual model of a smart city is also included in International Organization for Standardization (ISO) standard library known as ISO/IEC 30182:2017(en) smart city concept model. It guides establishing a model for data interoperability. It is seen as a first step of the organization towards the standardization of the various aspects of smart cities in the coming future (ISO/IEC, n.d.).

1.1. Motivation

Technology development has a major reason for bringing ease and innovation into daily human life. Smart cities are composed of information and communication technologies (ICT) and the IoT to increase operational efficiency, improve the quality of government services and citizen welfare, develop, deploy, and promote sustainable development practices to fulfill the ever-growing demands of citizens. Increasing the efficiency of these technologies can make them eco-friendly, more productive, and agile. Information and communication advancements empower better administration of accessible resources. Moreover, the research conducted on the emerging technologies also intends to bring efficiency to the present solutions. The digital revolution proved to be key to success wherever applied—keeping in view the easiness and efficiency in operation. In contrast, making an informed decision based on data and facts can be the key interacting factor in any field. The same holds for the Smart City arena. Thus, this makes a major cause of researching the improvement of upcoming technology to better human life. Envisioning the future aspects of smart cities through the current scenarios opens the door to new research. It helps the researchers develop a wholly new framework for the smart cities to view the interacting aspect mentioned in this paper. This paper can be regarded as a technical environment overview to decide the compatibility and functionalities of different technologies and their outcome when they work together. To the best of our knowledge, this is the first approach to looking into the future smart cities as a System of Systems and discussing the various interacting aspects of smart cities in a research-oriented way. The taxonomy presented in this paper covers the future smart cities from the angle of 360 degrees, i.e., try to encapsulate all the major aspects/systems interacting to become a system we know as Smart City.

A 360-degree technological coverage is required to make a city smart in true aspects. Fortunately, in the fourth industrial revolution, the area of communication, computing, and storage observed a drastic reduction in hardware costs, making this technology integration possible and cost-effective to reach the common person level. This paper briefly discusses 360-degree coverage requirements, challenges, and implementation strategies to make them a baseline standard for future smart cities. Fig. 1 presents 360-degree coverage of smart cities.

Fig. 2 depicts the taxonomy diagram of the proposed survey. The taxonomy includes seven significant aspects of advancing and developing a smart city, including 24 critical sub-sections of research areas necessary for developing the future smart city.

1.2. Contribution

As smart cities' concept is transforming with the advances in complementary technologies, there is a need to accumulate the works in these different fields and create a unified repository. This paper targets to present an in-depth survey and analysis of future technologies for smart cities. We summarize our contributions as follows.

1. We present an overview of the future smart cities, their robust capabilities to revolutionize living, and smart solutions to various problems. The requirements to achieve the proposed theory are also highlighted by studying the current state-of-the-art research and applications developed for future smart cities.
2. We analyze future smart cities' characteristics based on state-of-the-art technologies, including AI, IoT, and cybersecurity. Such technologies include DL, ML, IoT, mobile computing, big data, blockchain, 6G networks, WiFi-7, industry 5.0, robotic systems, HVAC,

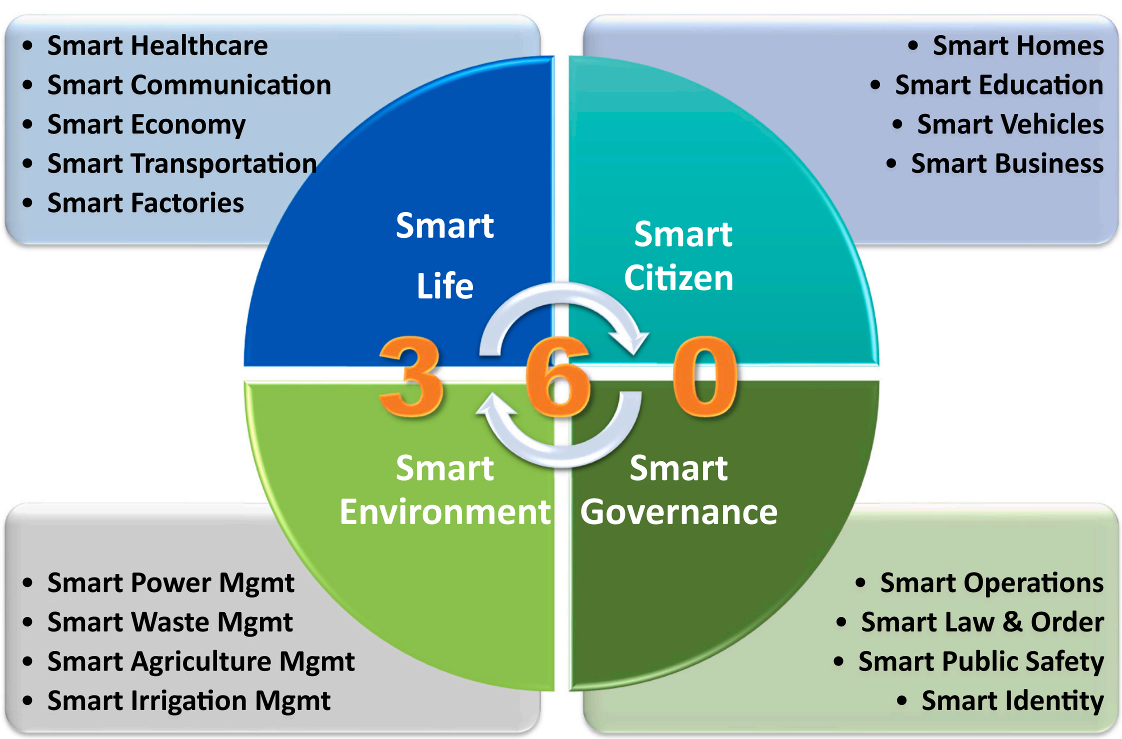

Fig. 1. 360 degrees of smartness in smart city - a system-of-systems approach.

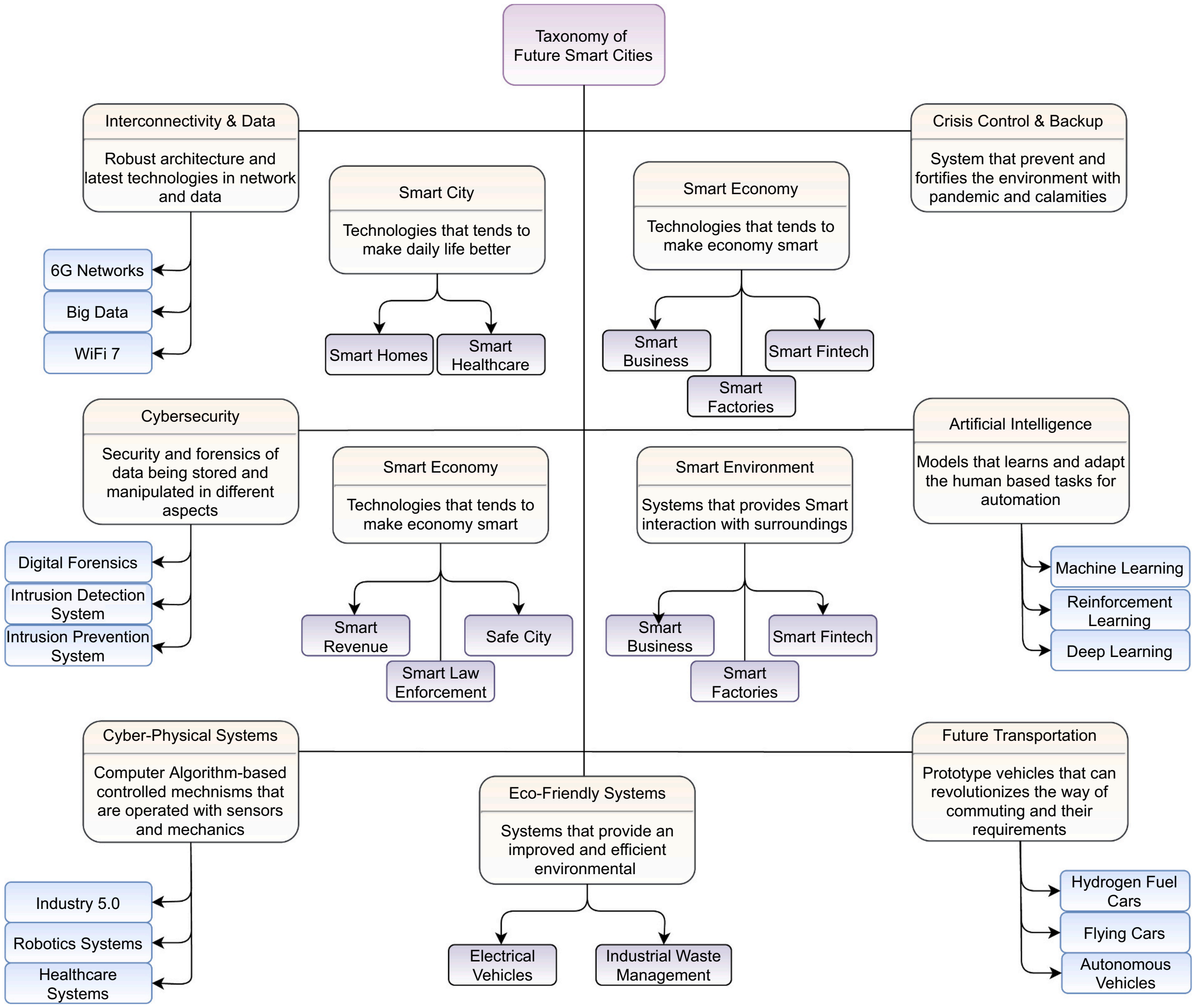

Fig. 2. Taxonomy diagram of future smart cities.

digital forensic, industrial control systems, connected and CAVs, electric vehicles, product recycling, flying cars, pantry backup, calamity backup and vital integration of cybersecurity to keep the user concerns secured.

3. The core contribution of this extensive research identifies and inspects the latest advancements in technology which acts as the foundation stone of the upcoming robust era. Such technologies include deep and ML, mobile computing, big data, blockchain, and vital cybersecurity integration to secure user concerns.
4. We analyze the most feasible frameworks and their proficiency that combines multiple technologies, ultimately resulting in the efficient implementation of procedures required to develop future smart cities.
5. Next, we provide technology challenges identified in the literature, and finally, the future directions are identified to develop smart cities further. Future research directions based on 6G networks, WIFI 7, Big data 2.0, industry 5.0, and the internet of nano things (IoNT) are also introduced.

1.3. *Paper organization*

Table 1 presents the notation used in the entire paper. The paper is further organized in the following section. Section 2 deals with the related studies on smart cities. Section 3 covers the requirements for future smart cities. Section 4 provides the application for future smart cities. Section 5 discusses the open research issues and future directions. Finally, Section 6 presents the conclusion.

2. Related studies

The latest state-of-the-art studies are reviewed in this section, and their crucial point of interest is highlighted. Moreover, a taxonomy comparison table has also been represented at the end of the section, which compares the proposed future smart city architecture with current state-of-the-art studies. It can be seen that the reviewed studies lack in several areas of research, which majorly include: *6G networks, WiFi-7, industry 5.0, robotic systems, human well-being, HVAC, pantry backup, calamity backup*. These mentioned research topics for future smart cities are critically essential to provide an accessible and sustainable lifestyle.

HCI saw a significant rise in the recent past after the emergence of the Fourth Industrial Revolution era (4IR). Technological advancements in the field of high-speed computing result in more powerful miniaturized machines available for utilization in every aspect of human life (Xhafa et al., 2020). This phenomenon also significantly shifts a portion of computing activities from cloud computing to edge computing.

The authors in (Alam, Malik, Khan, Pardy, et al., 2018a) reviewed advanced healthcare techniques with their technical properties and their different application areas. The authors also deeply reviewed communication technologies with different parametric configurations and then highlighted the significance and future aspects of IoT-based health care techniques. The authors in (Lai et al., 2020) presented a detailed review of smart city foundations and core elements. The smart cities' highest

Table 1
List of abbreviations.

Abbreviation	Description
G	Fourth Generation
IR	Fourth Industrial Revolution
G	Fifth Generation
G	Sixth Generation
AGVs	Automated Guided Vehicles
B5G	Beyond 5G
B2B	Business To Business
B2C	Business To Customer
B2G	Business To Government
C2B	Customer To Business
C2C	Customer To Customer
C2G	Customer To Government
CMU-MIMO	Clustering Multi-user Multiple-Input Multiple-Output
CNN	Convolutional Neural Network
CPS	Cyber-Physical System
CPSS	Cyber-Physical-Social System
CSMA/CA	Carrier Sense Multiple Access/Collission Avoidance
CV	Computer Vision
DFaaS	Digital Forensics as a Service
DL	Deep Learning
EHT	Extremely High Throughput
eMBB	Enhanced Mobile Broadband
EU	European Union
G2B	Government To Business
G2C	Government To Customer
G2G	Government To Government
GWSN	Green Wireless Sensor Network
HCI	Human Computer Interaction
HCPS	Human-Cyber-Physical Systems
HI	Human intelligence
H-IoT	Healthcare Internet Of things
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information Communication Technology
IDS	Intrusion Detection System
IIoT	Industrial Internet of Things
IoNT	Internet of Nano Things
IoT	Internet of Things
IPS	Intrusion Prevention System
IR5.0	Industrial Revolution 5.0
ISM	Industrial, Scientific and Medical
ITU	International Telecommunication Union
ISO	International Organization for Standardization
LEA	Law Enforcement Agencies
MELINDA	Multilevel Information Fusion Edge Architecture
MIMO	Multiple-Input Multiple Output
ML	Machine Learning
mMTC	Massive Machine Type Communication
mULC	Massive Ultra-reliale Low-latency Communication
NFV	Network Function Virtualization
OCHA	ordination for Humanitarian Affairs
PDS	Public Distribution System
RoI	Return on Investment
SDN	Software Defined Networks
UAVs	Unmanned Aerial Vehicles
UL MU-MIMO	UpLink MultiUser Multiple-Input Multiple-Output
ULBC	Ultra-Reliable Low-Latency Broad-Band Communication
uMBB	Ubiquitous Mobile Broadband
uRLLC	low latency communication
URLLC	Ultra-Reliable Low-Latency Communication
V2C	Vehicle to Cloud
V2D	Vehicle-to-devices
V2G	Vehicle-to-grid
V2H	Vehicle to Home
V2I	Vehicle to Infrastructure
V2N	Vehicle-to-Networks
V2P	Vehicle to Pedestrian
V2R	Vehicle-to-road-side unit
V2S	Vehicle to Sensors
V2V	Vehicle to Vehicle
V2X	Vehicle To Everything

standards are also presented to make a competitive comparison between state-of-the-art smart cities research. It has been discussed how smart cities make living standards comparatively better and wiser across various countries. This research also provides the technical aspects of developing smart cities, yet they present the latest research according to those technical standards.

The authors in (Zhao et al., 2020) proposed energy consumption prediction of electrifying vehicles under a smart city environment. They addressed the necessary causes and predicted results after implementing the proposed approach based on real-life data with an error rate of 8.44 %. The authors in (Baali et al., 2017) highlighted the issues in the advanced healthcare systems in their technical and non-technical depths. Hence, they review wearable devices' solutions, including sensors, power management, signal processing, computing architectures, and communication, and highlight the future research directions. The authors in (Jeong & Park, 2020) emphasized maintainable technological systems for future smart cities. The authors also highlighted product life cycle design and recycling procedures to examine the adverse effects on human life. Furthermore, the authors also reviewed the computing systems, including the electronic circuitry of essential IoT devices to industry-level data centers. Finally, the authors highlighted the safety, confidentiality, and effectiveness of maintainable computing for future smart cities.

The authors in (Serban & Lytras, 2020) deeply reviewed the AI-based developments in the RE region European Union (EU). They mainly highlighted energy consumption and efficiency of transformation procedures and consequences of renewable energy by sources such as sun, water, wind, and biomass. The authors in (Javadzadeh & Rahmani, 2020) comprehensively study the current recent work done over the region of fog computing concerned with smart cities. The authors also analyzed modern studies' literature reviews and highlighted the future research areas. The authors in (Radu, 2020) highlighted the issues in emerging technologies required to establish future smart cities. Their study includes the IoT, big data, blockchain, AI, data analytics, machine, and cognitive learning, implemented for health, energy, transportation, education, and public safety to provide a better, easier, and smarter life. The authors in (Khan et al., 2020a) highlighted the role of edge computing and new challenges for the emerging technologies. The authors also critically review the state-of-the-art studies based on edge computing applications in smart cities. The authors in (Muhammad et al., 2020) thoroughly surveyed the DL advancements and applications designed for smart cities. The authors also propose the current drawbacks in the model and provide a future research direction in DL.

The researcher in (Bilal et al., 2020) presents the features of critical segments of the information the board structure, surveys different smart city applications, and talks about protection and security challenges related to smart city information. From the point of view of information systems, it is seen that the information utilized in smart city applications is unstructured, coming from heterogeneous sources, i.e., sensors and web-based media, other than others. In this way, the assortment, preparation, examination, the executives, and representation of such information are tested. To play out these undertakings, ongoing advances, i.e., the IoT, and sensor organizations, have been utilized.

The researchers in (Bhattacharya, Somayaji, Gadekallu, Alazab, Maddikunta, 2020a) highlight the robustness of ICT that accomplished smart cities' idea. In a smart city, a few IoT sensors are sent across a few areas to gather information about traffic, waste, the versatility of residents, and the bits of knowledge acquired from this information is utilized to oversee assets, resources, and so on viably. Deep learning has been utilized widely on a few specialists' information created by IoT sensors in a smart city. Moreover, an endeavor is to review a few state-of-the-art DL on smart City information. A few future exploration headings are recommended towards the finish of the article.

The authors in (Songhorabadi et al., 2020) proposed a systematic literature review (SLR) for the best fog-based methodologies in smart urban communities. Moreover, as indicated by the investigation's substance, a scientific classification is proposed, which falls into three classes: administration-based, asset-based, and application-based. This SLR likewise explores each class's assessment factors, utilized devices, assessment techniques, benefits, and negative marks. Kinds of proposed calculations in each category are also referenced. Regardless of anything else, by considering different points of view, far-reaching and unmistakable open issues and difficulties are given through grouping future patterns and issues into reasonable sub-classes.

The researchers in article (Zhou et al., 2019) presented an overview of a portion of the momentum research work that adds to empowering cyber-physical-social systems (CPSSs). Some significant parts of CPSSs are distinguished, including the improvement from cyber-physical systems (CPSs) to CPSSs, engineering plan, applications, guidelines, genuine contextual analyses, empowering strategies, and organizations for CPSSs. To establish a framework for improving the open savvy world, we propose a virtualization design and a coordinated structure of storing, figuring, and systems administration for CPSSs. Reenactments confirm the presentation improvement of the proposition. Finally, some examination issues with difficulties and potential arrangements are uncovered for scientists in the connected exploration regions.

The authors in (Wang et al., 2019) present an extensive overview of unmanned aerial vehicle (UAV) networks from a CPS point of view. First and foremost, they survey the nuts and bolts and advances of the three CPS segments in UAV organizations. At that point, they look inside to explore how these parts add to the framework execution by characterizing UAV networks into three orders, i.e., cell level, framework level, and arrangement of framework level. Besides, the coupling impacts among these CPS segments are expressly delineated, edifying to manage the difficulties from every individual angle. New exploration bearings and open issues are talked about towards the finish of this review. With this escalated writing survey, they expect to give a novel understanding of the cutting edge in UAV organizations.

The utilization of AI has changed the healthcare IoT (H-IoT) frameworks at pretty much every level. The essential empowering innovations incorporate the correspondence frameworks between the detecting hubs and the processors and prepare calculations for producing a yield from the information gathered by the sensors. Notwithstanding, as of now, these empowering advances are likewise upheld by a few new advances. The fog/edge worldview brings the figuring power near the sent organization and consequently relieves numerous difficulties. In contrast, substantial information permits dealing with a gigantic measure of information. The IoNT and tactile internet (TI) are driving the advancement in H-IoT applications. Furthermore, the software-defined networks (SDNs) carry adaptability to the framework while the blockchains track down the most novel use cases in H-IoT frameworks. The Researchers in (Qadri et al., 2020) dig into how these innovations are changing the H-IoT frameworks and recognize the future course for improving the quality of service (QoS) utilizing these new advancements.

The authors in (Kirimtat et al., 2020) present an overview of shrewd city activities and dissect their key ideas and specific information on the executive's methods. They presented a solid writing overview and survey by applying an unpredictable writing framework, including terms similar to smart individuals, shrewd economy, keen administration, brilliant versatility, keen climate, and keen living. They also discuss various points of view of sensitive coasting urban areas in detail. With the proposed approach, late advances and pragmatic future freedoms for smart urban areas can be uncovered.Table 2 shows the detailed comparison of the above-reviewed studies. It can be seen that the current state-of-the-art studies still lack in providing the latest technology in all domains of development which are necessary for a future smart city of the 21st century.

3. Requirements for future smart cities

Shaping a robust future smart city has several fundamental requirements, also regarded as the building blocks of sustainable and advanced technologies. The proposed smart city requirements are justified by studying the current state-of-the-art research in light of the below-mentioned parameters.

3.1. Interoperability

The dawn of networking was the future endeavor for the concept of interoperability in today's modern technology. This concept's most significant invention is IoT's supremacy, yet still, under the phase of innovation (Wegner, 1996). The communication of the technologies is a significant aspect of IoT, and it allows the devices to be more compatible in the environment (Majid et al., 2022). It increases the technology's feature capacity as the capability of interpretation increases the data sharing among the device and lets them work with even more proficiency capabilities. Moreover, user experience is one of the most

Table 2

The Comparison of state-of-the-art for future smart cities. Key: Robotics System-RS, Big Data-BD, Digital Forensics-DF, Intrusion Detection System-IDS, Intrusion Prevention System-IPS, Electric Vehicles-EV, Industrial Waste Processing-IWP, Healthcare-HC, Product Recycling- PR, Machine Learning-ML, Deep Learning-DL, Computer Vision-CV, Hydrogen Fuel-HF, Flying Cars-FC, Autonomous Vehicles-AV, Heating, Ventilation, and Air Conditioning-HVAC, Pantry Backup-PB, Calamity Backup-CB, Industry 5.0-I5.0.

Ref.	6G	BD	WiFi 7	I5.0	RS	DF	IDS	IPS	EV	IWP	PR	ML	DL	CV	HF	FC	AV	HC	HVAC	PB	CB
(Lai et al., 2020)	X	✓	X	X	X	X	X	✓	✓	X	X	X	X	X	X	✓	✓	X	X	X	X
(Jeong & Park, 2020)	X	X	X	X	X	✓	✓	X	X	✓	✓	X	X	X	X	X	X	X	X	X	X
(Serban & Lytras, 2020)	X	X	X	X	X	X	X	X	X	X	✓	✓	✓	X	X	✓	✓	X	X	X	X
(Radu, 2020)	X	✓	X	X	X	X	X	X	X	X	X	X	X	X	X	✓	✓	X	X	X	X
(Javadzadeh & Rahmani, 2020)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	✓	✓	X	X	X	X
(Khan et al., 2020a)	X	✓	X	X	X	X	X	X	✓	✓	✓	✓	X	X	X	✓	X	X	X	X	X
(Muhammad et al., 2020)	X	✓	X	X	X	X	X	X	X	X	X	✓	X	X	X	X	X	X	X	X	X
(Bilal et al., 2020)	X	✓	X	X	✓	✓	X	X	X	✓	✓	X	X	X	✓	X	X	X	X	X	X
(Bhattacharya, Somayaji, Gadekallu, Alazab, Maddikunta, 2020a)	X	X	X	X	X	✓	✓	X	X	X	✓	✓	X	X	X	✓	X	X	X	X	X
(Songhorabadi et al., 2020)	X	✓	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
(Zhou et al., 2019)	X	✓	X	X	X	X	X	✓	X	X	X	X	X	X	X	✓	X	X	X	X	X
(Wang et al., 2019)	X	X	X	X	X	✓	✓	X	X	X	X	X	X	X	X	✓	X	X	X	X	X
(Qadri et al., 2020)	X	✓	X	X	X	X	X	X	X	✓	✓	✓	X	X	X	X	X	X	X	X	X
(Kirimtat et al., 2020)	X	✓	X	X	X	✓	✓	X	X	X	✓	✓	✓	X	X	X	X	X	X	X	X
This Survey	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

emphasized parameters in modern technologies. For a comfortable user experience, the interface acts as the foundation stone for that cause. Nevertheless, the interface is also regarded as playing a vital role in incrementing the interoperability in the latest technologies since it allows the users to interact with devices easily yet with significant extensions in features.

3.2. Scalability

It is defined as the versatile nature of any product. The scalability of a particular item is also emphasized in modern technologies to ensure suitable performance and efficiency. This parameter also measures the needs fulfilled by a specific technology in consumer requirements (Hill, 1990). Better scalability also ensures that a product can provide more features to consumers. The more features in the product also save the cost being spent on other items and enhance the usability of the product (Bondi, 2000).

3.3. Fast deployment

The design of the technology plays a crucial role in managing the space and deployment of the technology. In the modern era of technology, sustainable but portable deployment is preferred since it takes less time in implementation with less workforce. The intelligent technologies in construction materials or generic interfaces make the manufacturing procedures efficient and straightforward in terms of cost and time. The authors extensively provide information regarding developing innovative and robust conventional interfaces and deployment procedures for fast deployment.

3.4. Robustness

The rigorous trials in vast research fields are based on outperforming the base studies regarding performance and efficiency. This trend in research tends the upcoming technologies to be more advanced than the previous ones, which has regarded the robustness of the technologies. This robustness is considered to be an innovation as well in modern technology. In the technical terminology of robustness, it can be regarded as the rigorous procedures held at the testing phase of the technology to test the technology's capability to overcome the limitations and errors (Baker et al., 2008; Fernandez et al., 2005).

3.5. Eco friendly and efficiency

The fundamental source of power is the electricity that most technologies consume. However, the source of power can be based on multiple fuels. With the rise in global warming and adverse changes in global weather conditions (Han et al., 2011), research and manufacturing technologies have become highly eco-friendly and efficient oriented. Electronic appliances' power consumption has been significantly decreased with safe environmental emissions (Asman, 1992). This is necessary for society's global well-being, but it is also vital in defining products' cost-efficient manufacturing and usage.

3.6. Multi-modal access

This technique revolutionizes technology's behavior, and usage, especially in mobile computing (Bourguet, 2003). It is also concerned with the versatility of applications such that having multiple interfaces allows them to outcome the result of input in multiple forms. The sensors and AI-based algorithms provide a new gateway for developing applications. The extension of multi-modal access in the applications increases the inter-connectivity and usability of the technology, making the technology more practical, such as increasing the channels of communication with technology (text, voice, and mail) (Kettebekov & Sharma, 2001).

4. Future smart cities application frameworks

The use of the latest technology is inevitable for solving urban issues in a citizen-centric way. Smart cities are based on six fundamental pillars, which are composed of *smart life, smart economy, smart governance, smart environment, smart power, smart communication, and smart transportation* (Lai et al., 2021). This paper groups distributed smart cities' technological and management attributes to view the allied areas' trends and advancements into seven major categories. These seven categories contain 3 main subcategories, each making 28 taxonomies discussed regarding future smart cities. Up to the authors' knowledge, this paper is the first comprehensive effort to give such wide coverage in a single paper to shed light on future smart cities by using a top-down approach.

4.1. Inter-connectivity and data

In an ideal smart city, the citizen of the city benefit from the provision of state-of-the-art, high speed, and smart means of communication as well as transportation (Lai et al., 2021; Nagpal et al., 2022). Further, connectivity is the backbone of every aspect of a smart city. In a future smart city, the provision of a secure, efficient, high speed, and cross-domain compatible network is the crucial requirement (Gupta et al., 2020). The transfer of responsibilities among endpoint sensors, edge computing, fog computing, and cloud computing further highlights the necessity of a reliable communication infrastructure providing real-time data to the participating nodes. This transfer reduces the amount of data communicated to the cloud as the raw data is now being processed at the edge level using fog computing, and then processed information is then forwarded to cloud servers for analysis (Al Ridhawi et al., 2020; Liu et al., 2018).

Huge bandwidth requirements in the era of a smart city that once seemed impossible to achieve are now made possible by the 5G networks. 5G is the there reference term used for the fifth generation of high-speed communication technologies started back in 1980 for the sole purpose of tackling mobility in design (WEF, n.d.). The high speed promised by 5 g is already anticipated to replace the home WiFi networks as they offer a mere speed compared to the one available in 5G's proper implementation. Being planned in a higher spectrum, the speed promises of beyond 5G technologies are enough to fulfill today's and upcoming technologies' bandwidth requirements (Ali et al., 2021a). It will also generate around USD 13.2 trillion by 2035, as anticipated by World Economic Forum's white paper on 5G technologies. Focusing on enhanced mobile broadband (eMBB) provision, ultra-reliable low latency communication (uRLLC), security, massive machine type communication (mMTC), and power efficiency are the key drivers behind the wide adoption of 5G in current communication networks. The European telecommunications standards institute (ETSI) tackled the challenge of fast, efficient, and rapid data by introducing multi-access edge computing (MAEC). It processes the data at the edge level to forward processed/required information onward to decrease the communication load (Ranaweera et al., 2021).

The major challenge in today's cloud-centric smart city network is providing a secure, reliable, efficient, and fast network backbone. In this regard, measures were taken through research to minimize traffic flow volume from host to cloud using edge and fog computing. This way, the cloud's huge computing and storage resources can also be efficiently utilized (Al Ridhawi et al., 2020).

For future smart cities, the network complexity is anticipated to grow many folds as IoT's incorporation allows devices to talk with the devices and other nodes. This ocean of nodes uses complex architecture composed of the traditional network means, proprietary protocols, heterogeneous means of communication, infrastructure-based, ad-hoc, and mobile formations based on wired and wireless electrical and optical technologies. High speed and data rates offered by 5G and upcoming tera-hertz-based 6G technologies will cater to this ocean of devices' needs and communication requirements. Fig. 3 presents how

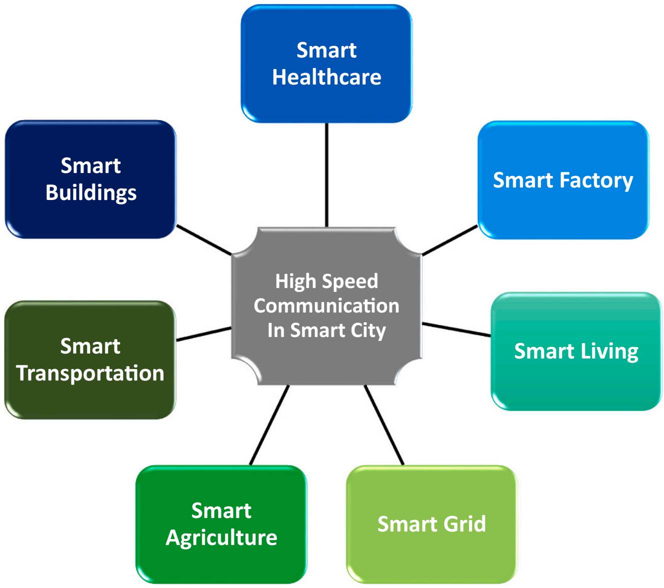

Fig. 3. High speed communication connecting smart cities.

high speed communication connecting smart cities.

Besides the technological and economic promises made by the 5G and beyond communication technologies, there are specific challenges to consider before reaping the benefits mentioned above. The first among all is the design level efficiency, regarded as the strength and base for improvements gained and results in incompatibility issues with the existing infrastructure of 4G and below. Currently deployed 5G testbeds are built along with the existing infrastructure, but they cannot unleash the true potential of 5G based on a higher spectrum. The requirement is to design the network with a core built for 5G specification, including the two main components, network function virtualization (NFV) and software-defined networks (SDN). Another challenge is translating the need for the IoT in connection profiles, bandwidth requirements, and coverage scopes.

Connection and provision of network services to mobile phones are entirely different and less complex, as mobile service provisioning is similar in terms of usage pattern. On the other hand, every kind of device group has its requirements for IoT. Then based on the deployment scenarios, the same group of IoT devices may possess veracity. Connecting a mobile phone, connecting a car, connecting a fire detection system, and connecting a water meter to the internet have their specifications and requirements. Some of them may require lower bandwidth, whereas some require higher, some need a shorter burst of data to be transferred, whereas some may have to send large amounts, and some devices have to communicate over a shorter distance. Whereas some may be required to transmit at higher distances, some devices may have less frequency of data connection. In contrast, some may have more frequency of connectivity with network infrastructure and so on (T. Group, n.d.). The international telecommunication union (ITU) is aggressively working on the standardization of ML usage in the network design and development based on 5G technologies (Union, n.d.-a).

For future smart cities, the basic building block is the importance of a high-speed communication backbone that is secure, resilient to attack, and always available. It has the required capacity and bandwidth to fulfill the growing needs (Ahmed et al., 2022). It is crucial to consider all those challenges to these future networks and evaluate them regarding requirements arising from technological advancement in smart cities. It becomes the future research area to identify the high-speed network requirements in future smart cities where network advancement evaluation can be done to identify gaps and limitations and their solutions and remediation.

Another challenge is to effectively use ML and DL technologies to analyze the node behavior to effectively suggest a workaround for the future and help intelligently heal the network infrastructure to disrupt services in some portion of the network. These edge computing technologies are becoming game-changing for the following generation networks and computing requirements to continue the era of IoT. Usage of edge computing and its impact on upcoming next-generation networks and computing were surveyed comprehensively in (Porambage et al., 2018).

4.1.1. 6G networks

5G communication evolved at a commercial scale in the year 2020. Many developed and underdeveloped countries now have a 5G commercial network available for everyday customers. The research community is already looking into the beyond 5G (B5G) or, in more concise words, 6G based network, which is targeted to fulfill the need of communication requirements in 2030 (Han et al., 2021).

Though the 5G offers the solution for bandwidth and connectivity requirements of current and future applications, the trend emerging due to such high-speed network offerings is exponential growth. Not only the high bandwidth but low latency and reliability of the network are also very significant (Yu et al., 2020a). The smart city architecture is also converging to chop the bandwidth by offering technological advancements and control to focus on more areas of the smart city previously out of the scope. This will leads to the need to have more advancements in the current 5G offerings. Rich multimedia based application, city-wide monitoring solutions with live audio-video, enhancements in screen resolution (like FHD, 4 K, etc.), communication between the device to device/device to cloud/device to customers/cloud to the customer, and increasing subscriber base of mobile communication will results in estimated 5+ Zeta-Bytes per month till 2030 (Union, n.d.-b). To accommodate this much bandwidth, research is underway to develop a new set of standards and technologies for the sixth generation communication infrastructure. The use cases of next-generation communication technology like high fidelity communication involving holographic and smart cities level high-speed communication were discussed w.r.t. their fulfillment by 6G, current challenges to 5G, and their solution promised by 6G (Tataria et al., 2020). Fig. 4 presents the transformation of 5G to 6G.

Major research activities in this high-speed mobile connectivity include eMBB, primarily used for customer-oriented high-speed mobile internet access for multimedia and rich media applications. URLLC in the mission-critical application environment where the requirements are strict for a reliable and consistent low latency network to provide reliable connectivity. The mMTC focuses on the provision of connectivity to a large number of low-cost, low-power devices to communicate while consuming as much less power as possible (Habibi et al., 2019). The upcoming improvements in this area will result in ubiquitous mobile broadband (uMBB) providing coverage to the whole planet in the 6G network, eventually upgrading eMBB. This uMBB will cater to bandwidth enhancements expected to cover a minimum 1Gbps per user to manage services like mobile virtual reality. Another critical improvement will be an ultra-reliable low-latency broadband communication (ULBC) to provide low-latency, highly reliable network connectivity with higher data throughput for automated guided vehicles (AGVs), robotics, and UAVs. To deploy massive sensors and actuators in verticals, massive ultra-reliable low-latency communication (mULC) will upgrade mMTC by utilizing and combining features from mMTC and URLLC. Seven critical use cases of URLLC as defined in (Ali et al., 2021b) will be further improved and implemented in 6G and beyond.

Key improvement indicators for 6G concerning 5G are as under (Han et al., 2021).

- Peak Data Rate from 20Gbps in 5G to 1Tbps in 6G
- User-Experience Data Rate from 100 Mbps in 5G to 1Gbps in 6G
- Latency from 1 to 4 ms in 5G to 10–100 Us in 6G.

Fig. 4. 5G To 6G transformation.

- Mobility up to 500 Km/h in 5G to up to 1000 Km/h in 6G
- Connection Density from 10 6/Km 2 in 5G to 10 7/Km 2 in 6G
- Network energy efficiency in 6G 10 to 100 times better than 5G
- Peak spectral efficiency from 30 bps/Hz in 5G to 90 bps/Hz in 6G
- Area traffic capacity from 10Mbps/m 2 in 5G to 1 Gbps/m 2 in 6G
- Reliability from 99.999 % in 5G to 99.99999 % in 6G
- Signal bandwidth from 100 MHz in 5G to 1GHz in 6G
- Positioning accuracy from 10 m in 5G to 10–100 cm in 6G

Fig. 5 in (Khan et al., 2020b) and referenced section in the paper comprehensively covers the mobile network security landscape as well as highlighting the key areas of 5G security while focusing on issues related to critical technologies, physical security, and privacy to conclude with the emphasis on security and standardization.

4.1.1.1. Critical analysis. Though current communication technologies efficiently manage the current communication/bandwidth requirements and need more smoothly, the anticipated growth in the connected system/devices with the internet and higher bandwidth requirements will make the currently available resources scarce. Advancements in the smart cities' architecture and the inclusion of further aspects of city management into the umbrella of smart will eventually result in more connected arenas and more bandwidth and connectivity requirements. A big chunk of bandwidth can also be used by the increased monitoring and control systems deployed for law enforcement, disaster management, and smart home use audio-visual technologies. 6G will be designed to fulfill the bandwidth requirements keeping in view the increase anticipated by 2030.

4.1.2. Big data

The IoT is all about significant data generation. Its usage and adoption of IoT-based devices and sensors in the automation of city infrastructure will eventually generate many big data islands in various aspects of a smart city. In this regard, a framework was proposed by (Bibri, 2020) which targets sustainable smart cities able to illustrate the informational landscape of smart city build-up on the cores of big data and IoT and ultimately brings the enhancements to the sustainable physical landscape. Different aspects of data must be analyzed carefully concerning future smart cities' requirements, as summarized below.

4.1.2.1. Data volume. The overall system of the smart city has already fallen into the big data problem. The continued conversion of traditional functionalities of the city into smarter ones added more and more data to generate, refine, and process. This results in the challenge of data storage, communication, and processing capabilities to cope with the pace of increase in volumes of data (Cappa et al., 2021). The costs of managing the ever-increasing data volumes are enormous, and they must be planned and addressed properly during the feasibility study of the smart city incorporation. Fig. 5 presents the management of the big data.

4.1.2.2. Data redundancy. The purpose behind big data analytics is to identify the patterns hidden behind the data and results informing the actual representation of the data (Shehab et al., 2021). To get the system's insight more accurately, one way usually utilized is to increase the number of sensors used to monitor the states. This results in redundancy as more sensors report the same state with a minor variation based on sensors' placement. The more data volume we have, the more storage, communication, and processing overhead we will face with the benefits of a rise in inaccuracy. To resolve such overheads, various techniques are applied (Guo et al., 2021). These techniques may include (but are not limited to) feature reduction, feature selection, time scale management, statistical means, and other methods.

4.1.2.3. Data cleaning. The data at the node level may need cleaning before its final submission to the system. The cleaning may be done on outbound, missing, or incorrect values as the volume of data at this level make it impossible to manage the cleaning process humanely. Hence the ML-based techniques are used for this purpose. Having the right tool for the said results in increasing the pace with which data can be fetched, imported, processed, cleaned, filtered, stored, and exported (Sharma et al., 2021). Fig. 6 presents the challenges faced by big data.

4.1.2.4. Data discritization. Though data discretization requirements can arrive in any research most of the time, it occurs while handling medical/healthcare-related data (Vamsi et al., 2021). Due to some needs and requirements, data must sometimes be changed from quantitative to qualitative or vice versa. Special care is required to define the categories

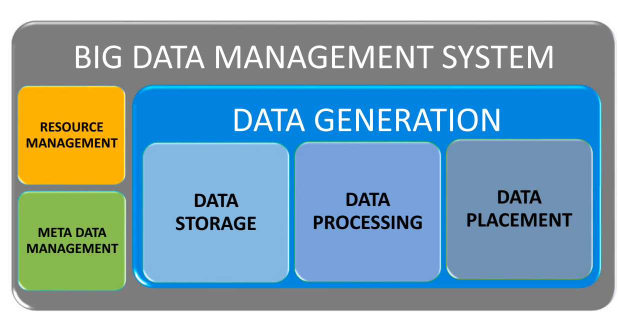

Fig. 5. Big data management.

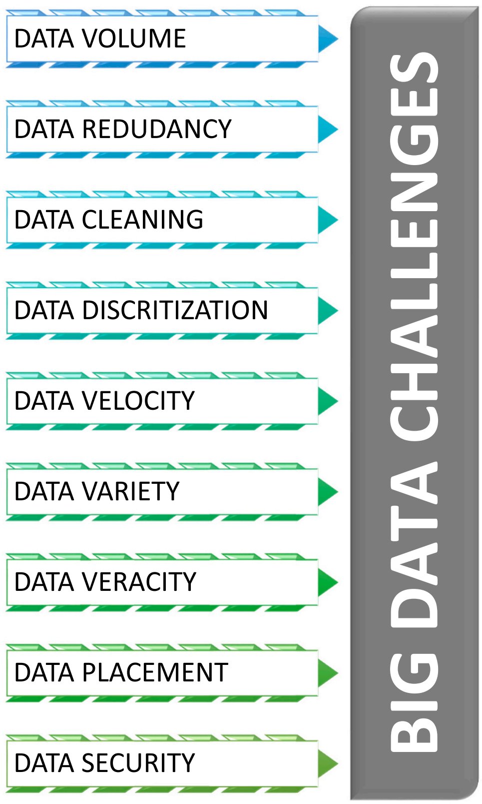

Fig. 6. Big data challenges.

and scaling of converted values. The approaches and schemes must be standardized on the system level to balance the converted values for effective utilization at the system scale.

4.1.2.5. Data velocity. The data velocity is the rate of data generation and can be measured at the component level or the system level. The velocity of the data in the smart city is increasing exponentially. There are two prime reasons behind this phenomenon. The first is the conversion of aspects of a smart city from traditional means to technology-based solutions. The second is the technological advancements that bring the state monitoring's precision by adding more and more sensors, especially after the IoNT. The more nodes the system has, the more data it needs to manage. The timely communication of this real-time system's data with proper security measures is a prime task in every smart city aspect.

4.1.2.6. Data variety. Due to the absence of standardization in IoT, mostly the sensors used proprietary formats. Hence, the system has to handle output in various formats generated by the devices provided by the different vendors. This challenge is faced more commonly in applications related to environment (Hajjaji et al., 2021). Extracting and merging information from such vendor inter-incompatible formats and standardization and availability to the whole system is another challenge. Further complexity can be added to this while managing the unstructured data.

4.1.2.7. Data veracity. The challenge of converting uncertainty on the data to certainty by performing different checks and filters is to solve before processing the system's upper hierarchies. The data may contain biases, noise, or abnormal readings, and such things should be normalized before the data is used for decision making. It is very pertinent to measure if the data is a relevant and suitable candidate for further analysis or not (Ardagna et al., 2018). The high volume of data further limits the time availability of measuring veracity.

4.1.2.8. Data placement. Due to the exponential increase in data generation and storage and processing capabilities, the technology is shifted from data-centric to knowledge-centric. The requirements arise for the availability of efficient, fast, and scalable support to the big data management (Mazumdar et al., 2019). The data may have different values within the system's components, and according to it, the data may be placed and processed at different levels. The most common levels are at the device, edge, fog, and cloud levels. Edge and fog computing result in prime savings in computing and communication resources at the cloud level.

4.1.2.9. Data security. Data is the most crucial asset in any system (Tanveer et al., 2022). Maintaining its confidentiality and integrity is a sensitive task for every system designer. Furthermore, the system and its subscribers depend on its in-time availability, which is also a challenge. The data in any system typically has two states. i.e., data in transit and data at rest. The data's confidentiality can be achieved using various ways on disks, networks, and processing channels. Wireless technology is increasing usage due to the ease of networking provided by it also possesses privacy and security concerns that need to be addressed (Garg et al., 2020).

4.1.2.10. Critical analysis. Data is becoming the new gold in the upcoming technology-oriented world where everything is based on careful data collection and analysis. Data dependency brings new challenges in collecting, handling, transporting, storing, analyzing, processing, and discarding data regarding confidentiality, integrity, and availability. Big data analysis and ML are becoming more involved in everyday life, and AI is involved in automating existing processes and tasks (Khan et al., 2020c). However, to fully reap big data benefits, the challenges related to big data must be addressed. In the long run, these challenges usually increase exponentially; hence an initial vision, long-term planning, strategy development, goals achievement process, and then procedures and actions to achieve those goals are required for successful big data analytics in the given scenario.

4.1.3. WiFi 7

WiFi has been the technology used in consumer wireless networks for more than 15 years. The adoption of WiFi is now a prevalent thing and is an essential component of smart homes, many of whose components rely on the WiFi technology for device and device to consumer communication (FEIBUSTech, n.d.). The wide adoption and popularity of WiFi, technically known as IEEE's 802.11 families of protocols, is based on a license-free spectrum of 2.5 GHz and 5 GHz. This unlicensed spectrum is also known as the industrial, scientific, and medical (ISM) band. Carrier sense multiple access/collision avoidance (CSMA/CA) is used as a MAC layer protocol for WiFi communication, making it half-duplex (Bellalta et al., 2016). Extensive use of WiFi in consumer and enterprise networks and public points like airports, hotels, and restaurants raises the need for connectivity, bandwidth, and speed advancements. Fig. 7 presents the comparative analysis of the bandwidth increase between WiFi generations.

802.11ax, commonly known as WiFi-6, is head to head in implementation along with 5G communication networks. 802.11n and 802.11 ac, commonly termed WiFi-4 and WiFi-5, are already implemented in current consumer-level products, and WiFi-6 is already heading its way to the consumer level. Multiple-input multiple-output (MIMO) was the base reason for having the high bandwidth possible in WiFi-4 and WiFi-5. 802.11be extremely high throughput (EHT) will be expected to be designated as WiFi-7. It is still under intense research, and the initial draft for the protocol is expected to be released in March–April 2020 with expected technology roll-out to the consumer market in 2024 (Khorov et al., 2020).

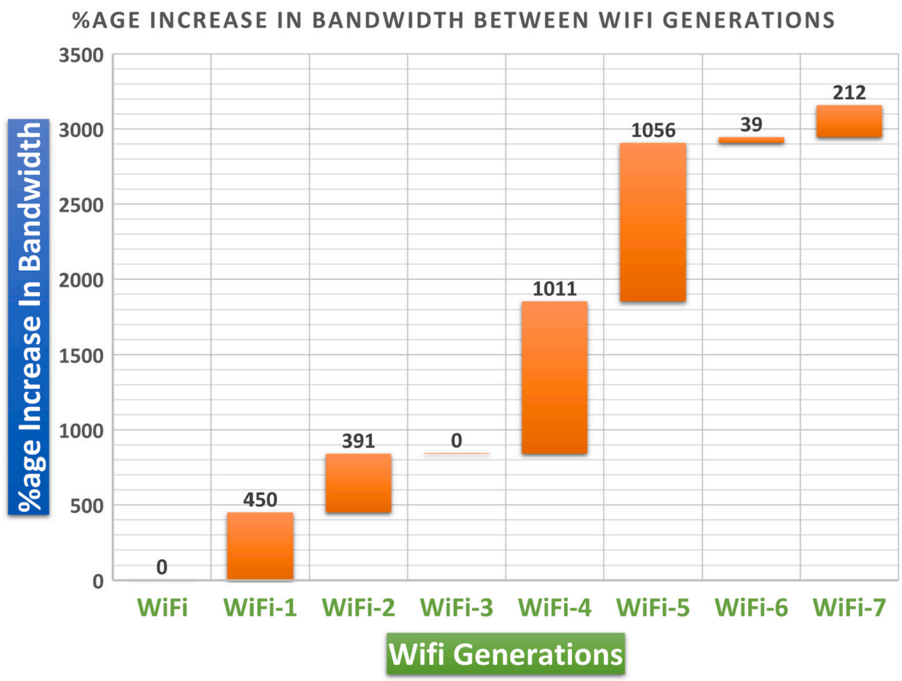

Fig. 7. Comparative bandwidth increase between WiFi generations.

WiFi6 and beyond converge MIMO into upLink multi-user multiple-input multiple-output(UL MU-MIMO). WiFi6 supports MU-MIMO technology providing 8 data streams at a time. WiFi7 extends it to 16 data streams by utilizing the technology of clustering multi-user multiple-input multiple-output (CMU-MIMO). WiFi 6 has a maximum supported throughput of 9.6Gbps, and WiFi 7 design improvement will expand to 30Gbps, more than three times. WiFi7 also uses the 4096-QAM signal modulation method instead of the 1024-QAM signal modulation method used by WiFi6. The significant shining improvement brought into WiFi7 is introducing a 6GHz band. Previously 802.11 only operated in 2.4 and 5 GHz bands, but for the first time, the 6GHz band will be utilized in WiFi7. Another aspect under research is the effective utilization of the available spectrum, and DL is also being utilized for solving some of these challenges, especially on the MAC layer of wireless network (Ali et al., 2020a).

4.1.3.1. Critical analysis. Keeping in view the implementation of IoT at the consumer level and the edge and fog computing and their interactive connectivity with cloud-based systems, WiFi7 will future proof the home/enterprise LAN networks in terms of bandwidth and connectivity requirements. In WiFi7, higher frequency utilization for communication will also resolve the challenges limiting the advancements due to limitations in the 2.4GHz and 5 GHz band and allow the author to achieve the targets without getting bounded by the previous limitations. Table 3 presents interconnective and data literature.

4.2. Cyber physical systems

Automation in factories is a traditional concept widely implemented to save time and resources. However, this approach further moves in a smarter aspect to impart the technological advancements into the traditional automation concept in the current era. This smartness revolves around bringing intelligence to automated systems. Hence the existing digital factories are now becoming intelligent factories (Chen et al., 2018a). Fig. 8 presents the cyber-physical security approach.

The next generation intelligent factories are built on the layered model having an End-user/management terminal layer, a cloud-based data analysis and decision support layer, a network layer looking after all levels of communications, and a physical resource layer managing the actual work done on the production line. Each layer then manages a couple of the devices and controller to perform the desired action (Chen et al., 2018a).

These advanced technology-based smart factories are known as CPS. The security of CPS is a hot research topic nowadays. The security in CPS mainly revolves around the privacy issues, dependability of components and layers, resiliency against accidents and attacks, interaction among layers and components and their coordination, operational security, system hardening, and most of the time, and system availability (Javed et al., 2020a; Yaacoub et al., 2020). The above-referred layers of the CPS have the standard of the component at each layer under computer, communication, storage, and physical world interaction using sensors and actuators of various kinds and nature.

4.2.1. Industry 5.0

The approximately 250-year-long history of industrial revolutions shows a gradual shift in the revolutions' x-centric behavior from machine and technology from the first three generations to cognitive intelligence and machine to machine intelligent communication in the fourth industrial revolution. In today's technology-oriented world, the shift is seen from comparatively less developed countries excelling in the latest technologies faster than their counterparts. Being at the top of the technological horizon is becoming more difficult nowadays (Nahavandi, 2019). The same is now going to become human-centric in Industry 5.0. It will make humans only in the design and control position. The laborious work will become fully automated and smart controlled by intelligent machines looking after every production process. It will result in everything customized to work for customer-centric industries. Each product from those industries will be customized as per the customer's requirements and personality, which will result in more convenience and satisfaction for the customer, lesser returns, and more value for money being made to order.

AI will be heavily used in industrial revolution 5.0 (IR5.0) to change management, transformation management, customer-centric production, and research and development. This era's major governing components will be IoT, big data, ML, AI, CPS, and direct human-robot interactions (Vogt, 2021). Another novel concept introduced by (Chen

Table 3
Summary of inter-connective and data literature.

Ref.	Paper aim	Proposed scheme/method/mechanism	Key features
(Lai et al., 2021)	Monitoring of necessities support in smart cities using smart sensors	Sheds light on different aspects of a smart city, including power, energy, water health, and transportation.	• Current technological developments in smart cities • Data analytics for solar energy • Blockchain application in microgrid infrastructure • Smart water management using Zigbee-based network • Smart temperature sensor deployment
(Gupta et al., 2020)	Smart farming security challenges	Discussed security challenges in smart farming and ways to tackle them.	• Potential cyber attack on the smart farming ecosystem. • Outline of multi-layered security architecture
(WEF, n.d.)	5G promises for the fourth industrial revolution	Implementation and benefits of 5G concerning the fourth industrial revolution.	• Use-case-driven approach towards next-generation networks • Factors to improve the network coverage • Quality service to the consumers
(Al Ridhawi et al., 2020)	Security and safety of communication channel from IoT devices to fog computing through edge devices	Proposed solution deployed on edge devices to provide a reliable and secure communication channel between end-user IoT devices and fog computing.	• Proposed complex services-based framework using fuzzification • Employed reinforcement learning techniques with inbuilt intrusion detection • Provided an efficient communication solution
(T. Group, n.d.)	Cyber security challenges for advanced telecommunication networks	Discussed the open and upcoming challenges for advanced telecommunication networks like 5G and how to tackle them efficiently.	Discussed challenges and possible solutions for the following • Agile virtual networks • Massive IoT-based customer-level connected objects • Data-driven networks • Cybersecurity
(Han et al., 2021)	Future next-generation high speed network	Looked into the factor enabling 6G networks to be deployed until 2030.	• Discussed technical rules and regulations, gains, benefits • Technological improvements for the next generation of high-speed communication networks
(Habibi et al., 2019)	Limitation of current communication technologies w.r.t upcoming requirements	Provided solutions for consumers' and industries' bandwidth requirements of high-speed 5G networks.	• Radio access networks (RAN) and architecture • Enhanced the quality of current RAN networks • Multi-access edge computing • Virtualization of network function (NFV) • Software-defined networks (SDN) • Multimeter wave
(Bibri, 2020)	Sustainable smart cities using IoT based monitoring	IoT monitoring and control-related tasks in sustainable smart cities.	• Conceptual framework to build sustainable smart cities
(Cappa et al., 2021)	Big data handling issues	Discussed the organization's big data needs and requirements, focusing on issues faced during big data handling.	• Big data variety negative impacts on the organization's • Discussed opportunities and circumstances to harvest the benefits of big data analysis
(FEIBUSTech, n. d.)	Study of WiFi technologies	Provided comprehensive coverage of WiFi current technologies and their impact on the industry and consumers.	• Outlined trends, technologies, and in-depth details of WiFi enhancements
(Khorov et al., 2020)	Advancements in IEEE 802.11	Provided comprehensive coverage of IEEE's 802.11 current and upcoming advancements and their impacts.	• Overview of WiFi 7 advancements (802.11be) • Coverage and analysis along with technological enhancement in WiFi

et al., 2021a) is human-cyber-physical systems (HCPS), which combines human intelligence (HI) with trained AI solutions to bring the cognitive smart CPSs. Cognitive intelligence is built using sensors (for taking the input from the environment and targets). It uses a translator to translate the input data into information, modeling for numerical analysis, and semi-supervised learning of the system to make it smart for future decision-making. It is also modeling intelligent decision-making for future unsupervised actions, analysis and upload of the data to the cloud, and human-system interaction for running the whole system (Javed et al., 2020b). Fig. 9 presents the concept of smart factories in today's world.

The overlapping interaction between the business, customer, and technology is the base of the industry 5.0 innovation (Aslam et al., 2020a). These, too, are heavily involved in the smart cities' architecture at their level. Their interaction will also impact their utilization within the smart cities system and eventually bring more citizen-centric smart cities. The innovations in these domains will eventually end in the overlapping intelligently communicating system, which was previously based on the interaction among each other (Kiran et al., 2020). The 5.0 is now becoming a symbol various areas and used as a symbol to the customer/citizen-centric approach (Rosemann et al., 2020) such as Retail 5.0 (a customer-centric next-generation business framework outlines) (Kowalkiewicz et al., 2017), Government 5.0 (A citizen-centric government framework) (Kowalkiewicz & Dootson, 2019), concepts of Entertainment 5.0 and Education 5.0 as discussed in (Rosemann et al., 2020), overview of Production 5.0 without mentioning the term (highly

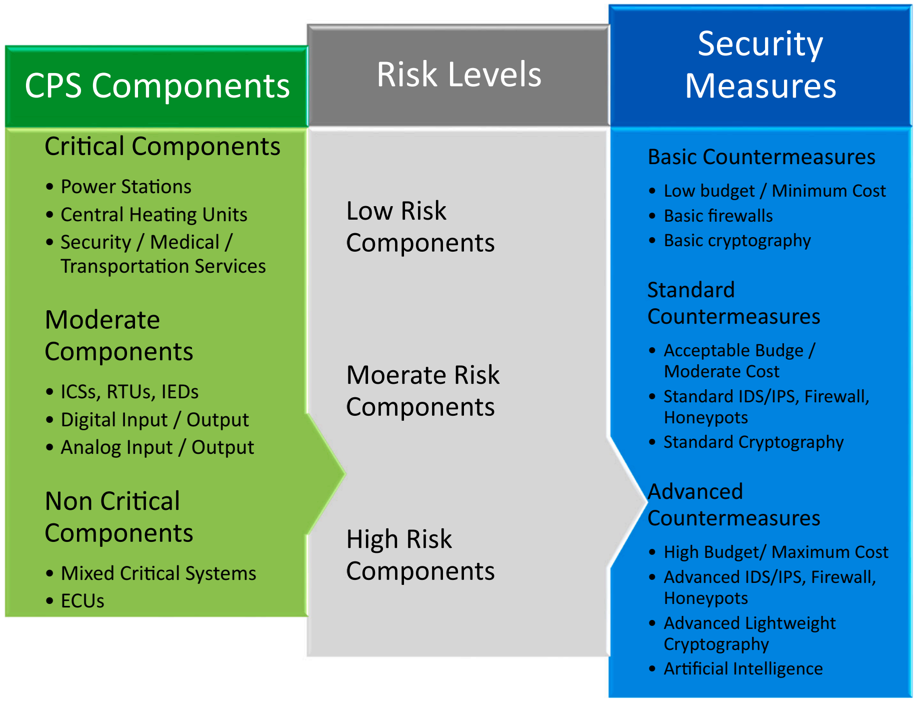

Fig. 8. Cyber physical security approach.

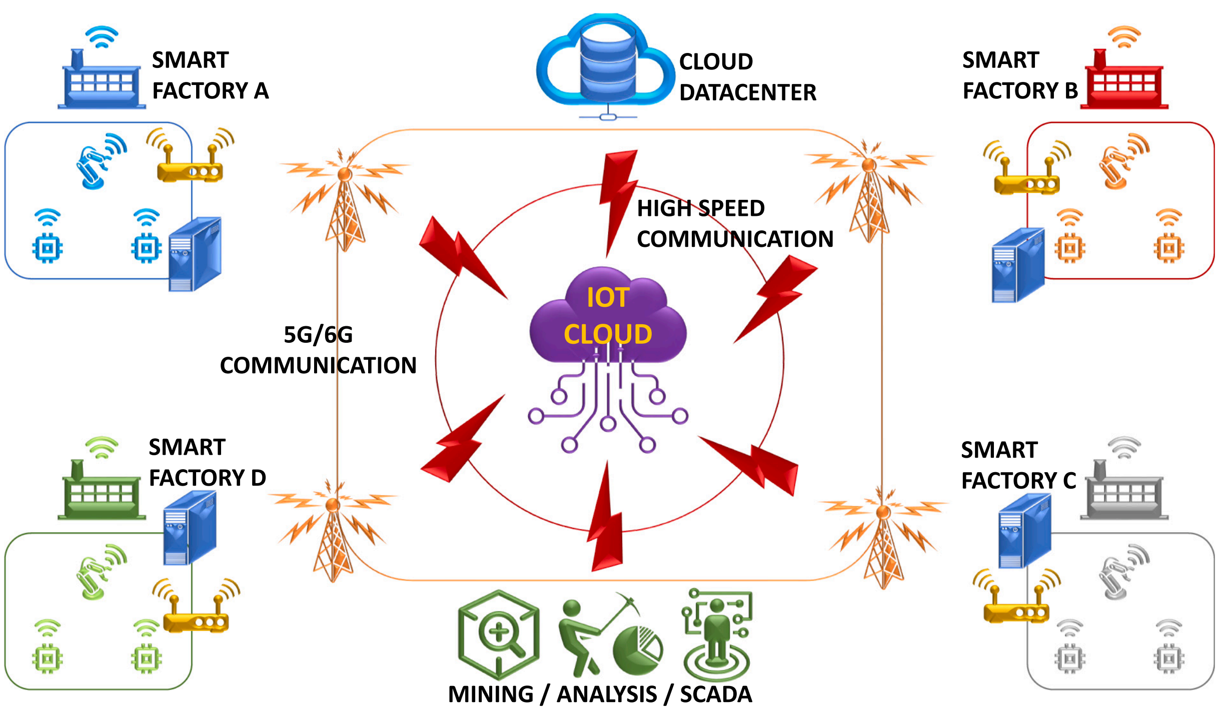

Fig. 9. Smart factories in today's world.

customized production approach towards customers variable requirements) in (Tookanlou & Wong, 2020), Industry 5.0 with discussion on impacts on customization trend on new market opportunities and environmental impacts in (ElFar et al., 2020) are to name a few. Fig. 10 presents the industrial revolutions chronology of smart cities.

4.2.1.1. Critical analysis. The Industrial Revolutions 5.0 revolves around the customer and will be more beneficial for the customer. Mass customization concerning individual customer demand is the next big thing to become a competitive advantage in the coming days. The customer will get the products customized to the needs, requirements, and new dimensions of personality, mood, and preference. The same paradigm will change the future smart city into becoming citizen-centric by offering and modifying the smart city services according to needs, demands, and living context by integrating cognitive intelligence into the already automated processes.

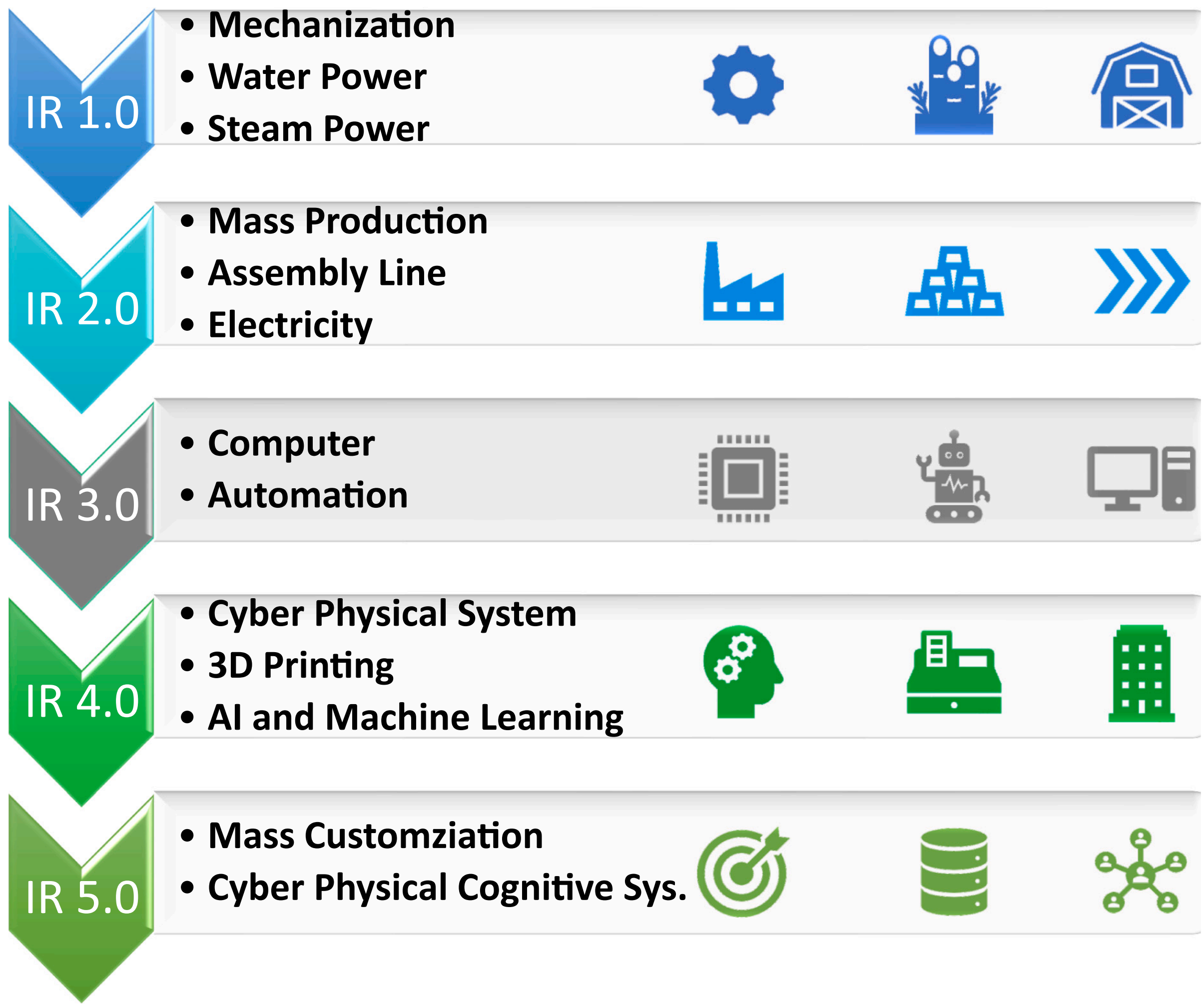

Fig. 10. Industrial revolutions chronology.

4.2.2. Robotics systems

Robotics has their history back when humans start mechanics to bring ease to their work. Since then, the concept of automation gradually evolved into intelligent automated machines capable of making decisions based on the situation before taking action and performing the task per the environment's requirements. However, modern robotics counts as the 1st generation of proper robotics since electronically managed machines perform specific tasks independent of continuous human supervision.

Automation technologies are continuously used throughout the world in smart cities. Robotics is a crucial part of this trend. Both of them are now become the natural partner in the cyber smart city arena (Studley & Little, 2020). For technological advancements, smart cities are used as testbeds to implement automation of various processes, services, and facilities using robotics and AI. AI and robotics can be used in various aspects of smart cities, including automation (i.e., big data, ML, DL), decision making (i.e., economy, governance), education (one-stop-shop, robotics assistants), smart infrastructures (i.e., sensors, robotics monitoring) and smart mobility (i.e., autonomous transportation, robot garages) (Macrorie et al., 2019). Fig. 11 presents the generations of robotics in smart cities environment.

Authors proposed (Kumaran & Chinnadurai, 2020) using a 3-tier approach in the city's crisis control and management in which control of crowd using AI and robotics. The system gets the data from the camera sensor. It analyzes it to interpret the situation's intention and intensity by processing the cloud using AI and deciding the necessary actions to implement crowd control, which got implemented using connected robots.

In the same way, robotics can be used to handle emergency solutions, where robots and drones can effectively support crisis management. Drones usage in fire fighting tasks is also proven helpful for monitoring, prevention, surveillance, and extinguishing (Akram et al., 2021; Chaudhry et al., 2021a; Roldán-Gómez et al., 2021). Russia is going to use advanced robotics in its emergency operations like bringing medicine immediately to the affected area, shifting the wounded person from the site, provision of tools and equipment in disaster situations, etc. (Mamchenko et al., 2021). A training data set for automated surgical operations by robots and methods for its propagation and sharing to other robotic platforms were discussed in (Gonzalez et al., 2021). The authors develop the capability to perform emergency medical/surgical procedures using AI to tackle the highly emergent situations where the availability of healthcare professionals risks lives. Those surgical maneuvers were compiled as a library for sharing for continuous learning and improvements. The latest advancements and research aspects were explored in (Huang et al., 2021; Krishna, 2021; Marchetti et al., 2022; Mitchell et al., 2021; Qureshi et al., 2021; Zaki et al., 2021) as published in the first month of 2021, showing the active research on autonomous robotics in various fields of public life.

4.2.2.1. Critical analysis. AI-backed autonomous robotic systems are being researched to assist human counterparts in various fields of human life. Even in some areas, robots are intelligent enough to replace human

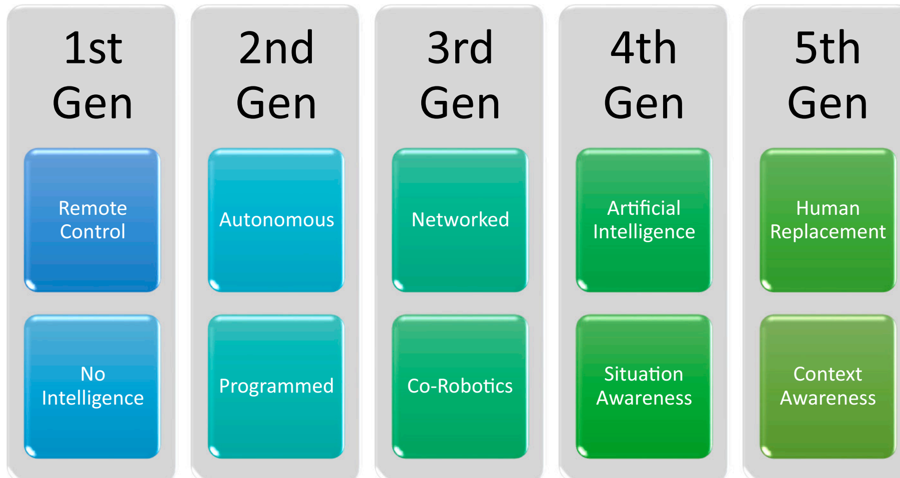

Fig. 11. Generations of robotics.

supervision and understand situations using ML and AI techniques. This will help save human lives from facing dangerous situations, and robots will perform the tasks in such unfavorable circumstances. This will help handle and manage disasters and incidents to respond effectively and efficiently. Another significant improvement in using autonomous robotics in healthcare and surgery is in progress. Home maid tasks will automatically be shifted from humans to robots to view intelligence and context awareness being improved day by day. The use of robotics for replacing human soldiers is also an active research area, but it is far out of this paper's scope.

4.2.3. Healthcare IOT

IoT technology has four main elements: 1) Internet, 2) Hardware, 3) Middleware, 4) Presentation. Any application proposal for a smart city must consider both policy and the technological challenges optimally favorable. It should not only during normal operations like parking, lighting, etc., but it should also be optimal for the data and systems in emergencies and disaster situations. (Soyata et al., 2019) Proposed a conceptual mesh network for smart cities, in which devices will use their own stored energy during grid source. It has two modes; normal and emergency. Healthcare management is vital to any future smart city (Qureshi et al., 2020a). City-level smart healthcare management components may include personal healthcare, smart hospital, telemedicine/

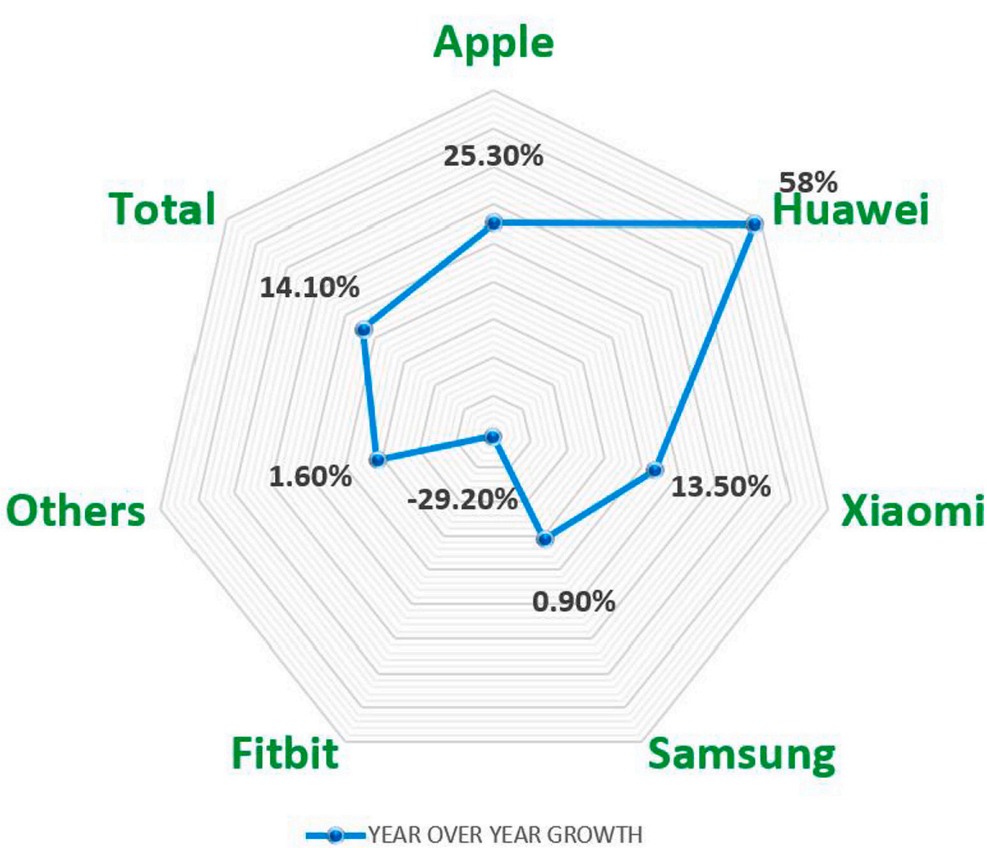

Fig. 12. Top 5 wearable companies year-over-year growth, Q2 2020.

online consultancy, smart medicine, smart disease control, and smart healthcare reporting. The first level of this system is the Personal Body Area Network with sensing devices to monitor a human body's various activities. These activities may include but are not limited to steps tracking, heart rate monitoring, blood oxygen level monitoring, and sleep monitoring (Javed et al., 2020c). These sensors are commonly referred to as the Healthcare IoT (H-IoT) (Qadri et al., 2020). Besides Covid-19 impacting businesses worldwide, the market of wearable devices is expected to see a rise of 14.5 % till Q4 2020 and will continue the trend in upcoming years till 2024 (Corporation, n.d.). Fig. 12 presents the top 5 wearables companies' growth year by year.

Edge computing patches low latency requirements between sensor and data processor by providing a shorter distance and higher processing speed. Compiled, cleaned, and aggregated data, then forwarded to the cloud for intelligent decision making. Also, the H-IoT sensor generates enormous data, and its manual compilation is not worth keeping the return on investment (RoI). ML and Big data analysis techniques are utilized in the current solutions to make the process more productive and in time (Manogaran et al., 2018).

Remote surgery is at the evolutionary edge where scientists and medical personnel try to free from geographical boundaries. The ultra-fast real-time network availability and IoT-based actuators with high-speed audio-visual aid technologies are helping in gradual progress in this field (Ecclestone et al., 2021; Latifi et al., 2021). Other healthcare aspects where next-generation technologies are being used include medical training, locomotive and sensory prosthesis, the precision involved procedures, virtual reality and augmented reality (VR/AR) based rehabilitation, and trauma rehabilitation (Qadri et al., 2020).

A very comprehensive research analysis is presented in (Yaqoob et al., 2019) in which the authors tested 100+ HIoT devices to evaluate security flaws. It ranges from unauthorized access, tampering, sniffing, denial of service, the man in the middle and ransomware, etc., to map the security-related footprints of different medical devices. Countermeasure to the typical flaws and policy-based control is also part of the solutions treating the risks due to the security flaws.

4.2.3.1. Critical analysis. IoT adoption in human life is so common nowadays that it has become a part of our regular life. The advantages offered by HIoT. The advancements in the IoT devices, technology (communication and compute), power sources (usage and storage), and reduction in costs will make these devices come into typical humans' lives. Future smart cities will have a coordinated network of IoT devices for commercial and industrial purposes, smart home management, and personal health and fitness recording and management. Such devices will monitor the patterns of vitals related to the end-users norms, immediately identify the anomalies, and update the local healthcare system to provide medical aid if requirements arise. Table 4 presents the summary of studies on cyber-physical systems.

4.3. Crisis control backup

One of the essential aspects of smart cities' governance and management is planning, monitoring, and controlling the city's crisis. Different stakeholders, including healthcare, law enforcement, administration, disaster management, and other departments, are taken on board for immediate threat detection. Mitigating the loss by sharing Information with the different departments, planning the course of action, and acting on sops.

For cities and states, crisis management is considered one of the essential tools which can help them to stop spreading unwanted events to a larger scale (Růžička & Navrátilová, 2020). Article (Bénaben et al., 2016) deals with developing a model of how to use knowledge in case of crisis management effectively.

Table 4
Summary of cyber-physical systems literature.

Ref.	Paper aim	Proposed scheme/ method/mechanism	Key features
(Chen et al., 2018a)	Future smart factories architecture	Presents a layered model for smart factories.	Discussed a layered model that includes • An End-user/ management terminal layer. • Cloud-based data analysis and decision support layer. • Network layer looking after all levels of communications. • Physical resource layer managing the actual work done on the production line.
(Yaacoub et al., 2020)	Accident and incident proofing of cyber-physical systems	Framework for the resiliency against accidents attacks interaction.	• Presented security framework for CPS for following privacy issues. • Dependability of components and layers. • Resiliency against accidents and attacks, interaction among layers. • Components and their coordination, operational security, system hardening, and most of the time, system availability.
(Vogt, 2021)	Use of artificial intelligence in next generation industrial revolution	AI in Industrial Revolution 5.0.	• Proposed that AI will be heavily used in Industrial Revolution 5.0.
(Chen et al., 2021a)	Intelligent human cyber physical system	Novel concept for HCPS.	• Combined human interaction with trained AI solutions to bring the cognitive intelligent CPSs.
(Aslam et al., 2020a)	Study of 3 dimensions of next-generation industrial revolution	Interaction between the business, customer, and technology.	• Presented the framework for overlapping interaction between the business, customer, and technology.
(Studley & Little, 2020)	Robotics and automation for future smart cities	Robotics and automation technologies.	• Suggested that Robotics has now become the crucial part of the smart city.
(Javed et al., 2020a)	Usage of deep learning for energy consumption	The authors proposed how Tree Partitioning and Deep Neural Network methods helped predict and identify energy consumption.	• Presented a framework of the intelligent system (IS) for efficient energy management.

4.3.1. Disaster backup

Disaster management is a crucial aspect to be taken care of for any traditional and smart city. It becomes more critical to take care of in a smart city as they are well organized and well managed, and all the actions are taken there are backed by the data. Planning and executing a disaster management operation in smart cities is relatively more straightforward than in traditional cities. The use of technology in the planning and management of disasters can increase human life savings and capital many folds (Fan et al., 2021). United Nations' office of co-ordination for humanitarian affairs (OCHA), in its strategic plan 2018–21, emphasized careful emergency response and disaster management in a well-coordinated way to minimize the wide-scale losses a city at the national level, (U. N. O. F. T. C. O. H. A. (OCHA), 2018). As per (U. N. O. F. T. C. O. H. A. (OCHA), 2021), humanitarian assistance and protection will be required for approx. Two hundred thirty-five million people in 2021. Fig. 13 presents the components of proactive disaster planning.

A proactive action is worth more than the reactive action done afterward. Analysis of existing infrastructure to sustain against relevant disaster and community tolerance against services disruption during a disaster are two critical factors needed to study for such preventive and proactive management steps against disasters (Dong et al., 2020). As the disaster planning is done by anticipating the expected disasters and planning accordingly long before the event's actual happening, there is ample time to review and gradually improve the planning. This planning focuses on the technology and infrastructure and on the human preparation for facing disaster.

To prepare and rehearse people about the possible issue faced during expected disasters and interact with them. Factors that impact human behavior towards a disaster situation include previous disaster-facing experience (if any), demographics, culture, and awareness about the situation (Petersen et al., 2020). Emphasis on these impacts will bring fruitful results in handling the disaster and responding to it from the human side. Efforts on the community level always get positive results in enhancing human capability in this regard (Andharia, 2020).

4.3.1.1. Critical analysis. As in smart cities, technological advancements exist at a high level; hence, disaster planning and management are based on data analysis. This data can provide complete insight into the issue and become a base for modeling, simulation, and making informed, intelligent decisions. Due to this, it is imperative to have a concise, compelling, targeted, and automated disaster response in current and future smart cities.

4.3.2. HVAC empowerment

Human thermal comfort is one of the significant aspects of providing comfort to humans in daily life routines. Though, improving human efficiency in terms of productivity is the basic necessity of every work. However, providing a comfortable environment to workers has turned out to be a significant improvement in work efficiency as well as stated by (Fayyaz et al., 2021; Rehman et al., 2020). The authors in (Li et al., 2020) proposed a novel approach to the adaptive HVAC control system in which the air conditioning systems regulate real-time through big data analytics. Their system monitors CO2 concentration, temperature, and threshold set by occupants for the optimal prediction of temperature for occupants. With the importance of HVAC in regulating human thermal comfort, it is also necessary to maintain the HVAC systems fit for the work as a state in (Mirnaghi & Haghighat, 2020). The HVAC systems fault detection mechanism was based on data-driven techniques such as AI algorithms and traditional research skills. The cost-efficient adaptive HVAC approach proposed in (Yu et al., 2020b) can work without the prior knowledge of cost expense data. The proposed HVAC management system uses real-time data and applies Multi-Agent Deep Reinforcement Learning over the data (Garca-Sanz-Calcedo et al., 2020). However, an HVAC control system's relationship is also critically linked with parameters such as embodied carbon.

4.3.2.1. Critical analysis. The reviewed studies prove that optimal HVAC is one of the vital necessities present in every work or residential environment. The methodologies applied for the optimal HVAC environment are mainly based on automated systems that work on data obtained through previous human thermal comfort predictions or metrics. The studies also state that the human work performance and efficiency also show a positive increment due to better human thermal comfort. Moreover, the reviewed studies also prove that the latest innovative methodologies automate the old conventional approaches, due to which less supervision and manual control are required.

4.3.3. Pantry backup

Disasters due to calamities or any pandemic crisis, war, or crop shortage cause severe damage to the country's economy and affect the public on a massive scale. Shortage of food supplies will make the remaining supplies very costly and unreachable for the common public. This situation also leads to the decrements in the work efficiency of man force around the country. The article from New York Times (Dahir, 2020) signifies the importance of pantry backup by highlighting that COVID-19 might kill the population with the virus rather than hunger. Authors in (Singh et al., 2020a) studied the effect of COVID-19 on logistics systems and disruptions in the food supply chain. The authors developed a public distribution system (PDS) to encounter the problematic factors in a resilient supply chain during the pandemic. Their proposed system can provide predictive support to food supply chain vehicles to reroute if they encounter any restricted route. The food yield requirement is justified in (Latham, 2021) for the coming year. The authors clarify the food's unreported requirements and thus estimate the food's future needs for the world population. The authors in (Pafnoiu, 2020) performed a critical survey of the global food crisis due to pandemics and highlighted the future challenges.

4.3.3.1. Critical analysis. The reviewed studies justify the need for pantry backup systems in multiple regions. Food is the fundamental necessity for human existence, and it is being ignored. In the coming times, the food crisis may lead to disasters in public infrastructure. The significance of pantry backup is highlighted in pandemic times, but it is more important in natural calamities and war times. The pantry backup system ensures the well defensive infrastructure to fulfill occupants' needs during tough conditions, making life comfortable and relaxed. It is

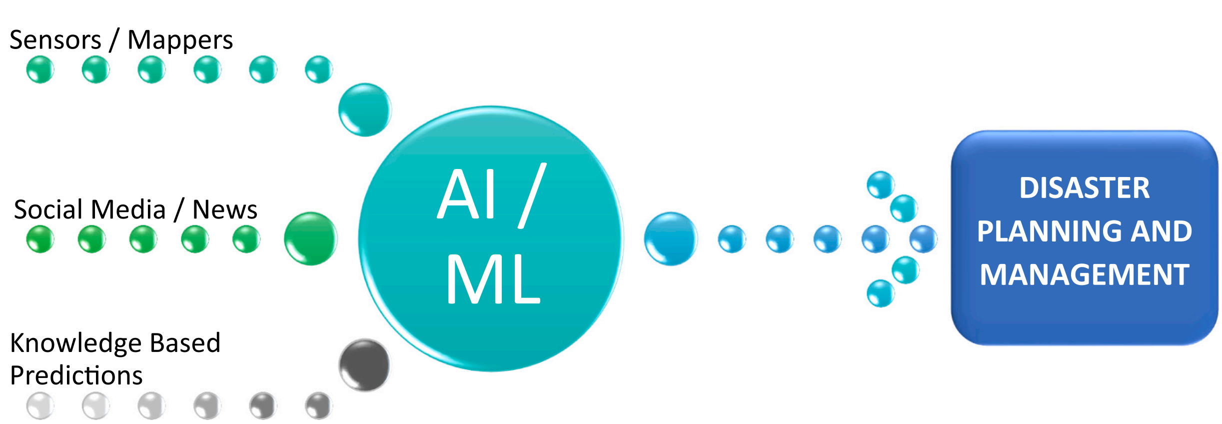

Fig. 13. Components of proactive disaster planning.

an important factor in a future smart city. Table 5 presents Crisis Control Backup Literature section tabular. Fig. 14 presents ML and AI relationship.

4.4. Artificial intelligence

It is anticipated that in 2050, 60 to 70 % of the world's population will shift to the urban areas (Liu et al., 2019) keeping in view the trend of urbanization in the population. The first-world countries started incorporating the latest technologies in the infrastructure and management of the cities to cater to this enormous shift and issues created by this population transfer. Due to the data-driven nature of the fourth industrial revolution technologies, their incorporation results in massive data. The interconnected technologies and their reliance on each other's output to make intelligent and data-centric decisions are handled by heavy usage of ML techniques and AI (Ullah et al., 2020).

The current smart cities see a trend of such incorporation. Various cities are on the way to achieving intelligent smartness in various city aspects (Cowley et al., 2018; Datta, 2018; Fernandez-Anez et al., 2018; Karvonen et al., 2019; Pinna et al., 2017; Valdez et al., 2018). The typical issues faced include but are not limited to pollution and degradation of the environmental quality, shortage of resources as compared to the need of the population, traffic jams, higher cost of living, decrease in living standards, higher poverty rate and other social issues (Wu et al., 2018). The city transformation project planning also requires careful planning, keeping in view the digitization and technical aspects and considering an unexpected spike in the population due to urbanization (Dowling et al., 2019).

According to (Joss et al., 2019), the current status of smart cities throughout the world is divided into three tiers, with "model smart cities" at tier 1 followed by tier 2 and tier 3 smart cities as "follower smart cities." The primary differentiation role between model and follower is advanced ML and AI techniques for overall management and decision-making.

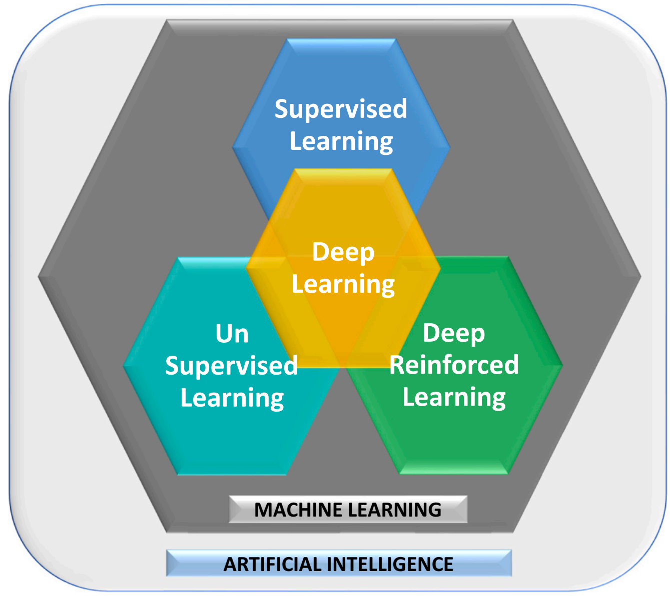

Fig. 14. Machine learning and artificial intelligence.

The most usual tasks and processes will be defined and managed automatically using artificial analysis in future smart cities. This will help in the synergy of system operations, bringing timely execution of the functions in different aspects of the smart city and providing a reliable living experience. Requirements generations in smart city

Table 5
Summary crisis control backup literature.

Ref.	Paper aim	Proposed scheme/method/mechanism	Key features
(Růžička & Navrátilová, 2020)	Traffic management in emergency situation	This paper discusses the importance of smart traffic management in the era of disaster and emergency and how we can utilize smart transportation during national and urban emergencies.	• Presented an analysis by reviewing existing crisis management systems and their approaches w.r.t smart trafficking and transportation. • Proposed a solution that can be merged into any crisis management solution.
(Bénaben et al., 2016)	Data collaboration in crisis situation	The article is based on the consideration of collaboration and data management issues in the crisis.	• Presented meta-model that acts as an information basis for other developed tools for crisis management and collaboration.
(Fan et al., 2021)	Disaster operations management using information-based decision making	Due to the increase in the frequency of natural and human-made disasters, relief operations saw a rising trend in the near past. This paper highlights the ICT and disaster/relief information linkages and importance.	• Proposed a solution for disaster operation management based on four main components of the city's disaster management: dynamic network analysis, data integration and data analytic, multi-data sensing, and multi-actor game-theoretic decision-making.
(Dong et al., 2020)	Impact of unavailability of critical infrastructures	Disturbance/unavailability of critical infrastructure and services during/after the disaster results in damage and slowdowns in the rehabilitation efforts. Resilience to such events eventually results in better disaster management.	• Proposed a framework to analyze the community's vulnerabilities that may damage critical infrastructure or unavailability of its services. • Calculated disruption tolerance index (DTI) to quantify the impact on healthcare facilities.
(Rehman et al., 2020)	Use of IoT in HVAC of smart buildings	The article is about the increasing usage of IoT devices in controlling, managing, and sensing the heating, ventilation, and air conditioning of smart buildings and their impact and efficiencies.	• Presented a model to predict the thermal sensation votes of a smart home resident. • Applied ML and DL models to predict the thermal sensation using the proposed model with attaining accuracy of above 85 %.
(Yu et al., 2020b)	HVAC energy-efficient consumption using deep learning	HVAC usually consumes 40–50 % of the cost of energy which becomes a burden on operations. Minimizing this cost can be very beneficial overall.	• Provided a model based on the Markov game without having prior knowledge of the building's thermal dynamics. • Controlled the HVAC based on multi-agent deep reinforcement learning with an attention mechanism.
(Latham, 2021)	Hunger and food deficit analysis	The growing concern in the agriculture field worldwide is the expected increasing food deficit. UN's food and agriculture organization (FAO) closely monitors and works on the issue.	• Provided in-depth analysis of the current situation of food-deficit crisis. • Stated major issue faced worldwide and the effort to fight against hunger and feed humans worldwide.
(Singh et al., 2020a)	Impact of covid on food chain supply	The Covid-19 virus impacted the lives of humans and crippled the healthcare systems, and severely churned out the economies. The global food supply chain is also one of the major areas that face its worst impact.	• Provided a simulated model to output a resilient supply chain model to the restriction • Provided alternate routes and measures to impose travel restrictions in specific areas.

scenarios bring advancements in AI techniques to fulfill those requirements. The same advancements in AI also generated further new requirements in the smart cities functions, which are a candidate to be solved using those techniques. Hence, both AI and smart cities' impact result in a win-win situation where both help each other excel in their respective fields while supporting advancements in each other.

The autonomous processing of information and smart decision-making based on AI-based ML and behavior analysis will be the major part of city governance and management in a smart future city. Human capabilities will be used for high-level decision-making and management. Day-to-day operations will be automated and reliably handled by the computer brains, which will act on competent will within the thresholds as per the system designers' feeding.

4.4.1. Machine learning

The dawn of AI has changed conventional methods into robust automated methods. ML is that branch of AI that deals with the automation of human-based tasks by training the model over specific data and then testing the trained model over the unseen data to get the predicted results (Alpaydin, 2020). AI plays a vital role in revolutionizing smart cities. There are tremendous applications of ML developed in smart cities. Few of the major applications are stated by (Ullah et al., 2020) which include intelligent transportation systems (ITSs), cybersecurity, smart grids (SGs), UAVs, 5G, and B5G communications, and smart health care systems in a smart city (Chaudhry et al., 2022; Irshad et al., 2021). The authors also highlighted the upcoming challenges in future research directions (Sarker, 2021). The authors in (Zekić-Sušac et al., 2020) proposed an ML-based approach for smart cities to make energy consumption efficient in terms of cost by providing the prediction of optimal configuration with the data collected by IoT networks and Big Data collections. The authors prescribe implementing this model in public sectors' business intelligence systems to predict investments in reconstruction measures. The authors in (Shafiq et al., 2020) surveyed the capabilities of data mining and ML techniques in the classification of network traffic. Their in-depth evaluation of the ML approaches also highlights the future perspectives of ML applications for sustainable smart cities. Authors in (Iskandaryan et al., 2020) worked on the living, environmental quality analysis. They evaluated the ML algorithms to examine the air pollution extent with sensors data. The applications of ML in smart cities are not limited to automating human-based work only. Rather their applications are extensively found in medicine and safety precaution systems. The authors in (Hashem et al., 2020) proposed an ML approach to detect the COVID-19 spread across the smart cities. Their study also covers the research areas of predicting the next epidemic, effective contact tracing, diagnosing COVID-19 cases, monitoring COVID-19 patients, COVID-19 vaccine development, tracking potential COVID-19 patients, and aiding in COVID-19 drug discovery. It provides a better understanding of the virus in smart cities through ML approaches. The authors in (Basit et al., 2020; Fard et al., 2020; Kim & Ben-Othman, 2020; Kumar et al., 2020; Rahman et al., 2020; Rashid et al., 2020) proposed ML-based state-of-the-art solutions for prevention of cyber attacks in smart cities. However, it is imperative to carefully bring this intelligence and automation to save from the possible negative impacts of the autonomous systems' automated decisions in the absence of emotions and contextual intelligence (Allam, 2021; Zehra et al., 2021).

Fig. 15 presents different techniques of ML. CPS security is the new, smart and intelligent critical infrastructure-based system. Using ML and the challenges, solutions proposed in published research can be secure. ML and future research directions in resiliency in ML, context awareness in ML, federated learning, and minimizing false positives and false negatives while detecting threats to the CPS are covered comprehensively in the paper (Lian et al., 2022; Olowononi et al., 2021). Another study (Mohasseb et al., 2020) focused on practical aspects of cybersecurity incidents detection, analysis, and classification using ML techniques which can be administered in the scenario of smart cities.

4.4.1.1. Critical analysis. The reviewed studies highlight the significance of AI applications in smart cities. Nevertheless, the ML approaches are considered the fundamental pillar of a smart city. The ML approaches automate the conventional tasks and provide solutions to complex problems monitored through humans. The intelligence brought to the systems must have a cap over them to control the autonomous decisions under human supervision. Though advances bring contextual and situation awareness into automated decision-making, carefully supervised learning is always necessary to protect from the possible harm

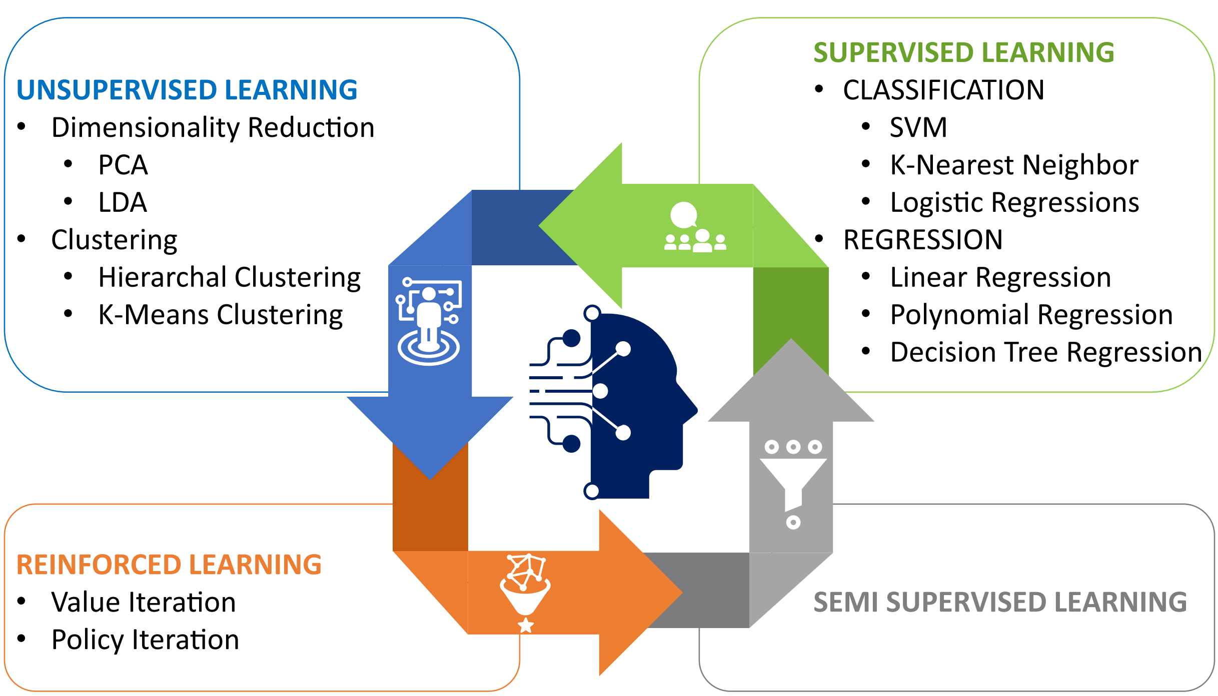

Fig. 15. Machine learning techniques.

due to the machine itself being factual decision-making. Defining a boundary to limit the machine's autonomous decision is a key challenge. The balance between automation and human control is the next big thing for future smart cities' technological advancements.

4.4.2. Deep learning

Deep learning is the advanced branch of AI that consists of neural networks (Imtiaz et al., 2020). These neural networks are composed of multiple hidden layers, making them superior classifiers and predictors (Wani et al., 2020). There are tremendous applications of DL algorithms in modern smart cities as these algorithms can solve the task with more capabilities and proficiency. The authors in (Bhattacharya, Somayaji, Gadekallu, Alazab, Maddikunta, 2020a; Muhammad et al., 2020) reviewed the DL application in future smart cities in depth. The authors surveyed topics that include urban modeling for smart cities, smart cities' intelligent infrastructure, smart mobility, transportation, smart urban governance, resilience and sustainability smart cities, smart education, and smart health solutions. With the development of smart devices and IoT interconnectivity, Many concerns relevant to cyber attacks and privacy issues have been raised. The DL algorithms, being considered for their supreme capability of anomaly detection and classification, encounter cyber threats with high proficiency. The researchers in (Afzal et al., 2021; Chen et al., 2020a; Elsaeidy et al., 2020; Ferrag et al., 2020a; Javed et al., 2020d; Magaia et al., 2020; Singh et al., 2020b; Vinayakumar et al., 2020) proposed several DL algorithm-based methods to detect and encounter the cyber-attack over the smart cities IoT based infrastructure. These studies also highlight future research directions by presenting the comparative analysis between DL algorithms regarding their accuracy.

The authors in (Aqib et al., 2020) proposed a DL algorithm for energy demand forecasting. The system's primary function is to analyze energy demands and consumption and optimize energy usage to optimize energy consumption in terms of cost and efficiency. The authors in (Ghose & Rehena, 2021) highlighted a drawback of air pollution due to cities' modernization. The industrial wastage and production of non-eco-friendly materials are causing the air to be polluted on a dangerous scale. The proposed system is based on a DL algorithm that analyzes the sensor's data to predict whether the air pollution at a certain place is increasing or not. Thus it indicates at earliest to control the pollution. This methodology is considered beneficial for smart city residents since it makes the environment safer and healthier for the occupants. DL applications are widely observed in modern smart cities in which disaster management is the primary one. The authors in (Aqib et al., 2020) proposed a DL-based system for smart cities to manage the disaster by predicting the optimal evacuation plans and traffic management strategies. Moreover, DL algorithms have proficient capabilities in manipulating tasks relevant to image processing. The authors in (Belhadi et al., 2021; Chen et al., 2021b; Khan et al., 2021; Tekouabou et al., 2020) devised state-of-the-art researches related to image processing task by using DL. The researchers in (Alghamdi et al., 2020) highlighted the usage of DL in smart cities' healthcare sector.

Due to the steep increase in usage and deployment of IoT devices in every industry, the security challenges related to IoT have become an integral part of these systems. Ensuring the security with many active IoT devices with veracity and variability in architecture, methodologies, interoperability, supported methods, and update cycles, it is almost impossible to identify security issues using traditional/manual methods. This concept was taken up in (Al-Garadi et al., 2020) to use power analytical methods provided by ML and DL to enhance IoT security at a large scale. The smart city has many components based on standard services like power, network, log correlation, access control, etc. Among them, the vital part played is power and then communication infrastructure. The heavy reliance on smart city infrastructure for intelligent data-based decisions makes communication essential for the whole operation. Use of reinforcement learning w.r.t communication within large-scale deployment like smart cities are discussed in (Luong et al., 2019) where authors present the application of deep reinforcement learning in applied scenarios of network and communication. Merging DL in an IoT environment can give better results-oriented benefits; however, challenges like low computational and power resources are yet to solve in this regard (Zikria et al., 2020).

4.4.2.1. Critical analysis. The reviewed studies conclude that DL robustness in revolutionizing conventional tasks is a great fortune for humankind. However, several other factors also revolutionize smart cities, and these algorithms automate tasks and solve daily life problems with more proficient accuracy than a human. Nevertheless, DL applications have shown great interoperability with other technologies, making DL a significant component for future smart cities.

4.4.3. Computer vision

Computer vision is a multidisciplinary approach towards acquiring, processing, analyzing, and understanding the images as per the defined contexts and requirements (Javed et al., 2021a). The process involves the usage of optics to acquire the image using digital/smart cameras using the biological vision patterns used by the human eye. Afterward, apply mathematics, statistics, and geometry for non-linear, multivariable signal processing to optimize and analyze the acquired image. Then applying ML techniques to understand the image cognitively using advanced AI and then utilizing the resulting knowledge to take actions in the real world or for automatic robot control. Fig. 16 presents the computer vision characteristics.

Computer vision has a very critical role in smart cities' various functions. The most robust computer vision implementation is in the monitoring domain, which intelligently manages the various issues and abnormalities in smart cities' functions. Example usage of computer vision in the smart city scenario was discussed in (Gupta & Sundar, 2020) regarding traffic and lane monitoring using smart traffic infrastructure. In (Chang et al., 2020), the authors discussed various practical aspects concerning computer vision usage in multi-camera vehicle re-identification and tracking, vehicle counting, and traffic anomalies detection. A DL approach was presented to detect an object in real-time in 2D and 3D in (Shanahan & Dai, 2020). Another very summarized discussion was presented in (Bhattacharya, Somayaji, Gadekallu, Alazab, Maddikunta, 2020b) regarding the usage of DL techniques on the data gathered by IoT based sensors deployed at a city scale for the modeling/analysis of various aspects of smart cities like traffic, healthcare, urban governance, education drainage of waste, movement of the citizen. Advanced computer vision can be used for medical imaging, bringing paperless transaction management in government offices, commercial organizations and financial institutions, medical imaging, urban planning, crowd control, human and assets tracking, and other allied areas. Another practical monitoring framework was proposed in (Shorfuzzaman et al., 2021) to utilize computer vision techniques to assess distance monitoring, crowd monitoring, physical contact monitoring, and symptoms highlighting as per SOPs Covid-19 in the smart city. The multilevel information fusion edge architecture (MELINDA) was proposed and discussed in (Neto et al., 2020; Rocha Neto et al., 2021). They further shed light on bringing the video frame processing to edge computing, keeping in view the increased load on server processing in a well-monitored smart city environment. An advanced DL-based office equipment occupancy analysis techniques are discussed in (Tien et al., 2021) to make intelligent HVAC requirement analysis and control as per the anticipated cooling requirement.

4.4.3.1. Critical analysis. Computer vision will have a crucial role in future smart cities. It will eventually become the backbone for intelligent monitoring, control, and decision-making in many aspects of a smart city. The application of computer vision in smart manufacturing, smart crime monitoring, safe city management, automated vehicle monitoring, smart road infrastructure, law enforcement activities,

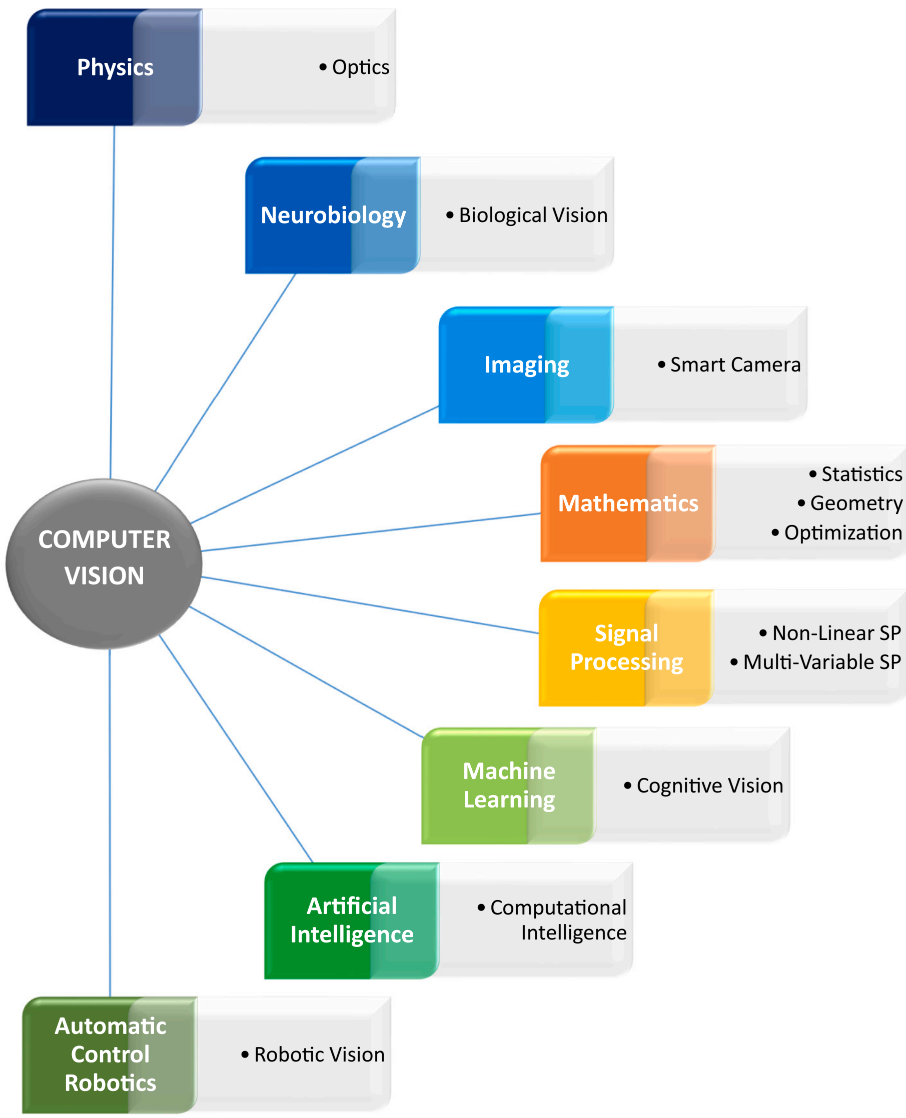

Fig. 16. Computer vision characteristics.

business and offices management, smart home, urban planning, smart transportation using smart cars, disaster management, robotics, and healthcare will eventually result in bringing intelligence and automation to the allied tasks. Table 6 presents the AI Literature section in tabular form.

4.5. *Future transportation*

Cloud-based technologies are in use to make the road infrastructure safe and secure for commuters. The roadside infrastructure uses sensors, including pressure detectors, inductive loop detectors, microwave detectors, image detectors, and ultrasonic and infrared detectors to detect objects. Their position and speed to perform complex calculations and then communicate the results to other components of the infrastructure as well as to smart vehicles traveling on the infrastructure (Hassan et al., 2022; Laudante et al., 2020).

The overall smart road infrastructure usually provides real-time monitoring, real-time information, journey planning, and guidance, intelligent road lighting system, smart road signaling system, road traffic load management, and road lane management based on the load. It also helps with smart ticketing and violation identification and ticketing, an electronic payment system for toll charges and fine payments, speed and environment management and an alert system, parking management and guidance, incidents and accidents response, control, and emergency system management (Finogeev, 2019). In the future, smart unmanned vehicle management, smart fleet monitoring, identification, and cross-border traffic management are the key systems to join the list. Fig. 17 presents the smart transport infrastructure.

Situational awareness is the main point on which smart road infrastructure works. The system's components make a model at the current point of time for the current point of a place containing the real-time data and then transfer it to other components/subscribers before calculating the updated model at the next point of time. Other stackholders of the system then receive the model using high-speed communication channels like 5G and others and utilize this information to further utilized in calculate the point of time model w.r.t their position within the infrastructure (Javed et al., 2021b). After calculation, the model was used to decide and give necessary information back to other components to calculate their point of time models.

The key components of smart next-generation transportation for future smart cities rely heavily on power usage, which is also researched for shifting its generation to clean and green energy sources. The researcher in (Chen et al., 2020b) divides the outcome of their papers into the following four classifications based on their usage and impact. They are power, communication, computer, and security. These classes of future smart transportation are discussed briefly, focusing on

Table 6
Summary of artificial intelligence literature.

Ref.	Paper aim	Proposed scheme/ method/mechanism	Key features
(Liu et al., 2019)	IoT based energy management systems	Designed an energy management system (EMS) for IoT-based infrastructure for edge computing.	• Overview of the IoT infrastructure based on the EMS. • Proposed IoT-based framework and software system with edge computing. • Scheduling scheme based on efficient energy using the deep reinforcement learning method. • Described the effectiveness of the presented framework.
(Ullah et al., 2020)	Role of AI in smart cities development	The author's primary purpose is to explore the role of ML, AI, and DL in developing smart cities.	• Details of different applications prior techniques in smart cities. • Discussed research challenges and future directions for smart cities.
(Zekić-Sušac et al., 2020)	Automatic energy requirement predictions using ML	The authors proposed how tree partitioning and deep neural network methods helped predict and identify energy consumption.	• Framework of IS for the public sector for efficient energy management. • Big data, IoT, and different ML methods are used in the proposed framework for data collection.
(Shafiq et al., 2020)	Traffic classification using machine learning	For sustainable smart cities, the authors present ML and Data Mining methods for traffic classification.	• Presented ML and data mining methods for traffic classification for sustainable smart cities.
(Imtiaz et al., 2020)	Classification of malware using ML techniques	The authors presented the deep ANN method for defending against Android malware.	• Assessed the efficiency of the Deep ANN method and traditional classifiers.
(Aqib et al., 2020)	Efficient computational infrastructure for disaster management	The authors proposed a framework for GPU-based DL and big data management and computations.	• Traffic behavior prediction in disaster and evacuation situations. • Combined different technologies like in-memory and data-driven computations, DL, and GPU.
(Javed & Jalil, 2020)	Real-time digital forensics and analysis	The authors provide a new method for real-time problem solving for digital forensics investigators to investigate the suspect machine.	• Collected byte-level data from the acquired computers. • Performed accurate and fast image detection using a DL algorithm. • Identification of suspicious images and their flagging.
(Gupta & Sundar, 2020)	Data-driven smart road development	The proposed study aims to give an essential solution for continuous land acquisition to overcome increasing traffic using the encouraging application of flexible lane dividers in the smart cities environment.	• Provided a lane span that handles the width of the road, evading the necessity of road development. • Collected video-based data from cameras alongside the single stretch and examined in real-time for decision.

interdisciplinary management of energy and information related to infrastructure.

4.5.1. *Autonomous vehicles*

The smart transportation aspect in the smart city has a unique feature of inter/intra vehicle communication consisting of the vehicle to infrastructure (V2I), vehicle to pedestrian (V2P), vehicle to vehicle (V2V), vehicle to sensors (V2S), vehicle to cloud (V2C) and vehicle to home (V2H) (Rehman Javed et al., 2020). If done in an organized way, this communication can help solve the city's transportation infrastructure problems. Fig. 20 presents vehicle to everything (V2X) characteristics. Authors in (Gyawali et al., 2021) performed an in-depth review of communication technologies challenges and solutions concerning the physical layer of communication, security, synchronization issues, MBMS, and management of resources in a V2X network backed by LTE infrastructure. The solutions were analyzed for the scenarios like availability of multiple communication service providers, availability of single communication service providers, or the case when the vehicles are out of the coverage area of communication providers.

The coordinated communication for transportation infrastructure can play a vital role in smart cities' traffic problems, tested by partial deployments in the world's megacities (Belhadi et al., 2021). Fig. 18 presents the overview of the communication structure of a smart vehicle. Around 1000 cities worldwide are trying to implement smart city structures within them, and more than half of these cities are in China (Yan et al., 2020). This rapid engagement of smart initiatives also forces allied industries like vehicle manufacturers to provide intelligence and support for smart city infrastructures in their vehicles. Initially limited to the drive support systems, this support now enhances their scope for a driver-less experience. Future smart cities will see self-driving vehicles very soon. Smart autonomous vehicles will make it possible to commute more safely and effortlessly while enjoying a driver-less experience (Bakioglu & Atahan, 2021). The adoption of self-driving cars by the general public will increase with the advancement and incorporation of such technologies in the infrastructure of smart cities. Situational awareness, route planning, drive control, and actuator management are the topics on which currently published literature is reviewed in (Hussain & Zeadally, 2019). The paper covers state-of-the-art technologies, design and implementation issues, and future challenges w.r.t autonomous vehicles.

4.5.1.1. Critical analysis. A driverless, self-running, and autonomous transport system is needed for future smart cities. Researches on the multiple aspects of autonomous vehicles are in full swing: complexity calculation, risk identification, scenario analysis, and accurate and real-time decision making. While propagating the decision to the other vehicular nodes around to help them make an informed decision and doing all this under the strict control of transport infrastructure rules and control applied on the location of presence are the emerging challenges to tackle appropriately. Table 7 presents the future Transportation Literature section in tabular form.

4.5.2. *Hydrogen fuel cars*

Alternate energy consideration for transportation has been an area of research for decades. Currently, forms of fuels are limited, and many alternatives were considered for the same performance with a lesser change in engine technology and cost-effectiveness. In power automobiles, hydrogen cells with hydrogen (h2) can be utilized as fuel, which proves effective and economical along with lesser greenhouse impact than traditional gasoline-based fuels (Liu et al., 2020). The demand for hydrogen is increasing globally year by year, showing the increase in hydrogen usage as a fuel for automotive and other industries (I. E. A. (IEA), n.d.). As per (Sorlei et al., 2021), the global fuel cell market, whose site was USD 342 million in 2019, will be anticipated to reach USD 1059 million by 2024 positively. Fig. 19 presents the year-wise

Fig. 17. Overview of Smart Transport Infrastructure showing the smart transport infrastructure communication theme. The purple communication lines are between communication providers within STI. Yellow colour lines represent the communication between the infrastructure participants, i.e., smart vehicles. An increase in traffic density requires increased bandwidth, and at the larger scale of city-level STI, satellite and high-speed communication can result in optimized operations of overall infrastructure. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

global hydrogen demand.

However, there are barriers like high initial costs, relatively lesser lifetime, and lack of hydrogen fuel refueling infrastructure, which are preventing the broader adoption of this energy-efficient and climate-friendly alternate fueling system by the masses (Ferrara et al., 2021). The user acceptance for such conversion of fuel source mainly depends on the cost and performance optimization of hydrogen fuel cells, which still have enough room for research (Olabi et al., 2021).

4.5.2.1. Critical analysis. Alternate fueling for transportation infrastructure is a hot research topic. The gradually depleting fossil fuel reservoirs and their negative impacts on the environment force the authors to look for alternate sources to fulfill the fuel requirements of transport infrastructure.

4.5.3. Flying cars

Traffic congestion issue is a significant concern for the big cities' management. The more populated the city becomes, the more commuters come on the road and load the transportation infrastructure. Careful planning is a crucial factor used to distribute the traffic load by placing commercial hubs and areas in intelligently selected points for smooth traffic flow. A new paradigm of the solution in this regard is the use of flying cars. The use of flying cars (obviously under meticulous planning and control) can provide an efficient and faster solution to this issue (Mofolasayo, 2020). A recent study in this regard (Postorino & Sarné, 2020) which was focused on an agent-based approach, finds out that trip origin/destination points, average distances traveled in the urban contexts, and the transition location nodes are the main factors that impact travel cost. Making such travel cost-effective and bearable is a critical challenge in further progress. Each aspect of flying cars' infrastructure development and implementation requires deep and intensive research to produce a well-designed, cyber-safe, cost-effective, and easily adaptable system for real success. The significant challenges in this domain include safety of the overall transport infrastructure, training certification, and worldwide standardization in the domain of pilot, as well as cars manufacturing, flying traffic rules and regulations, environmental impacts, logistics and sustainability, human adoption, and cybersecurity (Ahmed et al., 2020). Some online store giants are already integrating drones to deliver goods to customers. Amazon's Prime Delivery is an example where amazon will deliver the parcel up to 5 kg within 15 miles radius in 30 min after order (Wilke, n.d.). It is not very far in the future; if the technology adoption trends go at the same pace that we will see the flying cars available as ride-sharing services for

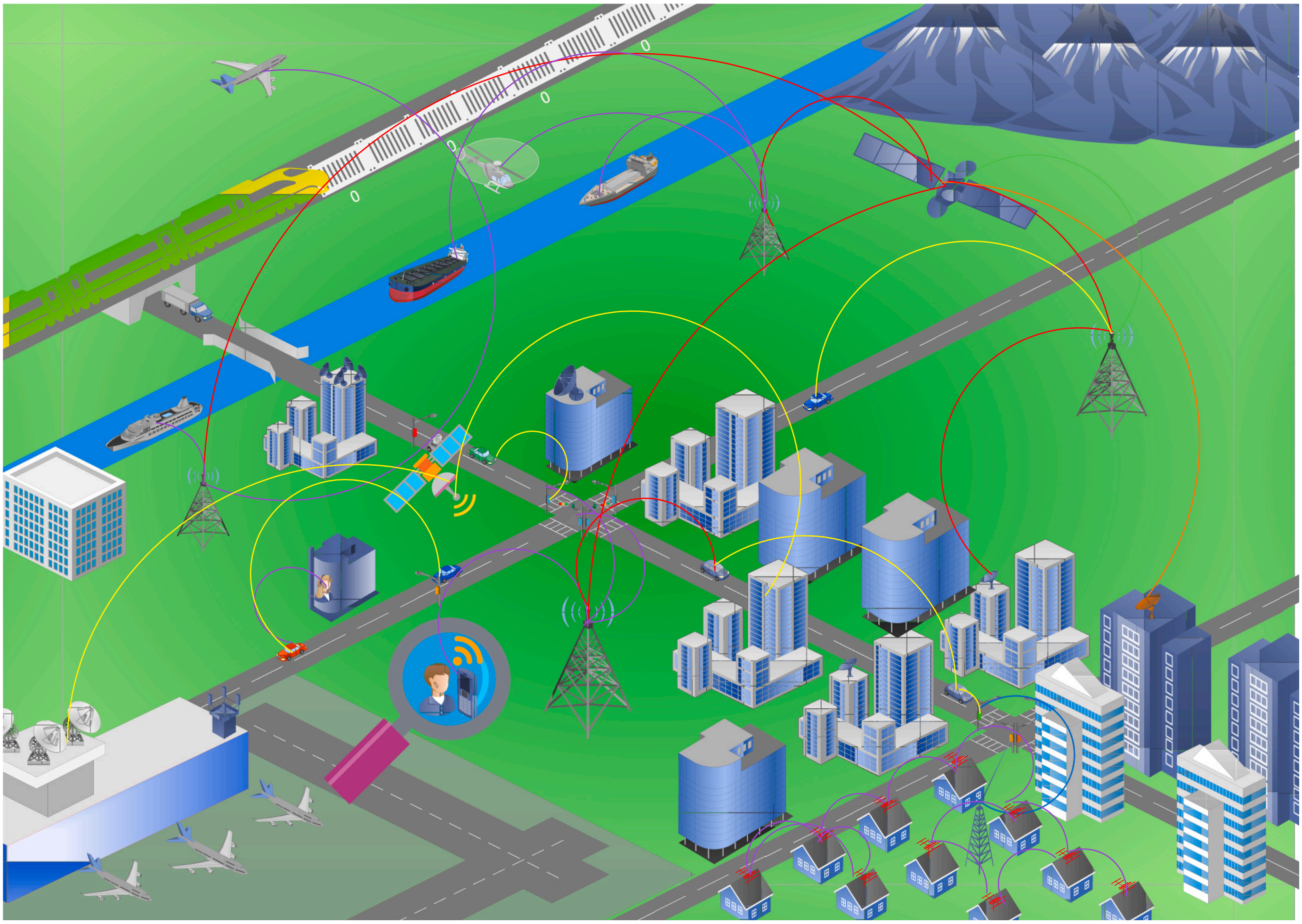

Fig. 18. An overview of the communication structure of a smart vehicle. The communication medium represented in this figure is composed of edge communication (represented in yellow), backbone communication (represented in purple), and high-speed satellite communication (represented in red). In a smart city, smart traffic infrastructure, the transportation network (sea /land /air) and interconnected with smart buildings and smart vehicles (including road/rail/air vehicles). Backbone satellite links can provide large geographic coverage and bandwidth requirement fulfillment. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

a common commuter (Ahmed et al., 2021a).

The challenges mentioned in (Wang et al., 2020) though being targeted on UAVs, are pretty aligned with the challenges and issues in the scenario of the flying car with little or no modification like heterogeneous network convergence, computation management and offloading, resource scheduling, energy conservation, security, and performance. To secure autonomous flying vehicles like drones, a certificate-based access control framework is proposed in (Chaudhry et al., 2021b) which is designed to provide security while keeping the efficiencies in computing and power consumption.

4.5.3.1. Critical analysis. Flying cars is a dream which is near to come true. Recent experiments in the UAE for flying support by law enforcement personnel and flying delivery services by amazon are examples of practical experiments. However, the area has much room for improvements in the definition of laws and protocols of traveling, air traffic infrastructure, control mechanisms, and flying vehicle secure design and operation. Flying transportation will be a premium addition to the advanced level technology-based facilitation provided in future smart cities. The purely technical infrastructure already available for future smart cities resolves hurdles in flying cars and transportation infrastructure with relative ease.

4.6. Eco-friendly systems

In this subsection, the environmental-friendly systems are reviewed based on smart cities. Renewable energy sources play a vital role in maintaining a healthier environment. Not only this, but these resources provide effectively efficient methods to obtain energy resources. The authors in (Sanjeevikumar, 2021) reviewed research focusing on a solar photovoltaic hybrid system for eco-friendly electric vehicle charging and house based on an ML system. The authors also proposed a comparative analysis between different methods based on logical advancements and optimization. Treatment of wastewater is one of the necessities of smart cities because it can cause diseases in nearby areas if not treated. If it is flushed into the seawater, it can affect aquatic life. The authors in (Park et al., 2018) proposed treating wastewater effluent with an enhanced pond and wetland (EPW) system. The system is claimed to be ECO and cost-friendly since it contains two high rate algal ponds (HRAPs), two surface flow constructed wetlands (SFCWs), and a woodchip denitrification filter (WDF). Manufacturing products are processes in which several parameters are involved with a significant loss of power and material. The authors in (Iqbal & Al-Ghamdi, 2018) proposed an approach to optimize the product manufacturing procedure to conserve manufacturing energy. The researchers claim to save up to 26 % of energy consumption in the manufacturing process. The authors in (Banjo et al., 2019) examined HC600a refrigerant to verify its eco-

Table 7
Summary of future transportation literature.

Ref.	Paper aim	Proposed scheme/ method/mechanism	Key features
(Finogeev, 2019)	Smart transportation system	The study is the outcome of research on developing and implementing various aspects of a system to monitor the traffic and incidents intelligent enough to operate independently.	• Focused on the smart road monitoring system using photo radar. • Collected, processed, and analyzed big data related to incidents and emergencies on the road.
(Laudante et al., 2020)	Road safety for smart cities	This paper is about the cloud-based implementation of the model used to improve road safety. Distributed smart devices were used for the purpose by the authors.	• Proposed a system based on edge devices and their interaction with cloud-based servers. • Installed these devices in various countries and provided positive results while providing room for further improvements.
(Sorlei et al., 2021)	Energy efficient fuel cells for electrical vehicles	To minimize the greenhouse effect, car manufacturers worldwide consider shifting their vehicles to electric or hybrid fuel engines. Countries bring this change regularized in their governing law and regulations.	• Covered electric fuel cell technologies. • Presented a comparison, pros, and cons of the existing and proposed typologies of electric fuel cells.
(Olabi et al., 2021)	Alternate fuels for automobile for green cities	The automobile industry ranks in higher grades while counting for the global emission percentage. The root cause of this higher participation is fossil fuel as the primary fuel for vehicles.	• Presented a comprehensive review of currently used different kinds of fuels in the automobile industry. • Highlighted the advancements made in the current path in this area. • Covered fuel technologies from a future perspective.
(Ahmed et al., 2020)	Cost-effective air transportation	Extreme traffic, overuse, repair work, emergencies, and other allied issues made road transportation a full hassle mode. The research focuses on air transportation to study challenges in getting a consumer-level adoption of air-level transportation using flying cars.	• Presented a comprehensive study approach towards using flying cars. • Discussed the challenges of adopting standards and regulations to govern effective air vehicle transportation, safety, human factory, cybersecurity proofing, navigation, economies of scale, and infrastructure development.
(Ahmed et al., 2021a)	Adoption of air transportation	Flying car transportation is in the full-scale research and development phase, and it is anticipated that consumer interaction with such a mode of transportation will start by 2025. Urban shared transport services like Uber and Lyft are expected to adopt it mainly due to economies of operations.	• Discussed customer point of view if they are willing to accept the new mode of transportation, i.e., flying cars, and the questions in their mind. • The outcomes show that various socio-demographic characteristics can affect customers' willingness to adopt the flying mode of shared transportation.
(Yan et al., 2020)	Automated smart transportation system	Smart cities' development and growth worldwide bring needs for improvement and advancement in multiple aspects of the city, and transportation is one of them. Automation of transport infrastructure is one key area that is the main focus of this paper.	• Focused on the important components of smartness in the smart city. • Divided them into three dimensions: smart cells, communication infrastructure, and development mechanism to combine two for the smartness. • Reviewed the Chinese smart cities' smart transportation infrastructure as a case study.
(Bakioglu & Atahan, 2021)	Risk analysis of autonomous vehicles	The autonomous self-driving car is the new future of transportation currently in the final stages of research. The key challenges in this regard are risk identification and treatment while self/ autonomous driving.	• Analyzed self-driving risks using a risk prioritizing approach. • Proposed a hybrid multi-criteria decision-making (MCDM) approach for risk prioritizing. • Revealed that the model produces reliable results presenting the impreciseness and deficiencies in the decision-making approaches.

friendly characteristics, which include electric power consumption, coefficient of performance (COP), cooling load, and pull-down time (PDT). The authors in (Topaloglu et al., 2018) proposed an approach to type-2 fuzzy several parameter methodologies to evaluate the smart city environment's waste collection systems. The researchers in (Issac et al., 2020) proposed a system to conserve the energy consumed by the street light for the smart cities.

4.6.1. *Critical analysis*

The future of this planet is considered brighter if and only if we modernize ourselves in a way that could be earth-friendly. The reviewed studies highlight the importance of earth-friendly technologies and propose a healthier solution to conventional non-environmental friendly technologies. The studies also perform a comparative analysis to verify the impact of green technologies and methodologies on the environment.

4.6.2. *Electric vehicles*

In this subsection, electric vehicles have been reviewed in the context of smart cities. It is one of the significant components of making the environment healthier. These eco-friendly vehicles also have some parameters to be considered before being deployed in smart cities since they must be an efficient solution to the conventional ones. The authors in (Urooj et al., 2021) proposed an efficient algorithm to monitor IoT-

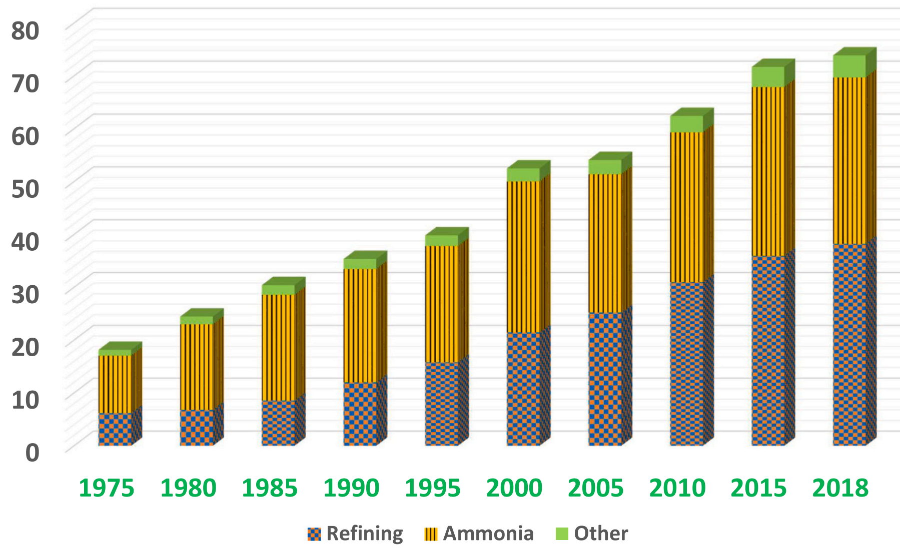

Fig. 19. Global hydrogen demand.

Fig. 20. Vehicle to everything (V2X).

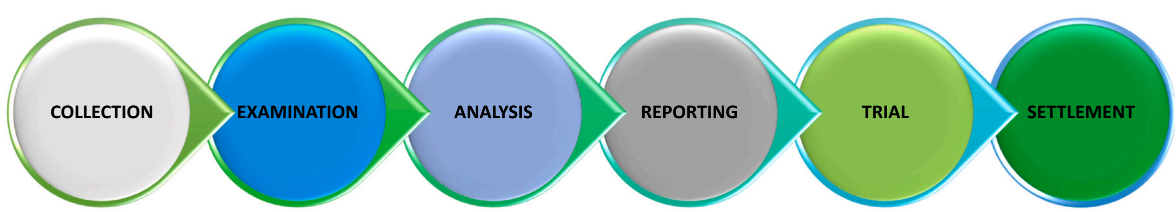

Fig. 21. Digital forensics lifecycle.

enabled electric vehicles' power consumption and make their efficiency better. The researchers in (Aloqaily et al., 2019) proposed cybersecurity systems to make autonomous electric vehicles safer from cyber-attacks. The authors in (Palanca et al., 2020) improvised an approach to help the electric vehicles locate the charging stations in smart cities. The authors in (Ejaz & Anpalagan, 2019) proposed a thorough study of the effects of electric vehicles on smart cities. They highlighted the overall power consumption of cities and the availability of electric vehicles in multiple places. The authors in (Laroui et al., 2019) proposed a DL approach to monitor and optimize electric vehicles' power consumption in smart cities. The authors in (Hu et al., 2019) proposed a framework to monitor the electric-vehicles driver's preferred routes and the power consumption.

4.6.2.1. Critical analysis. The reviewed studies show that the prominent beneficial electric vehicles have some crucial parameters to be configured to be efficient in real meaning. The Internet-of-things and Edge of things enabled a new eco-friendly transport machinery era with better capabilities and efficiency, which revolutionized transport by adding an intelligent transportation system.

4.6.3. *Waste processing*

Waste recycling has always been one of the major problems of modernization. It requires a good dumping area and a proficient

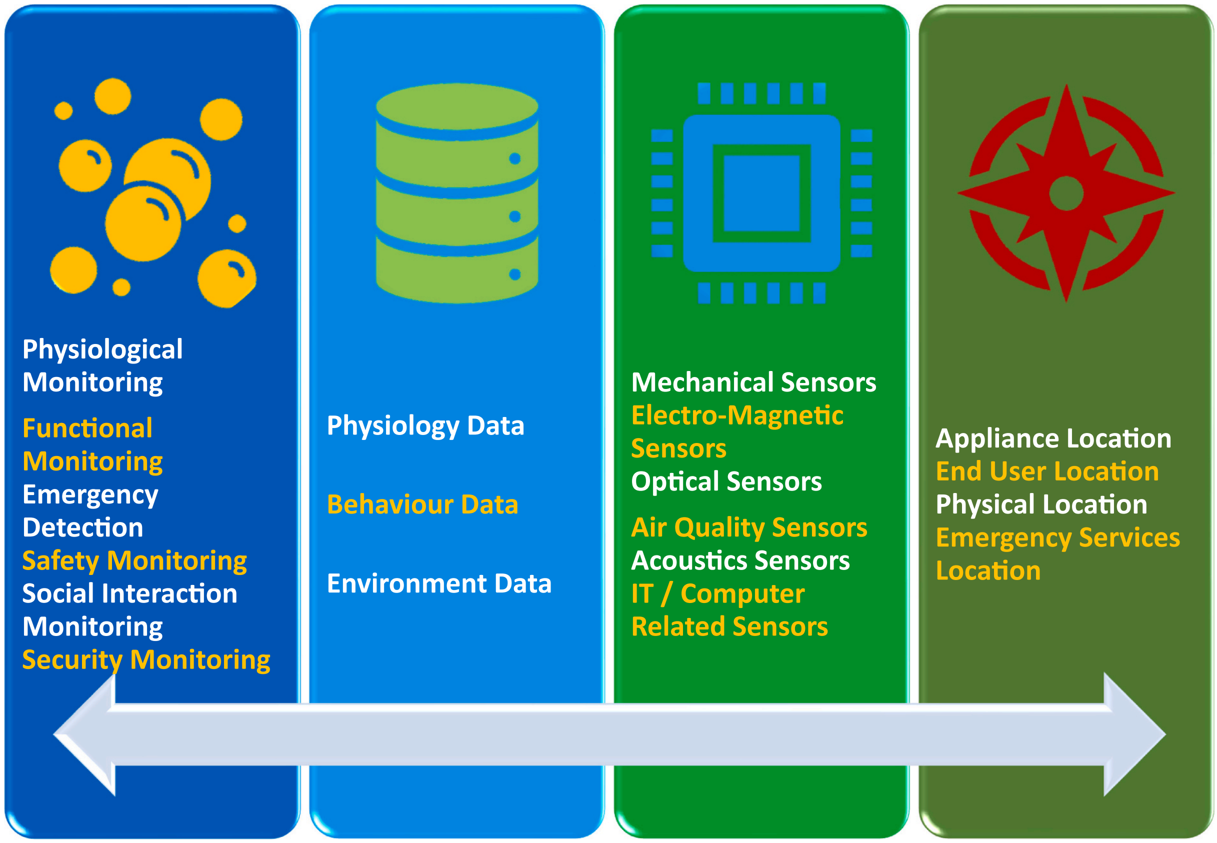

Fig. 22. Personal healthcare monitoring components.

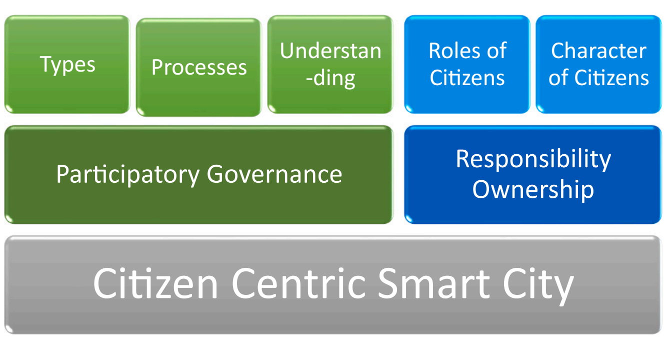

Fig. 23. Citizen centric smart governance [faisal].

methodology to convert the waste material into re-usable material. It also plays a major role in sustaining a healthier and good economy of a smart city. The authors in (Mahmood & Zubairi, 2019) surveyed the traditional methods of waste management systems and proposed multiple approaches to make the dumping and recycling procedures economical and efficient. The researcher in (Ali et al., 2020b; Chaudhari et al., 2019) proposed an IoT empowered waste collection system. This system monitors the waste bin through the sensors and indicates the management authority to empty it when needed. The authors in (Aceleanu et al., 2019) studied 3Rs (reuse, recirculation, recycling) and increased the products' life span. Their study promoted the efficient management of municipal waste in the circular economy vision. The authors in (Sharma et al., 2020) studied the barriers between the IoT-based smart waste management system and the local policies. However, they define the necessary changes needed to optimize the IoT-based waste management system. The researchers in (Alqahtani et al., 2020) proposed a waste management approach using Cuckoo Search Algorithm to monitor the smart waste bins. The researchers in (Idwan et al., 2020) proposed an algorithm named a two-step heuristic algorithm multiple trucks routing algorithm (MITRA) for identifying the optimal ways for the waste-collecting vehicles in the smart cities. Finally, the authors in (Mingaleva et al., 2020) highlighted the importance of waste management systems in the context of smart cities.

4.6.3.1. Critical analysis. Waste management is a crucial task for modern cities but doing it efficiently is the art that makes it suitable for smart cities. The reviewed studies highlight the importance of waste management regarding the city's health and overall cleanliness. The reviewed research emphasizes the more competent IoT-based method to do this task. Table 8 presents the Eco-Friendly Systems Literature section in tabular form.

4.7. Cyber security

The significant challenges to the security of future smart cities are identifying threats/malicious activity within the systems, malfunction detection, security of the system's data and access, and its availability to its consumers (either other systems or citizens) (Srinivasan et al., 2021). The whole system's security and components are critical to ensure the smooth operations of all smart cities' functions. The confidentiality, integrity, and availability of the functions are necessary to provide relevant services to other cities' integrated system components.

As the smart city is composed of different aspects of city life working in a coordinated way with a technical infrastructure to support management, governance, and control of the city affairs, working on one aspect may depend on the output of another aspect's functionality. Hence the unavailability of one aspect of the smart city may disrupt city life in other dependent aspects. The systems must be designed to have a backup plan to support the functionality (even in the reduced form to

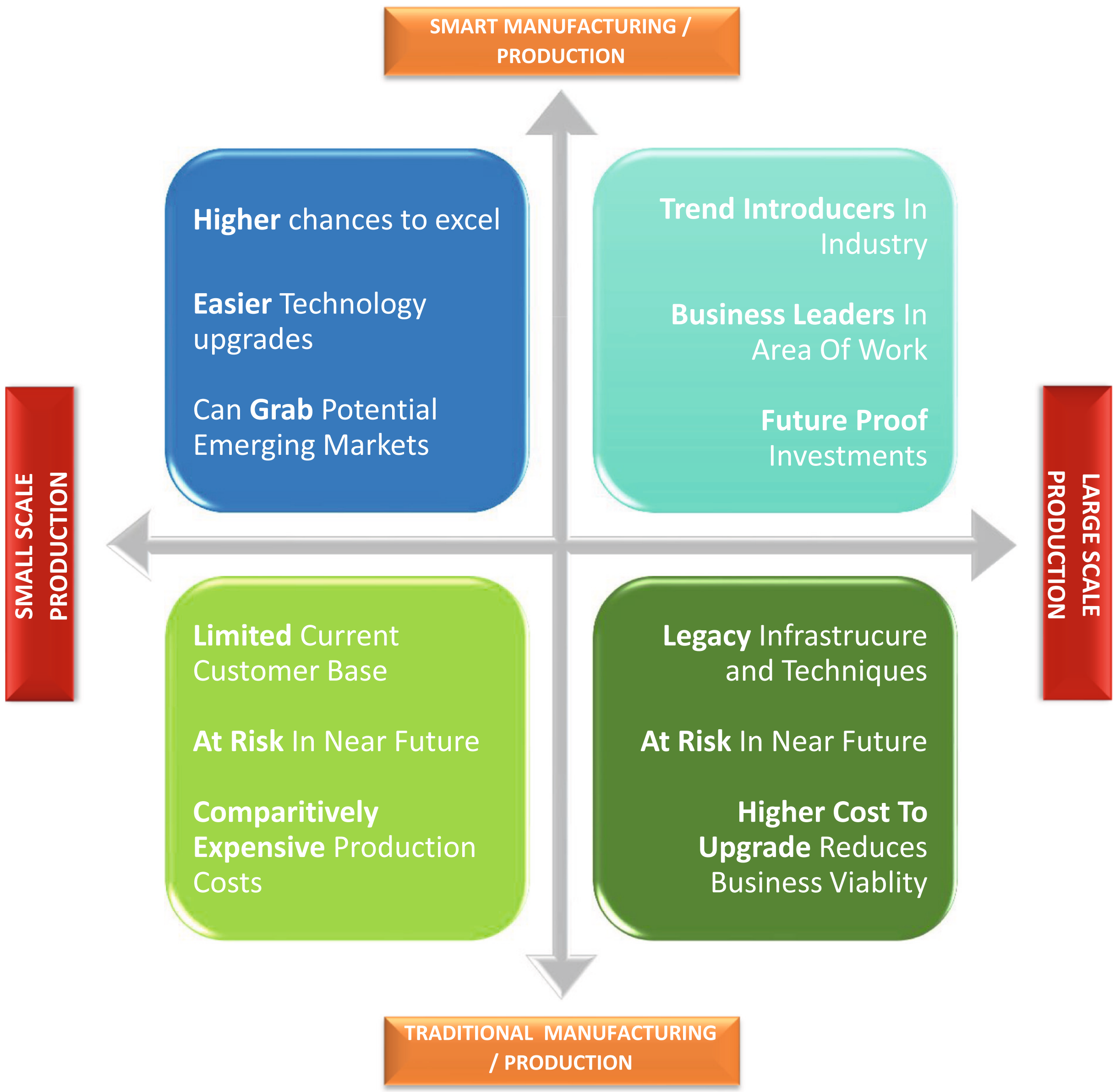

Fig. 24. Prospective benefits/threats to smart production.

keep on the only critical functions of that aspect) and maintain the business continuity.

Security is the prime part of healthcare data management and governs under strict rules like the health insurance portability and accountability act (HIPAA) in the United States. Many kinds of research were conducted to utilize blockchain in the healthcare industry for healthcare data management, data privacy, data protection, data handling, and efficiency in data processing (Song et al., 2022; Tandon et al., 2020). MIT's computer science and artificial intelligence lab (CSAIL) came out with an implementable solution with the name of CryptDB for managing query processing over encrypted data (Popa et al., 2011). The same was analyzed for its implementation in the healthcare industry with high throughput applications and was found practically implementable in data-protected scenarios of national-level healthcare systems (Shahzad et al., 2015). Ensuring privacy while sharing required data is another aspect that requires greater concern. Sharing of required information with authenticity while ensuring privacy protection is the theme discussed in the (Mishra et al., 2021) with the provision of a complete framework based on blockchain to share information of the individual with the government companies and other stakeholders with privacy preserved surety and complete authenticity.

As various aspects of smart cities have different financial attractions to the malicious actors, these actors try to find a loophole or vulnerability. It may gain success for the malicious actors, Due to the multitude of technologies used in developing different aspects and their possible incompatibilities or misconfiguration. On the other hand, cybersecurity defenders tried their best to patch all potential vulnerabilities and close all possible loopholes to stay ahead of the hackers (Kitchin & Dodge, 2019).

Ensuring confidentiality, integrity, and data availability is of utmost importance (Liu et al., 2021). Hack proofing of the system must be guaranteed that processes are self security-aware and must have an inbuilt resistance to any unauthorized and malicious attempt to interact with them or their data.

4.7.1. *Digital forensics*

Crime existence is expected to the same extent in smart cities as in traditional cities. To tackle the crime and catch the culprit, forensics can help the investigators reach a conclusion and get their hands on the facts and evidence that can be used to convict the criminals (Javed & Jalil,

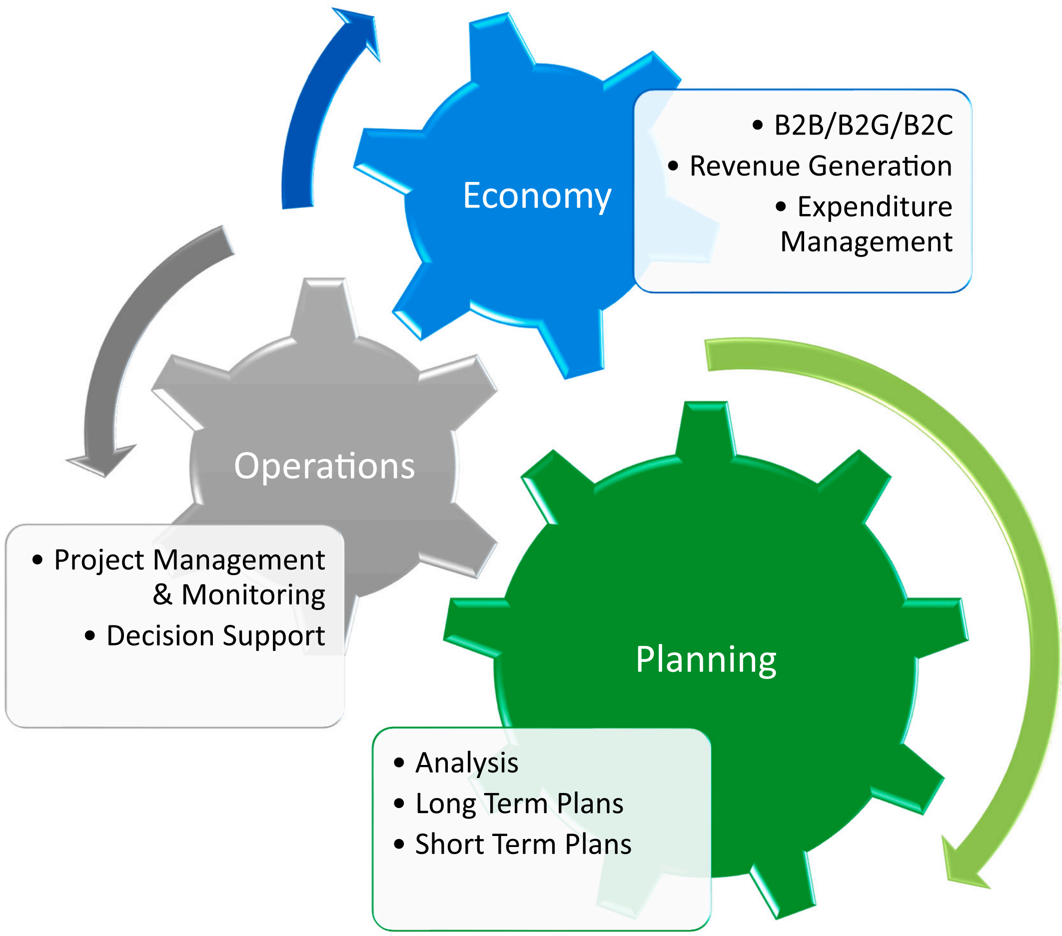

Fig. 25. Dimension of smart governance.

Fig. 26. Safe city process flow.

2020). Keeping in view the sizeable technological base in any smart city aspect, there is a significant chance that crime might involve digital aspects in their commitment (Baig et al., 2017; Javed et al., 2021a). A

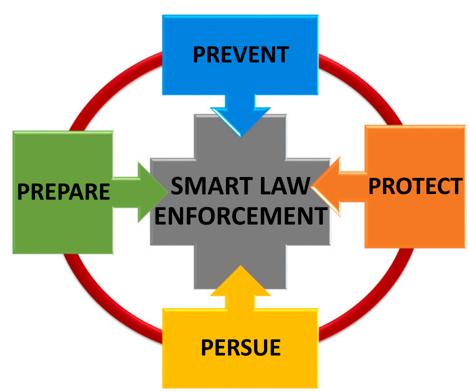

Fig. 27. Four pillars of smart law enforcement.

solid digital forensic base must be established to investigate the future crime committed. However, to do so, maintenance of balance carefully between data/log collection and breach of individual/organization's privacy is a challenge (Losavio et al., 2018). A study (Ahmed et al., 2021b) covers the forensics investigation aspects of increased usage of social media applications by criminals for communication purposes which are the usual trend nowadays, keeping in view the confidentiality and integrity provided through end-to-end encryption. The use of machine learning techniques for effective forensic analysis of the huge artifacts data is also rising, and the results are so promising that it is now covering almost every aspect of digital forensics (Shahzad et al., 2022).

Recently, smart cities have begun to provide a variety of services to

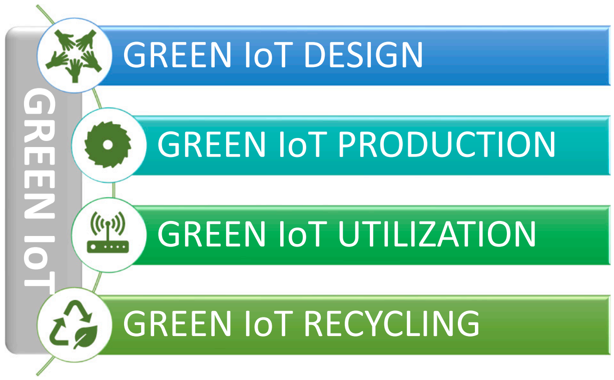

Fig. 28. Green IoT lifecycle.

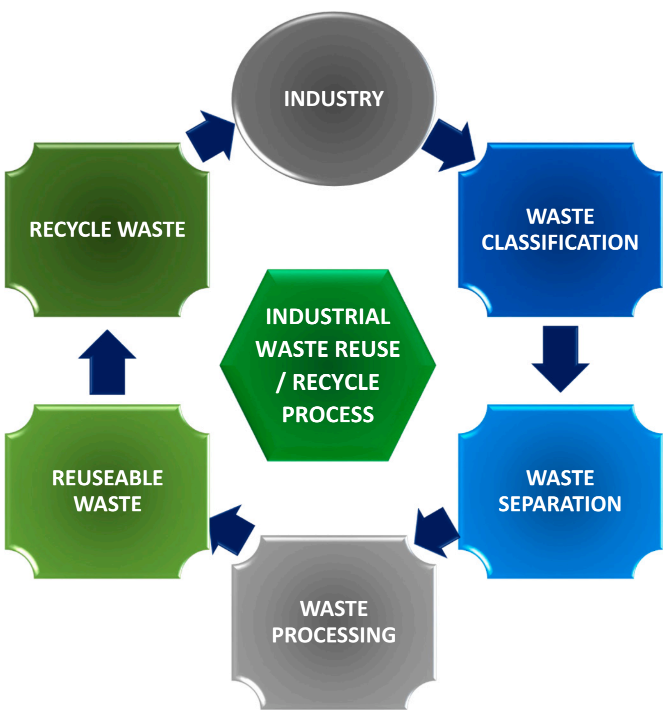

Fig. 29. Waste management in smart city.

inhabitants due to the confluence of information and communication technology with businesses such as transportation, health care, and vehicles. As a result, the number of smart gadgets that employ artificial intelligence technology to store user data to deliver services more effectively is expanding. Through digital forensics, smart devices may be utilized to capture critical evidence that can also be used as evidence in court. In (Kim et al., 2022), the authors obtain and evaluate user data stored on wearable devices using a framework for smart device data acquisition (Mughal et al., 2022). This study aids in the collection of critical evidence for future inquiries. The researchers in (Janarthanan et al., 2021) provide a concise introduction of the IoT forensics problems by examining a typical smart home investigation and comparing the various frameworks for conducting IoT forensics investigations. Several of these obstacles include the uncertainty of data location, collection, device variety, diverse data formats, data volatility, and a lack of sufficient forensics tools. Additionally, while there are numerous technical challenges in IoT forensics, there are also non-technical ones. Such as defining what constitutes an IoT device, forensically acquiring data, and securing the chain of custody, among other branching paths, such as training resources or the type of applied analysis tools (Buquerin et al.,

Table 8
Summary of eco-friendly systems literature.

Ref.	Paper aim	Proposed scheme/ method/mechanism	Key features
(Iqbal & Al-Ghamdi, 2018)	Energy-efficient production	The authors proposed a solution for saving production and transportation energy.	• Saved production and transportation energy by optimizing the distribution of processes into machines and categorizing machines in manufacturing cells. • A job shop is an energy-efficient replacement for an optimally-forming cellular manufacturing system.
(Banjo et al., 2019)	Enhanced / Smart HVAC system	The authors proposed a novel technique for enhancing and improving refrigeration system performance.	• Investigated performance characteristics to enhance and improve the performance of refrigeration systems. • Experimented and replaced HC600a with HFC134a in eco-friendly refrigerants. • Proved that when using 46 g of hydrocarbon, COP increased by 32.2 % with an energy reduction of 4.5 % in the refrigerant.
(Urooj et al., 2021)	Cost-effective electric vehicle operations	The authors confer the importance and need for electric vehicles using IoT technology, which helped monitor the electric vehicles' battery life.	• Improved visual analysis method on the vehicle. • Lesser cost where 74.3 % almost increases the vehicle's capacity after monitoring through sensors.
(Aloqaily et al., 2019)	Communication security for smart vehicles	Proposed how to achieve high-performance cloud services, assorted, and solve security problems regarding communication during deployment of advanced technologies in smart cities.	• An automated secure cloud service availability method for the smart vehicles included an intrusion detection system (IDS). • Security attack detection • Different services for users' requirements, quality of experience, and quality of service.
(Mahmood & Zubairi, 2019)	Waste management in smart cities	The authors presented a novel IoT application for waste transportation and illustrated a case study design for smart waste management transportation processes for Islamabad.	• An IoT-based smart waste transportation solution. • The system was simulated and modeled at the city level to prove the proposed solution's effectiveness (performance gain and resource-saving).

(*continued on next page*)

Table 8 (*continued*)

Ref.	Paper aim	Proposed scheme/ method/mechanism	Key features
(Ali et al., 2020b)	Waste management and monitoring system	The authors reviewed and investigated many smart city issues directly connected with increased waste material and difficulty to handle.	• Municipal solid waste management system (MSWM) and smart waste bin monitoring (SWBM) for smart waste management based on IoT technology. • Solved waste material problems and provided IoT-based automatic waste collection in smart cities.

2021; Fagbola & Venter, 2022; Kebande et al., 2021).

Secure management of evidence throughout its life cycle is also critical. After becoming the prospective evidence, secure handling, processing, and digital evidence storage are crucial to ensuring integrity. A blockchain-based solution, "LEChain" (Li et al., 2021) is one of the current developments in this regard. Further researches are underway to target various aspects of digital forensics.Fig. 21 presents the life cycle of digital forensics.

The process of digital forensics starts with crime reporting. It ends after the completion of the case passing through the phases of collection of artifacts, their examination for possible linkages with the crime, analysis of suspected artifacts for data collection, reporting of findings in a presentable court way, testimony, and presentation of evidence during the trial and completion and storage of the evidence after the conclusion of the case. Keeping the evidence's integrity and keeping the chain of custody document against each artifact is of the utmost importance during the whole process. Different kinds of systems, sources, and devices used in different scenarios and processes to fulfill tasks in different smart cities' systems make this harder to have standardized data collection procedures (Mrdovic, 2021).

Another challenge in digital forensics is the availability of expert digital forensics practitioners in sufficient numbers. Further, due to continuous advancements in the technology arena, the experts must update themselves about the recent advancements to remain familiar with the current state of technology to analyze it as and when required (Arumugam & Shunmuganathan, 2021).

A coordinated approach is always a better approach. A centralized pool of experts may be managed where the expertise is shared to make them aware of the latest trends in technologies. Later, a central platform was transformed to provide digital forensics (DaaS) to other organizations like law enforcement agencies. It provides expert-level forensics to digital crimes and has a platform for experienced value addition and knowledge addition and development. Such DFaaS offerings are beneficial in cost-effectiveness, knowledge base development, expert operations, skills pooling, enhancement, and legal acceptability (van Beek et al., 2020).

Extensive usage of IoT devices and their intentional or unintentional involvement in cyber crimes shifts the focus of researchers in the forensic field to the forensics of IoT devices to investigate ever-increasing cybercrimes (Ahmad et al., 2021a). The forensics of IoT has further encompassed forensics of cloud, network, and IoT devices themselves. The mind map presented in Fig. 6 of the study (Stoyanova et al., 2020) is the best graphical representation of the challenges faced in IoT forensics by current researchers and practitioners.

4.7.1.1. Critical analysis. The use of state-of-the-art technologies, automation, and digitization in future smart cities with big data management and analysis and informed decision-making will eventually result in crime investigation too shifted from traditional domains to the digital domain. Effective investigations in criminal cases will eventually require enhanced logging and monitoring to safeguard the future smart city's processes, people, and technology infrastructure. The same data will then be used for digital forensics investigations. Having the required number of experts, having expertise in various technical domains of smart cities, and in-depth analysis capability development depends on human resource development in cybersecurity and digital forensics. Therefore, it is anticipated that workforce development and technical research center establishment must be planned for current and future smart cities to fulfilling the everyday need of cyber savers, preventing and investigating digital crimes in future smart cities.

4.7.2. Intrusion detection systems

The increasing connectivity in smart cities also poses a growing threat to every connected node. The enhancement of the cybersecurity side is a crucial challenge in the smart cities' future. Various security threat detection techniques are evolved to counter the threats in smart cities' connected world, including analysis of protocol, analysis of traffic, analysis of behavior, analysis of control process, and mining of data (Hu et al., 2018). In this regard, intrusion detection systems remedy ongoing events by looking for abnormal behavior of already known malicious activity patterns. In case of detection, the same will be intimated to the configured recipients through alerts and other communication measures to intimate about the possible hazards (Mittal et al., 2020; Usman Sarwar et al., 2021). Years-long research has resulted in very effective and efficient techniques for detecting such events. However, this area requires ongoing research and development to fulfill the need for improvements in already flourished techniques. A significant chunk of effort is devoted to regularly detecting new threats and patterns. The intrusion is usually detected based on anomaly detection, specification, and misuse detection.

Incidents can cause serious trouble and may disturb the everyday life of citizens, along with other losses. Hence early detection is key to uninterrupted smooth life within the cities, traditional or smart. However, current research is more focused on detecting the intrusion in advance before the incident (Al-Turjman, 2020).

4.7.2.1. Critical analysis. An intrusion detection system (IDS) is undoubtedly the critical component of today's and future data-driven smart cities. Due to its critical nature, many systems rely on correct data availability at the correct time without irrelevant processes/people having their hands on the data. To let all functions of the smart cities work flawlessly, detection of flaws before their occurrences or before they harm the system can only be done using a proactive approach, and the best practice is the use of IDS. However, the attacker always has a universal advantage to attack that device on the target network, which has the least security. IDS can help us in such situations by the pattern of traffic matching from the expected attacks. In this regard, the heterogeneous nature of components of smart cities and their individual and combined/interconnected requirements may require research and upgrade to the existing IDS technologies.

4.7.3. Intrusion prevention systems

An intrusion prevention system is that component of the cybersecurity domain that comes into action after successfully detecting the system's cyberattack, which is the job of IDS. According to the administrator's pre-defined rules and associated actions, intrusion prevention systems defend the system from being harmed by cyberattacks. With the modernization of traditional cities into IoT-powered smart cities, there arises a much need for intrusion prevention systems to secure the smart cities (Iwendi et al., 2020; Rehman et al., 2021; ur Rehman et al., 2021). The authors in (Li et al., 2019; Ravi et al., 2021; Sriram et al., 2020) proposed a DL-based approach to detect and prevent cyberattacks over smart cities. The proposed system also uses an IoT feature extraction methodology to enhance the proposed model's accuracy. The authors in

(Yang et al., 2019) review the current state-of-the-art security mechanism for the e-government applications and assess their capabilities. Finally, they also proposed an AI and blockchain technology-based decentralized mechanism to provide all-in-one security in the context of smart cities. The authors in (Ramadan, 2020) proposed intrusion detection algorithms for the smart cities' wireless communications. The proposed algorithms are based on threshold-based intrusion detection systems (TBIDS) and multi-path-based intrusion detection systems (MBIDS). A cross-layer methodology has been integrated into the application and network layers for intrusion detection. The authors in (Vinayakumar et al., 2020) proposed a DL-based approach for the detection of botnet attacks over IoT-based smart city components. The proposed approach mainly analyzes the DNS data to identify and prevent the system from attacks. The authors in (Mohammad, 2019) proposed a multilevel intrusion prevention system that includes component level, system level, and security operation center for the smart cities. The authors in (Aldaej, 2019) proposed a proficient algorithm-based intrusion prevention system that mainly detects DDOS attacks over the smart city applications. The proposed system analyzes the network bandwidth and data to identify the DDoS attack over the network. The authors in (Qureshi et al., 2020b) proposed a novel approach to detect HELLO-Flood attacks, Version number attacks, Sinkhole attacks, and Blackhole attacks in the networks of smart cities. The authors in (Ismagilova et al., 2020) thoroughly reviewed the security systems of modern technologies for smart cities.

IIoT has become part of everyday tools and equipment to add efficiency and control to their usage. To prevent misuse of this vast number of IoT devices, authors in (Chaabouni et al., 2019) comprehensively cover the need, requirements, design, and implementation of the network-based intrusion detection system (NIDS) for IoT devices. The IoT NIDS ecosystem is introduced to focus on learning terminologies and state-of-the-art solutions, carefully evaluating their pros and cons. To prevent intrusion in IoT devices, (Rana et al., 2021) analyzed and proposed the authentication scheme to prevent unauthenticated access and prevent the intruder from having entered the network to act maliciously.

4.7.3.1. Critical analysis. An intrusion prevention system is one of the core components of smart cities' sustainability. It ensures a streamlined working of the various components of the smart cities, which are based on technologies like IoT, traditional computing networks, cloud-based infrastructure, real-time systems, and edge and fog computing. If there are no IPS in the mix of such different technologies, this leaves them vulnerable to cyberattacks, and thus when they get exploited, it could lead to devastation. Research, update, and standardization in the aspects related to IDS/IPS like rules and engines standardization, openness, cross-platform detection, unification of taxonomies and terminologies, etc., are the areas seeking the interests of current research advancements and betterment of existing solutions and technologies. Table 9 presents the Cyber Security Literature section tabularly.

Table 9
Summary of cyber security literature.

Ref.	Paper aim	Proposed scheme/method/mechanism	Key features
(Tandon et al., 2020)	SLR on blockchain for healthcare	This study presents a systematic literature review (SLR) of 42 articles, presenting state-of-the-art research in blockchain usage for healthcare.	• Implemented blockchain in healthcare, medical diagnostics, fraud detection, avoidance, legal and regulatory compliances, etc.
(Kitchin & Dodge, 2019)	Security threat analysis of future smart cities	The future smart cities are attracted to malicious actors both at the state level or otherwise. The paper categorizes the vulnerabilities and risks of smart city technologies into five categories.	• Design level security of smart cities • Mandatory regular vulnerability assessment, patch management, regulations, and sops, and the establishment of CERT for incident response.
(Mrdovic, 2021)	Cryptacus project review and analysis	Technology everywhere increases the risk of exposure and compromise of systems and their information. The book focuses on the outcome of the EU COST project CRYPTACUS.	• Scientific challenges in information security, information privacy, cryptography, and embedded systems. • Focused on Ubiquitous Devices, Lightweight Cryptography, Contemporary Symmetric Encryption, Block cipher standardization, and Electronic Identity Technologies.
(Arumugam & Shunmuganathan, 2021)	Identification of essential skill-set for forensic professionals	Extended use of technologies in everyday life also increases the risk of cybercrime linked specifically with data theft, exposure, or leakage. This then increases the need for the availability of Expert Forensic Practitioners.	• Evaluated and identified the various skills required for cyber forensic professionals and practitioners in today's technology-based world. • The multi-agent approach is evaluated for the identification of the skills which are effective for forensic laboratory investigation.
(Mittal et al., 2020)	Wireless network intrusion detection	The preferred communication mode is shifted to wireless in the past decade. The openness of the physical medium of wireless networks makes it lucrative for attackers. Routing attacks are also common in such scenarios.	• Evaluated LEACH protocol with levenberg-Marquardt neural network (LEACH-LMNN) in a real-life example to evaluate the network's lifetime. • Differentiated traffic by performing intrusion detection using a gated mechanism (LSTM and GRU) in the same wireless sensor network with a higher detection rate.
(Usman Sarwar et al., 2021)	Activities detection of smartphone owner	Smartphones have become a common commodity for everyone. The Digital and technological aspects of smartphones have become an integral part of our daily life. The associated risks due to inherent vulnerabilities also did the same.	• Two-layered approach named PARCIV to recognize the physical activities done by the people correctly. • Developed an android based application to collect labeled data from the end-users using phone sensors. • PARCIV achieved 99 % accuracy on the self-collected data set, whereas 95 % accuracy on the publicly available dataset.
(Li et al., 2019)	Intrusion detection in smart city environment	In the current era of post 4IR, the industrial foundation is now widely based on IoT devices. The malicious activity on such devices will have a devastating impact as they are no more network-only devices and interact with real-world systems.	• Novel method for smart cities using a deep learning algorithm • Results in intrusion detection in a relatively shorter time with high detection accuracy.
(Ismagilova et al., 2020)	Impact of social, economic, and political challenges for smart cities	As different layers of smart cities are interdependent and are closely mixed, risk manageable to one layer might be destructive for the other layer. Security of these intermixed layers is a crucial challenge.	• Comprehensive insight into the technical, economic, social, and political challenges the smart city faces. • Discussed privacy and security, mobile and smart devices, healthcare, communication, power, infrastructure, citizen's life, and governance.

4.8. Smart life

All the processes and management structures in the smart cities have a common target to achieve, and that target is to import the quality of life of that city. The increased digitization and automation bring so many changes in citizens' everyday life routines of citizens (Niemann & Pisla, 2021). Sustainable growth is required economically—technologically, environmentally, and spatially (Kim & Jun, 2021). A study (Srivastava et al., 2021) revealed that decreased quality of life could be turned up by giving more priority to investment in development and support of community services and social capital (Srivastava et al., 2021).

4.8.1. Smart homes

Urbanization is increasing worldwide. This exerts pressure on the city's population, which ultimately degrades the city's life due to overpopulation. The central unit of city life is home, and technological advancement in smart home technologies gives an up-shift to live a healthy life at home (Orosz, 2021). To provide quality of life to its citizen, smart homes in the smart city play a backbone role. Home automation is the essential aspect of smart homes, and IoT devices act as a backbone to home automation (K. D et al., 2021). The integrated system consists of these devices must be energy conscious and have to provide a user-friendly environment to the end user (Shafeer et al., 2021).

IoT enables access to information from any location, at any time, and on any device and has transformed all areas by tackling a range of societal problems using real-time data from networked devices. Among these categories, smart homes are one of the major areas where the IoT has had a big impact. Smart homes connected to the IoT have spawned a new realm, dubbed smart home-IoT (Choi et al., 2021; Haque et al., 2021). The authors in (Kim et al., 2021) conducted a quantitative evaluation of the research on smart homes and cities and a qualitative review to identify hurdles to the advancement of smart homes to sustainable smart cities. Based on the findings from the holistic framework for each domain (smart house and city) and the technological-functional hurdles, this study recommends that creative solutions be used appropriately to improve energy conservation systems in sustainable smart cities. Inside the home, the provision of ease by automation of everyday tasks is made using AI, IoT, and IoNT devices connected with either each other directly or through central smart home managers like Alexa and google home. Such smart home manager results in standardization and compatibility of various communication and data sharing protocols as well as for the control management (Siddiqa et al., 2021).

The life of future smart city residents will be free from unproductive tasks. An example can be quoted when the smart citizens must not care about how many eggs are there in the smart fridge of their home. The sensors in the smart fridge will keep track of the remaining inventory of the eggs in the egg basket of the fridge. The smart fridge automatically orders the eggs from an online store upon reaching thresh hold level. The payment was made through the citizen's credit card, and the next day, the eggs will be delivered to replenish the egg inventory. Another critical area of research in this field is activity identification within a smart city. Using the sensors, key features were extracted from the events happening within smart homes and based upon the perceived information and rules, activities such as movement, walking, eating, and bathing is identified to make smart home situation-aware (Tahir et al., 2020).

4.8.1.1. Critical analysis. The smart home's target is to provide residents with a user-friendly automated environment customized based on the residents' requirements. The Voice user interface (VOI) is heavily utilized for controlling home automation. Many big names like Google, Amazon, and Apple are trying to win the future smart homes controlled by the Assistant Devices. Future smart cities will benefit from the advancements and improvements in these technologies. However, lack of standardization and interoperability are the major hurdles.

4.8.2. Smart healthcare

Advancement in technology in the healthcare sector is revolutionary and makes humans' lives secure from diseases to a great extent. Health monitoring plays a significant role in identifying the issue at earlier stages. The use of AI, ML, and IoT devices in smart homes together provides healthcare monitoring at the personal level virtually 24/7, As emphasized in (Javed et al., 2021c; Javed et al., 2021d; Wang et al., 2021). Availability of high-speed communication networks, cloud computing, and multimedia services in the smart city also possess enormous potential in the field of telemedicine, remote medical services, and medical data analysis and movement (Oueida et al., 2019). Fig. 22 presents the components of the personal healthcare monitoring system.

Healthcare data generated from multiple types of devices produced from different vendors have different accuracy and storage interfaces. In case their accuracy can be made above specific threshold w.r.t medical standards. It can be integrated with the medical electronic health record of the person so that his / her general medical conditions/vitals may be available daily for later analysis by the healthcare professional as per requirement (Xu et al., 2018). The building blocks for such a system are composed of the device, the patient/user, connectivity, gateways, cloud-based servers, and analytical engine (Gavrilović & Mishra, 2020). The output from the analyzed and processed results can then be accessed centrally by the healthcare professional as and when required.

4.8.2.1. Critical analysis. Healthcare facilities are a necessary part of the city's life to take care of the citizens' well-being. Technological advancement in smart cities also significantly increases the possible ways citizen health can be taken care of in such cities. Network and compute facilities emerge H-IoT as a new industry by creating a demand for personal health assistants and their continuous data management, storage, and analysis regarding one's health dynamics (Javed et al., 2021e; Shabbir et al., 2021).

4.8.3. Smart citizen

The whole concept of a smart city revolves around the citizens (Kumar & Dahiya, 2017). They are the central element of smart cities. All other functions of smart cities are meant to facilitate the city's smart citizens in one way or another. The smart city is backed by creativity and new ideas, and the source of these ideas and creativity are its citizens. Empowerment of the smart city citizens by their inclusion or participation within the city can be measured to identify the bond between citizens and the city (Cardullo & Kitchin, 2019). A major change was observed when the funding programs for creating smart cities by the European Commission were renamed as European innovation partnerships for smart cities and communities (EIP-SSC). They have managed an entire cluster mainly focused on citizens. Hence, the reason for the latest technology integration is to produce innovative solutions which can provide quality of life and easiness to the citizens (Simonofski et al., 2021). For this, the citizens must be part of the city governance. In the absence of normal citizens' participation both on the responsibility fulfillment and decision-making side, the citizen-centric Government is not possible (Malek et al., 2021). Fig. 23 presents the governance of smart citizen-centric.

It is anticipated that the future smart cities will prevail with the citizen-centric approach to governance and management. In a proper citizen-centric smart city, the interacting factors are government role, technological base, citizen intelligence, and cognitive liabilities (Han & Kim, 2021). In (Ji et al., 2021), the authors implemented the citizen-centric approach towards smart cities in Taiwan and based their study on 35 city services from 07 domains grouped into two domains. The results show a positive trend towards adopting the approach to improve citizens' well-being and quality of life.

4.8.3.1. Critical analysis. The traditional city structure revolves around the city government, the dominating factor in its operations. Policies were devised and implemented for the city's smooth operations, and citizens had to abide by them. However, in developed countries and now in smart cities, the focus has been shifted to the citizen-centric approach. Now the systems and processes are designed in such a way to facilitate the citizen more than before. It brings the concept of participatory governance, where citizens have an active role in designing and managing governing processes. This phenomenon is extracted from the concept of democracy, which is considered the government of the people and the people. Provision and facilitation of quality and well-being are of the utmost importance in such consideration (Zarecor et al., 2021). Table 10 presents the summary of smart life literature.

4.9. *Smart economy*

Great democratization of information communication technology (ICT) around different world countries leads to a debate on resource-conserving, sustainable, smart cities, and resilient smart cities' economic development appropriate to different countries. Different continents have their own emerging patterns for urbanization, requiring strategies, policies, and diverse approaches. Each city of the country or continent will possess its challenges regarding the economic development of smart cities (Kumar & Dahiya, 2017).

Authors in (I. L.A, 2017) proposed a Unique composition of validation of sectoral improvement directions in a smart economy dependent on recognizable proof of gaps among current. They required degrees of advancement and the use of a complex of changeable plans of action as an instrument for conquering these gaps. Authors in (I. L.A, 2017) also identified three types (horizontal, vertical, and mixed) of basic trajectories for sectoral advancement based on different business models, government support levels, and available resources had been point identified.

Authors in (Svobodová & Bednarska-Olejniczak, 2020) presented the following key points that differentiate a smart city: economic competitiveness, quality of life, and sustainability showing that economic activities are the key component of a smart city. To get fruitful results, it is necessary to adopt the mitigating strategies to remove/minimize the barriers impacting industrial growth, which ultimately results in economic growth (Govindan et al., 2020). This section will undergo the three primary aspects of the economy, i.e., businesses, financial sector, and production facilities, which make an economic horizon.

4.9.1. *Smart business*

Business activities are crucial to city life. A technologically coherent business system is required for future smart cities based on calculated and predicted KPIs to provide the economic and requirement-oriented system governing the need to consume the product's life cycle. The smart manufacturing system is way more productive and efficient than the traditional manufacturing approach and is incorporated by the top manufacturers incorporate it into their production methodologies. This approach's suitability is far better in terms of capital expenditures, supply chain, allied processes, and manufacturing alone (Kamble et al., 2020). Keeping in view the limited budget available for SMEs, the incorporation of advanced manufacturing technologies, especially 3d printing, augmented reality, IoT, big data analytics, cloud, fog and edge computing, additive manufacturing, simulations, and horizontal and vertical integration, bring exponential growth opportunities to the businesses in today's, and upcoming smart business world (Chen et al., 2018b; Liu et al., 2017) is challenging. According to (Chaudhuri, 2021), the major factors required to win customers' trust for the digital offering of the products are attitude, behavior, environment, and experience. Along with this, the key to success for smart business lies in the adoption of complex and dynamic strategies in a technology-based organizational environment (Mkansi, 2021). Combining the technology with the generic processes to get more fruitful results is doing the business more smartly and is the core component of future smart cities.

Table 10
Summary of smart life literature.

Ref.	Paper aim	Proposed scheme/ method/mechanism	Key features
(Kim & Jun, 2021)	Sustainable smart living	The authors review assistance in occupant's sustainable living in communities and buildings, highlight and discuss issues related to the sustainable development of the environment, and emphasize the lives from green and smart design perspectives.	• Detailed survey on the models, proposed methods, and available applications related to sustainability. • Provide and discuss the understanding and the adoption of sustainability. • Research challenges sustainable communities and buildings, which will provide a sustainable livelihood for the whole society.
(Orosz, 2021)	Performance evaluation of smart homes	In this study, the authors discuss smart homes and smart cities and show how smart cities' performance is increased and how smart homes contribute to smart cities' performance.	• Created a model for smart cities based on the available literature. • The developed model help in two new factors of smart cities: the importance of education and people in smart cities.
(K. D et al., 2021)	Use of AI in Energy Monitoring	The authors proposed how AI techniques help and use in the energy sector.	• The study explored how AI techniques work using traditional models in smart grid, robotics, IoT, controllability, cyber attack deterrence, big data management, energy efficiency optimization, computational effectiveness, and predictive control.
(Wang et al., 2021)	Health monitoring using IoT sensors.	The research work provides a complete guide on how the available sensor technology help in smart home monitoring.	• Detailed literature review and summarized the existing state-of-the-art research on available sensor technology for health monitoring in the home. • Developed four terminology monitoring functions, data, unobtrusive sensor, and location for the structured analysis.
(Oueida et al., 2019)	Efficient smart healthcare resource utilization	The authors proposed a model to improve the utilization and delivery of healthcare resources in a smart environment. This paper introduces a model that can provide improved delivery and utilization of resources.	• Introduced a quality reward model to react and study the contentment factors of the healthcare systems in a smart environment. • Proposed an algorithm called the Maximum Reward Algorithm to deliver and use healthcare resources. • The algorithms tested through simulations and

(*continued on next page*)

Table 10 (*continued*)

Ref.	Paper aim	Proposed scheme/ method/mechanism	Key features
			experiments provide efficiency reliability and achieve 50 to 77 % performance.
(Xu et al., 2018)	Healthcare big data analysis	To help doctors regarding patient health, for regional medical unions, healthcare data analysis system is proposed to assess the patient's health condition based on overall data view from hospital to doctors from different hospitals.	• Labeled social data to search the topics related to people corporeal in the joint region. • Analyzed human behavior from vital physiological values.
(Gavrilović & Mishra, 2020)	IoT available architecture analysis	The authors presented the available software framework related to IoT systems in smart agriculture, smart healthcare, and smart cities.	• Analyzed different types of IoT architecture like cloud-based, service-oriented. • Analyzed layered architecture applications in various areas of IoT.
(Malek et al., 2021)	Citizen-centric smart cities	The purpose of this study is to identify the key indicators related to citizen-centric smart cities from the participative domination practices and inhabitants' accountabilities perspectives.	• Elaborates an SLR of social enclosure pointers for structure citizen-centric in the smart cities environment to achieve the proposed research aim.

4.9.1.1. Critical analysis. Ways to do business are changing worldwide. Especially in the post-Covid19 world, the lockdowns and interaction less environment due to safety and care results in a boost in the business incorporating or shifting to online business models even in the traditional business world. However, in smart cities, smart businesses are not only online but also automated. Consider a smart fridge getting a continuous check on several eggs in the egg basket using smart sensors. Upon detecting the threshold level, e.g., four eggs, automatically put the order to the nearest online store and pay through the credit card of the house owner. It was also delivered on the same day using smart delivery without the involvement of the house owner to get worried about such aspects.

4.9.2. Smart FinTech

The documented economy provides blood to the financial sector of the economy. This prevents misuse of money and violation of laws. It also helps in the revenue estimation and collection for the smooth running of governance and development projects. The banking industry and other fintech organizations provide this service to the Government, organizations, and the general public. The inclusion of the latest trends and technologies is on the rise in this sector compared to other smart cities (Starnawska, 2020). The provision of smart services to the residents is the basic philosophy of smart life in a smart city, and financial services are the basic unit of this philosophy. Smart citizens, smart governance, smart business, and smart life are significant subscribers. The services also come in handy after introducing mobile banking services as now everything in the financial arena can be managed from the person's palm (Ahmed et al., 2021c). However, in the future of smart cities, the reliance on financial services is majorly based on AIDS (artificial intelligence and data Sciences). However, it covers broadly classical AI, modern AI, and data sciences. The classical AI includes logic, planning, modeling, simulation, image processing, decision making, decision support system (DSS), autonomous systems, knowledge representation multi-agent systems, expert system (ES), pattern recognition, and natural language processing (NLP). Modern AI and data sciences include complexity science, mathematical modeling, statistical modeling, knowledge discovery, representation learning, ML, optimization, data analytics, computational intelligence, event and behavior analysis, social media/network analysis, DL, and cognitive computing (Cao, 2020). FinTech companies started to utilize the power of blockchain and smart contracts to bring transparency to the processes (Wang & Xu, 2021).

4.9.2.1. Critical analysis. The smart financial technology (FinTech) for future smart cities will cover the inclusion of AI, ML, and Data Analytics for the operations in the field of smart banking, smart insurance, smart lending, smart marketing, smart payment, smart regulations, smart financial risks management, smart financial security, smart trading, and smart wealth management. These inclusions will result in a scalable, expandable, auditable, and available financial management platform to deliver B2B, B2C, C2C, G2B, G2C, and G2G services most efficient and auditable way.

4.9.3. Smart factories

The production process is the part that shows the industrial strength of the country/city. Realizing the importance of manufacturing, many cities started offering special industrial zones with facilities for commercial manufacturing ventures or molding the city's industrial sector to become a hub for expert and quality manufacturing for specific technology areas/products. Moreover, the research is now going to multi-plant smart manufacturing, and multiple parties with expertise in their particular areas now work together to produce final products using smart manufacturing. A recent research (Ren et al., 2021) proposed a detailed review of identity and authorization management frameworks for Industrial IoT (IIoT), which is the critical requirement for secure smart manufacturing.

To have automated control, the following three major areas of manufacturing must be shifted to data-based automated control: 1) product tracking technology, 2) process data acquisition system and 3) fault detection based on neural networks (Lee et al., 2021).

Based on the data gathered from all these aspects, the production quality, quantity and operations can be effectively controlled and automated. Reaping additional benefits like production trend analysis, future prediction, quality control, process, product defect detection, root cause analysis of issues, and other allied statistics gathered using ML approaches. Factories, traditional or smart, are usually divided into two major categories, i.e., Large scale manufacturing and small and medium-scale factories (Strozzi et al., 2017). Fig. 24 discusses prospective benefits and edges gained by smart factories over the traditional ones in the case of both large-scale manufacturers and small-scale factories. (Resman et al., 2021) discusses the methodology for planning a smart factory from scratch. Large-scale and smart factories have enormous benefits in shifting their manufacturing plants to be based on smart technologies. This is the era of 3D Printing and additive manufacturing (AM) (Goh et al., 2021). During the Covid-19 pandemic era, it was observed that the shortage of essential medical supplies was fulfilled using 3d printing technology (Oladapo et al., 2021). This creates a new dimension for manufacturing at a small scale, diminishing special manufacturing units' need for developing the products. Further to this, on-demand manufacturing and personalized/customized manufacturing also result in freedom from managing inventories (Sgarbossa et al., 2021).

4.9.3.1. Critical analysis. With the introduction of Just In Time production, Zero inventories, robotics, automation of production plants, AI and ML, and 3D printing, the manufacturing sector faced further new challenges. Due to advancement in technologies and their incorporation into every sector related to human life, ways of manufacturing/production also get influenced. Those units jumping into the manufacturing have the Edge over the older traditional manufacturers. They can use the LeapFrog Technique to incorporate the latest technologies from their production/manufacturing. This will give them the Edge to rapidly capture more markets, more accessible technology updates, introduce new trends, future-proofing their investments, and ultimately begin their journey to become global business leaders. On the other hand, those who choose not to upgrade will eventually diminish from the scene. They will have a limited customer base, expensive comparative product prices, higher costs for technology upgrades, and a lack of customer satisfaction due to batch manufacturing. Table 11 presents the summary of smart economic literature.

4.10. *Smart governance*

Smart cities cannot become smart enough unless they have smartness in their governance structure. Becoming a smartly governed city not only requires the use of technology but the incorporation of technology in the governance processes (Jiang, 2020). The evolution of smart cities also highlights that cities that run on information must have such information generation more smartly. This can only be done by reinventing the governance structure and replacing the manual theme of work with the more automated, technology-backed, and digital (Barns, 2018). This transformation needs to be done in two aspects. i.e., technology-enabled automation in the processes and technology-backed intelligence in the decision support and management (Pereira et al., 2018). Key challenges in these aspects are the best use of technology to generate critical data in the required time for processing, the provision of information to the other processes of the governance structure, and the best utilization of that data in decision-making processes. The success factor is incorporated into a future smart city's critical performance indicators that reshape the governance structure. As well as allied governance processes at the local government departments and agencies and other stakeholders directly or indirectly (Alawadhi & Scholl, 2016).

The concept of electronic Government is now widely implemented in major cities of developed/developing countries. Past research brings the efficiencies at large by identifying and removing the issue and challenges (Rose et al., 2015). However, it mainly revolves around the digitization of the classic governance structure. Electronic governance, however, became the foundation for the idea of smart governance when a delay in processes was identified, which was previously hidden before digitization. A significant portion of the future smart city will be linked directly or indirectly with the city's smart governance.

It is perceived that every citizen has the past, present, and future to get the true benefits of technology. It must be visible to accommodate their role in the overall governance structure, even if it is on the receiving side of the action. It will also help generate future infrastructure requirements to fulfill the needs. Smart governance must process the past ten years' trends to analyze and anticipate the next ten years' requirements and directions. Near to accurate guess requires quality and quantity of data and trends. The true challenge in this regard is to gather the pre-smart era data in the required form while keeping the citizens' privacy intact. Technology-backed and technology-based government infrastructure is evolving, and it is on its way to a mature, smart governance structure. Big data analysis is the key part of the future smart governance initiative enabling the solution of day-to-day problems and smart decision and planning management (Kulkarni & Akhilesh, 2020). Big data analytics is the integrated part of every smart city aspect. However, its inclusion is more significantly highlighted by supporting high-level current and future decision-making. Fig. 25 presents the different dimensions of smart governance.

4.10.1. *Smart revenue*

Revenue generation is the prime source of income for not only businesses and enterprises but also for government infrastructure too. To

Table 11
Summary of smart economy literature.

Ref.	Paper aim	Proposed scheme/method/mechanism	Key features
(Svobodová & Bednarska-Olejniczak, 2020)	Smart economy issues and challenges	A smart economy is considered one of the key components of smart cities. Key issues and challenges to the smart economy were discussed in the literature. The article reviews the published literature for the same.	• Surveyed published literature on smart cities and economy. • Major portion of such research was done in the USA and India. • The main keywords identified are smart cities, urbanization, governance, innovation, and economy.
(I. L.A, 2017)	Vertical, horizontal and mixed sector development using advanced technologies	Digitization, technology development, and development in IoT increase pressure on sectoral development in smart economies.	• Identified the gap between actual and required sectoral development is very necessary and the theme of this research. • Built the matrix based on digitization, market trends, and the development in the relevant sector in advanced technologies to identify government support and resource management requirements for vertical, horizontal, and mixed sector development.
(Chaudhuri, 2021)	Ways to make e-business operationally effective and efficient.	Covid-19 badly impacts the economic world, businesses, and production houses. However, online shopping trends observe a steep rise due to less physical interaction during the pandemic.	• Trustworthy digital design and deployment. • Controlled regulations and planned technological upgrades. • Made business operationally competent, robust, and competitive.
(Mkansi, 2021)	*E*-business adoption strategies for small business.	Initial setup costs and recurring operational costs are a big hurdle in small organizations starting an online e-business. This study reviews these challenges.	• Adopted the multi-case study model while adopting the qualitative approach. • Provided government-supported/funded services to the small business organization regarding e-business hosting and setup may better adopt e-business strategies by small organizations.
(Cao, 2020)	Technology adoption in the financial sector	The speed and abruption in processes of the smart city require the associated systems to work in real-time. The financial back-end is the backbone of any city, and smart	• Comprehensively covers the various aspect of fintech work areas • Review the methods and technologies for the inclusion of technologies in work processes. • Inclusion of AI to better fintech

(*continued on next page*)

Table 11 (*continued*)

Ref.	Paper aim	Proposed scheme/method/mechanism	Key features
		cities are not an exception.	companies of the future smart cities in audit, control, and operations to deliver intelligence-driven services to the economy.
(Wang & Xu, 2021)	Adoption of smart contract and smart invoices by fintech companies	Contracts are an important part of the economy, and the smart economy is now widely using technologies for record management and contractual operations. The adoption of smart contact by fintech companies results in faster and more efficient contract-related operations.	• Used a two-stage game-theoretic model to test supply chain finance theory for various fintech applications • To gauge the performance and operational strategies for pre-shipment and post-shipment scenarios as per the smart contract liabilities. • The outcome is the guidelines for when to adopt smart contracts and smart invoices and how they can be beneficial in a true sense to the business.
(Lee et al., 2021)	Transformation of factories into smart factories.	The classical factories are now transforming into smart factories to reap the benefit of smart technologies in the work processes and face challenges during adoption.	• Proposed a novel and cost-effective approach for product tracking. • Discussed data acquisition systems for processes. • Discussed a fault detection system that uses an artificial neural network.
(Oladapo et al., 2021)	Overcome shortage of medical supplies using 3D printing	Covid-19, like a pandemic, can cause a major loss to the production facilities due to lockdowns, etc. This may result in a scarcity of important items.	• Proposed 3-D printing technologies to fight the shortage of essential medical supplies. • Reviewed the production of bio-materials and bio-products using 3D printing, which will overcome the challenge of producing medical items during lockdowns for covid control.

cover their running expenses and fund the public sector development projects, increase the overall revenue to cover the expenditures and costs. In the modern era,e of intelligent tools, technologies, and algorithms is integrated into revenue generation and management (Helmold, 2020). A bottom-up approach is recommended to transform the overall governmental infrastructure's various revenue generation systems into a smart technological-based system. An efficient, based on occupancy model, parking slot to the vehicle with a dynamic cost model was suggested by (Saharan et al., 2020) using ML techniques for competitive parking cost calculation. The same model can also be utilized with modifications to other scenarios of revenue collection.

4.10.1.1. Critical analysis. Revenue generation is an essential aspect of city governance which has many facets in its implementation. The revenue may be generated from tax collections, utility usage payments, and fees for various facilities like parking, fines, and taxes collected from multiple revenue sources. Automation, the crucial factor for smart cities, helps smart cities ease management, application, collection, and auditing of revenue imposed, generated, collected, and spent. ML and AI can be utilized to the full extent to further dig deep into the different scenarios to find out the possible sources of revenue collection and the possible areas where the spent amount will yield the most beneficial outcomes for the city's betterment.

4.10.2. Safe city

In smart city governance, monitoring the city is a crucial task. An electronic, real-time, visual-based system is currently deployed in major cities worldwide, having central control rooms established to monitor the city's state. The defining of crucial points for the monitoring is the foundation for the safe city's whole architecture. This is usually done via predicting the risks and impacts study and adding entry/exit points and the invisible boundaries of the city area (Ristvej et al., 2020). After finalizing monitoring points and technologies, the comprehensive, round-the-clock monitoring and analysis are executed for a proactive response. Automated and manual alert management is done upon identifying an incident/crisis, which is then propagated to the appropriate stakeholders like health authorities, law management and enforcement authorities, and Local Governments for appropriate actions and containment of the situation. Fig. 26 presents the safe city process flow.

Safe city design is the most crucial step in the overall lifecycle of future smart city safety. Safety must be incorporated into the design of smart city processes. The anticipation of threats and how to tackle them is the central question at this stage. More effectively and deeply, the thought process at this stage will result in security and safety at later stages. After the design, the monitoring process takes place to monitor the city processes 24/7. The analysis was performed near real-time using advanced AI techniques for possible pattern matching with the issue. After the match's occurrence, the alert is generated per the pattern's severity, and necessary actions were performed to neutralize the situation. The whole process is managed and controlled centrally.

4.10.2.1. Critical analysis. Controlling crime is the primary function of any city, and smart cities are no exception. Maintaining a law and order situation is crucial for maintaining the quality of life in smart cities. Future smart cities will use advanced technologies to monitor the city situation and prevent unpleasant situations. It involves strict monitoring using sensors and cameras placed at appropriate locations, AI, and ML techniques to predict and act according to the model's outcome. Further, law enforcement officials use the latest technologies like drones, forensics tools, and big data analytics, resulting in faster analysis and investigations and often more accurate investigations. More reliance and technology integration in future smart cities will further ease the LEAs to make those cities safer.

4.10.3. Smart law enforcement

In the modern world, the inclusion of technology in law enforcement agencies' work increases many folds. Drone technologies, real-time monitoring, spying and bugging, crime investigation, and criminal tracking are now done more effectively and efficiently using the latest information technology and digital forensics developments. AI is also used for crime suspect analysis and detection, and in a specific condition, the technology-based solution performs better than its counterpart human police officers (Rademacher, 2020). It applies ML algorithms to identify possible crime-related activity. Using AI can update the nearby law enforcement personnel or the public as per the situation about the likely happening of the unwanted event (de Haan & Butot, 2021). The same technologies can also be used for safety and crime prevention by monitoring and analyzing the situation at the target place.

The four main pillars for smart law enforcement operations are Prepare, Prevent, Protect and Pursue. To effectively use smart law enforcement's technological base, the process and human resources should be trained enough to incorporate the technological advancement into their day-to-day operations to improve accuracy and productivity. After executing this step, the next challenge is to prevent the crime before happening. ML, DL, and AI techniques can be used for context-aware situation monitoring and crime anticipating. In case of a crime, law enforcement personnel must be trained to protect human lives at any cost. The remaining importance goes to the property and governance. If the criminal successfully executes the crime, the law enforcement then uses safe city infrastructure to identify, detect and pursue the criminal to deliver justice to the victims. Fig. 27 presents the four main pillars of smart law enforcement in a smart city.

These pillars overlap and connect, creating a solid mesh bond to support and strengthen each other.

UAE is using an utterly technology-based e-Trial within the judicial system. While creating bonds, contracts, and other agreements, blockchain can result in verifiable and denial/tamper resistance built into it. This will result in less load on LEAs due to cases filed for financial and business frauds. The role of UAV is also increasing in LEA operations and is widely used in operations by the LEA personnel in developed countries (Srivastava et al., 2021).

A video monitor is a critical part of law enforcement activities. It requires monitoring (manually or intelligently) to deploy and manage optical surveillance equipment mainly based on fiber-optic communication. The work of (Saif et al., 2020) sheds light on recent trends and technologies in optical performance modeling using ML. The authors focus on using ML-based optical performance modeling (OPM) and modulation format identification (FDI) by discussing key advantages gained after deploying optical networks in different scenarios.

4.10.3.1. Critical analysis. Future cities will eventually see a decrease in crime rate due to increasing technological advancement, and it will become difficult to execute a crime successfully. The empowerment gained by the LEA will result in more focus on the prevention of crime and making it difficult for malicious persons to commit a crime. Monitoring and analysis solutions based on DL techniques and pattern recognition and facial recognition will update the local law enforcement and emergency service personnel about the possible areas their services are required. Root cause analysis to prevent crimes can also be done using the data collected, stored, and analyzed during the operations. However, there is a cost to pay for such implementation, which compromises the persons' privacy. Privacy concerns are already raised on such monitoring activities and are increasing daily. The major challenge is privacy-aware monitoring, analysis, and ML. Table 12 presents the smart governance literature section tabularly.

4.11. Smart environment

Another primary target for a smart city is transformation by effective and efficient utilization of renewable energy sources, reduced waste production, and cycling and re-usage to reduce the environment's impact. This is one of the crucial pillars of a smart city and requires smart thinking while planning and designing any future smart city, focusing on impacts and outcomes on the People, Places, and Planet (Govada et al., 2020).

The smart environment is the broader term that covers water and air quality, pollution, weather, radiation, waste, health, and natural disasters. Under this scope, a grid of sensors, monitors, analyzers, and actuators worked together to achieve a specific sub-task. These sub-tasks are categorically divided into two domains, i.e., environmental resource management and environment quality and protection management.

Table 12
Summary of smart governance literature.

Ref.	Paper aim	Proposed scheme/ method/ mechanism	Key features
(Jiang, 2020)	Utilization of ICT backed city governance in socio-technical way.	In this paper, the authors addressed how to govern the urban challenges using smart urban governance.	• Demonstrated urban issues, stimulating demand-driven smart governance modes, and determining more technological intelligence and informally, issues were discussed.
(Barns, 2018)	Effective alignment of smart governance objective with urban data interfaces.	In this research paper, the authors address the role of urban data boards in supporting city governments' transport of smart city creativity.	• Discussed the explosion of urban data platforms. • Focused on setting urban platforms as a key site for developing new models for smart city governance.
(Pereira et al., 2018)	Relationships between concepts of smart governance.	The researcher discusses electronic and smart governance to shed light on the smart government in smart cities and establish the framework of concepts and relationships with smart cities.	• Discussed the contribution to developing a framework and defining smart city governance for building new models that address different challenges of smart society • Information sharing, collaborative governance, transparency, and citizen engagement are key areas discussed.
(Rose et al., 2015)	Citizen engagement towards smart government	The authors proposed to analyze the value of traditions in administration literature, the adaption of traditions value for *E*-Government, and synthesize three different prominent values.	• Conducted a qualitative survey showing administrative efficiency and citizen engagement concerns through a manager's value position. • Discussed the imperative efficiency implications.
(Kulkarni & Akhilesh, 2020)	Performance evaluation of smart city	The authors proposed different dimensions which help in assessing smart city performance.	• Identified several well-accepted models for assessing the smart city performance. • Smart governance is one of the most important dimensions from the identified dimensions.
(Saharan et al., 2020)	Smart Parking Slot Finder	The authors proposed a novel mechanism for the interested vehicle owners to find the unoccupied parking slot with the least overhead.	• ML-based novel approach to predict unoccupied parking slots used to assume possession of arriving vehicles. • For training, testing, and comparing available ML algorithms, a

(*continued on next page*)

Table 12 (*continued*)

Ref.	Paper aim	Proposed scheme/ method/ mechanism	Key features
			data set of on-street Seattle city is used.
(Ristvej et al., 2020)	Design of framework for Safe and Smart city	The authors proposed a framework for the interconnected safe city and smart city concepts. The proposed framework is similar concepts and is common to both.	• Communication and experiences with executives responsible for and managing the smart city development (SCD), describing system layers and concepts are presented for the proposed framework.
(Rademacher, 2020)	Safety management in smart cities	Review the importance of urban safety management applications.	• Reviewed academic literature related to safety and smart city in general, analyzing the policy discoursed and commercial smart city creativities around Rotterdam city.

4.11.1. Green smart cities IoT

It is essential to take the necessary steps to promote energy efficiency and prevent energy depletion by implementing green IoT. Using clustering, we can extend the lifetime and efficiency of networks like IoT, depending on the quality of clustering schemes selection (Chithaluru et al., 2020). IoT is an eco network, not only used for transferring data into and between different networks; it is connected with cloud computing and Big Data to provide intelligence and recognize connected devices' behaviors. Authors in (Albreem et al., 2017) presented a comprehensive overview of the green IoT, including its applications, challenges, concepts, and technologies. After increasing the popularity of IoT, IoT-based applications and devices like smart city applications, low power, and long-range wireless-based connectivity solutions are increased day by day (Aslam et al., 2020b). To improve the sensor-based communication in smart cities (Chithaluru et al., 2020) presented an IoT method for constructing a green wireless sensor network (GWSN) with minimal power usage, minimum radio frequency impacts, and better performance. (Cao et al., 2021) applied a convolutional neural to a green IoT network for monitoring. Fig. 28 presents the lifecycle of green IoT in smart cities.

As urbanization results in a reduction of ecological land and an increase in climate disturbance, keeping in view the danger to nature, the metropolitan-level green urban spaces are promoted in developed countries (Zhang et al., 2021). The idea and empowerment behind green growth make the climate impact as little as possible by implementing technology to get the most benefits. The most devastating one is brown energy for powering up / charging these devices, which cost-wise damage is most prominent among all (Liu & Ansari, 2019). In the field of smart agriculture, green IoT-based agriculture is proposed through the implementation of four layers at the agriculture sensor level, fog computing level, the core layer, and a cloud layer in (Ferrag et al., 2020b; Mei et al., 2018). The overall green IoT life cycle is based on the green by design, green during production, green in utilization, and green while recycling, i.e., having minimum to no impact on the environment during all these phases (Albreem et al., 2017).

After the continual rise in hacking incidents involving IoT devices, the new IoT enhancement realized the need to develop secure IoT (SIoT). Security by design is the long-term solution for battling the security risks aligned with IoT devices in smart factories, smart homes, smart transportation, smart fintech, and smart healthcare, to name a few. This is the central concept behind (Hamad et al., 2020) research motives.

IoT is composed of embedded systems with communication to the internet, making the true green IoT achievable. The communication part must be given importance for efficiency and lesser resource hungry. (Chen et al., 2019) provides a comprehensive overview of the latest research in the physical and cross-layer integrated systems. The physical layer section discusses coded modulation schemes based on P-LDPC. The cross-layer section discusses the JSCC, JCPNC, and JCC-DCSK to make communication efficient and green.

4.11.1.1. Critical analysis. Excessive use of technology results in extra resource usage, resulting in many impacts on climate. As most solution implemented in the smart city is heavily based on IoT, optimization efforts are made to minimize the adverse effects of such implementations on the environment. These impacts may be direct or indirect, and both are hazardous in the long run. To control the damaging effects of technologies, the challenge was accepted to reduce the negative impact by using various corrective and preventive measures to make the technologies green enough to show the difference in past and present. The major work was done in the field of power consumption of IoT devices and the network area. Devices, protocols, and algorithms are devised to view the challenge of minimizing power consumption to increase the product work-life and keep in view the harsh environment devices may face after deployment and the reduction in impact on climate minimizing electromagnetic emissions.

4.11.2. Smart waste management

Once considered a responsibility to fulfill clean environment requirements, Waste management is evolving as a new opportunities highway. The improvement in the quality of life and advancement in technology often results in a degradation in the climate (Kumar et al., 2021). In the city, innovative or conventional, it was considered a challenge to manage the life cycle of waste, i.e., waste generation, collection, transportation, separation, and treatment. Treatment may include recycling, incineration, and land-filling (Pardini et al., 2020). The initial implementation of smart waste management revolves around including technology in the whole process. Researches in different areas now make it possible to generate products from waste in different ways. Wastewater is now treated and provided for irrigation purposes. In some areas, electricity is produced while incinerating the waste at the city level. Plastic from the waste is not molded and reformed for later utilization in various ways. A relatively more minor portion of waste that is not utilizable is now left at the end of the cycle for disposal. Fig. 29 presents the waste management system in a smart city.

For future smart cities, automation in waste management requires a technology-based automated and coordinated system to analyze, manage, and reprocess/recycle the waste. Sensor-based IoT devices are in use for the same in today's industries (Curtis et al., 2021).

4.11.2.1. Critical analysis. The smart city's waste management will be an iterative process where the waste will be processed and reused for other activities. The approach in the future smart city regarding waste would be REUse, REDuce and RECycle. Initially, waste management was considered overhead, but now it transforms entirely differently. Waste management now becomes a revenue generation stream where industrial waste is recycled and reused in several industries and saves crucial foreign reserves. Another advantage is the lesser harm to the climate due to lesser production of waste after reuse/recycling. Waste processing is now turning into an industry that generates wealth out of waste. Advanced technologies will eventually transform this industry into providers of processed raw materials to other industries and reduce the waste output of the smart cities.

4.11.3. *Smart power*

Electricity is the commodity of life, which becomes an integral part of human life, like air, food, or water. Not only do the essential gadgets and communication tools need power, but the recent shift to green transportation creates the need for electric power to run electric vehicles. Hence, the city cannot manage its affairs and operations without power. The technology dependence of smart cities requires the supply of enough and uninterrupted energy as per requirements. One of the best solutions to produce green energy with minimal impact on the environment is solar energy, which provides a sustainable and continuous (daytime) energy source at small and large scale and supports modular development/implementation approach (Govada et al., 2020). Fulfilling the future smart city's energy needs will be a big challenge to solve as a lack of adequate power, even for a short time, will result in significant disruption (Alam et al., 2021). As a smart city's main requirement is to have a reliable, energy-efficient, and continuous supply of power, the complexity of such uninterrupted power supply increases by many fold (Khalil, 2021). (Tharwat & Khattab, 2021) suggests using a clustering technique to resolve complexity in the scalability of the power grids and other CPSs for future smart cities. (Konstantinou, 2021) emphasize the requirements of an electrical energy system that is prone to unwanted issues and incidents like cyber attacks and physical risks for future smart cities.

Gaining operational efficiencies can be one of the crucial aspects in the power sector of future smart cities, and it can be attained using hybrid tactics based on management, data analytics, and trend analysis. There is a need to use advanced AI and ML approaches in every aspect of power generation, from requirement analysis to end-users utilization. This will optimize the utilization of existing generation approaches and prevent energy starvation (Ahmad et al., 2021b). Further to this, power generation and distribution companies must also enhance their technical competence to remain competitive in the relevant market.

4.11.3.1. Critical analysis. Power acts as the blood in smart cities. Due to the complete technology base back-end in every aspect of the smart cities, the power outage can standstill the city's running life. On the other hand, the power requirement is an ever-increasing phenomenon, and with the advancement in technologies, more power requirements in anticipated in the coming years. The growth in power generation is not at that pace and also possesses cost overheads. The future-proof approach generates most of the required energy using renewable technologies from natural sources such as wind, water, and the sun. The power infrastructure's security and threat management are crucial as power outages may negatively impact the smart city. Further inclusion of AI and ML techniques to monitor the demand and supply can help achieve optimum operational efficiencies. Table 13 presents the literature on the smart environment.

5. Open research issues and future directions

System of Systems is the phenomenon of collecting complex systems that coordinate with each other and work collectively and cumulatively to appear as a single system to the end-user. The internal systems pool their resources and capabilities to offer more services as a joint single entity/system. Smart cities are one such example of a system of systems. Several open issues and challenges need to be considered with the wide range of potential research and applications in smart cities. Researchers are working on the architectures and models of smart cities to deploy, integrate and build smart city applications. Examples of these broad range issues included inter-connectivity, communication and security, and smart cities' seamless integration. Several smart city approaches and policies are also under investigation. Governing bodies of smart cities are already working on the operation guidelines, regulations, and policies. These efforts will guide and help access more smart cities' applicable technologies, improve operability, smooth development efforts

Table 13
Summary of smart environment literature.

Ref.	Paper aim	Proposed scheme/ method/mechanism	Key features
(Govada et al., 2020)	Smart environment and sustainable smart cities.	Applied smart thinking for sustainable and smart environments.	• Reviewed and assessed the effort in making a sustainable and smart city.
(Chithaluru et al., 2020)	Green wireless sensor network (GWSN) using IoT for future smart cities.	Development of Green Wireless Sensor Network with the help of IoT Network to improve sensor-based communication quality in smart cities.	• Discussed the main challenges in improving energy efficiency: the death of the last node, half node, and first node death.
(Aslam et al., 2020b)	Long-range green IoT network communication with minimal energy consumption.	For energy-efficient connectivity, the authors proposed using a multi-hop LoRa network in a smart city environment.	• Compared and evaluated the single and multi-hop LoRa network in terms of energy efficiency and range extension • Used evaluation packet reception ration method for different spreading factors, transmission powers, and distances. • Multi-hop LoRa network enhanced coverage and saved significant energy.
(Cao et al., 2021)	Intelligent safety/ security related violation detection using ML	Using a convolutional neural network (CNN), the authors proposed the intelligent safety surveillance (ISS) method. For detecting workers' helmets, CNN is a supervised auto technique.	• Trained ISS model using the CNN technique and labeling of datasets. • Redesigned the CNN framework and loss functions which are based on YOLOv3. • Enabled the different models to learn labeled information from datasets.
(Zhang et al., 2021)	Green Accessibility Index (GAI) for urbanization ecological impact	The authors proposed and developed a green accessibility index method to represent the efficiency of assessing public green spaces.	• Improved trip time and optimized path choice time estimation. • Estimated green space accessibility. • Improved the capacity of public urban green spaces to inform planning.
(Liu & Ansari, 2019)	Balance green energy availability and utilization for IoT devices using wireless charging	The authors proposed green energy to give IoT devices power and revolutionary wireless charging.	• Proposed green IoT in three steps: i. e., ambient energy harvesting, energy wireless charging, and energy balancing • Used the harvested energy from green power sources to charge green IoT devices • Made green IoT devices able to use harvested energy intelligently and efficiently.

(*continued on next page*)

Table 13 (*continued*)

Ref.	Paper aim	Proposed scheme/ method/mechanism	Key features
(Ferrag et al., 2020b)	Highlight security challenges in the field of green IoT for agriculture.	The research paper proposed privacy and security issues challenges in IoT-based agriculture.	• Summarized existing surveys on smart agriculture. • Four-tier green IoT framework for agriculture • Categorization included integrity, authentication, privacy, availability, and confidentiality in the classification of threat models used in green IoT.
(Kumar et al., 2021)	Use of machine learning and AI for smart waste segregation and management	For effective waste disposal and recycling using a DL strategy, a novel technique is proposed for waste management.	• Performed detection task and comparative assessment using YOLOv3. • YOLOv3 framework yields acceptable simplification capability for all classes with the variability of waste material.

and services, simplify seamless integration with other systems, and fully integrate different applications in smart cities.

5.1. Technical risks and challenges

Technology advancement is an opportunity and an issue in the paradigm of smart cities. The increasing pace in the invention of new technology lacks standardization. It is possible only when one has a stable technology to benchmark and design or define minimal to maintain. Further, the latest technologies may have issues integrating with the existing technologies. They may require changes within the established systems that will again need to assess the system's stability and functionality before incorporating.

In communication, smart cities' fundamental components and computing, storage, and reporting have dealt with different challenges. A careful analysis is required in terms of node communication component cost, network cost, battery survival, data throughput, real-time communication requirement, coverage area, range of communication, mobility requirement of nodes, deployment model, and latency management (Alam, Malik, Khan, Pardy, et al., 2018b).

The birth of IoNT is a significant breakthrough in the recent past which adds miniaturization to the size of IoT devices and makes their wide-scale implementation further easy. However, adding more nodes in the system means more data in the compute and network layers. Multiple sensors get a more precise status of the aspect without bringing significant addition to the size and power consumption requirements (Al-Turjman, 2020).

5.1.1. Resources

Resources required to convert a city's infrastructure into a smart one require resources and investments in technological, financial, and human sectors.

5.1.2. Implementation

Generally, one of the two approaches is followed for smart city projects (i.e., top-down and bottom-up). The top-down approach is used when converting an established city from tradition to smart. The top tiers of the systems are converted to smart. Based on their data requirements, the systems beneath them are identified and converted gradually, resulting in the whole transformation taking years. A bottom-up approach is used in designing a new smart city project. The system's components are designed by incorporating smartness in them. Then their outputs are integrated and utilized at a higher level for further processing and utilization in decision support. Selecting the best-suited methodology is essential for a practical smart city project.

5.1.3. Technology reliance

The smart city concept is nothing but the inclusion of technology in a smarter way to join different technology-based solutions within the various aspects of city life to combine the effort in a coordinated manner to achieve a better standard of living in that city. These included technology has some hazards and threats too, which, after their utilization into smart city functions, added those threats to the horizon of smart city infrastructure.

5.2. Open issues based on the literature review

We highlight several open issues, challenges, and practical future directions based on the literature review with the wide range of potential research and applications in smart cities.

5.2.1. 6G networks

The need for a faster network connection is the result of 5G. However, the recent development of technology is rigorously progressing in terms of processing. It requires an even faster network connection to keep the synchronizations of the system, and this requirement gives rise to 6G networks. The supreme connectivity abilities of 6G inefficiency and faster bandwidth will experience virtual and augmented reality (VR/AR). The aspiration to impart at ever higher information rates will not ever stop. It is inescapable to work at ever more elevated recurrence groups to achieve each subsequent information rate at terabytes. Enormous scope receiving antenna exhibits is expected to beat the expanded way misfortune. Other spread marvels need the help of different equipment parts, including signal blenders, ADCs/DACs, and power amplifiers. The significant expense and force utilization of these segments at the mmWave and THz groups make it hard to receive traditional handset structures, thus influencing the design of signal processing algorithms. Cooperation among the equipment and algorithms domains will be required; the equipment calculation co-plan should be supported.

5.2.2. Big data 2.0

The potential for data will probably continue growing. The prime grounds behind this are the extreme increment in handheld, and internet-connected apparatus predicted to rise within an empirical purchase. SQL will continue to be the norm for information investigation, and Spark will emerge, which could emerge as the numerical instrument for information investigation. Programs such as investigation minus the current clear presence of an analyst have been put to shoot more than together with Micro Soft and sales-force both not too long ago declaring attributes permitting non-coders to generate programs for seeing data. According to IDC, all company analytics applications include intelligence needed from 2020. To put it differently, it might be explained that prescriptive analytics will soon likely probably be constructed into the business program. Apps such as Kafka and Spark will let end customers create conclusions inside real life. ML will possess a much more significant part in data prep and predictive investigation from businesses in the forthcoming times. Security and privacy challenges linked to huge statistics will rise; from 2018, 50 % of organization integrity violations will undoubtedly soon probably be associated with info. Chief info officer will probably be quite a frequent sight in most organizations in the long run though it is thought it will not continue long term. Autonomous robots and agents, autonomous cars, digital private assistants, and intelligent apparatus will undoubtedly probably soon become a vast tendency. Substantial data ability dip will certainly reduce from the forthcoming times since can be observed those times. The International Institute for Analytics forecasts that employers will probably work with internal and recruiting teaching for budding statistics boffins to receive their issues. Organizations will shortly have the ability to get calculations instead of system them and insert their data. Existing products and providers such as Algorithmia, DataXu, and also Kaggle will rise to an enormous scale; this will be, and algorithm economies will probably arise. More organizations will take to draw their earnings out of their data. The difference between comprehension and activity from big numbers can probably diminish, and much more energy will be awarded to gaining execution and insights instead of collecting big data. Speedy and technical data will probably replace colossal information. Organizations are to request the most relevant issues and make much better usage of this information, and their vast numbers are fresh nowadays.

5.2.3. WiFi 7

Lead improvements on Wi-Fi to include multi-band/multi-channel aggregation and performance and deliver increased range and electrical strength efficacy, far superior disturbance mitigations, greater power density, and greater cost-efficiency. 802.11ax, the usage of high modulation orders, proactively encouraging Aid of 320 MHz broadcasts, that is twice the 160 MHz of all 4096-QAM– upward from 1024-QAM from 802.11ax– and also the feasibility of numerous when in comparison to Wi-Fi 6, Wi-Fi 7 (or 802.11 Function as) may additionally utilize for the Wi-Fi standard. The Wi-Fi 7th generation can also be known as Wi-Fi's substantial throughput because of its estimated capacity to aid up to 30Gbps Throughput, about three times speedier than Wi-Fi 6. Additionally, there are many proposed characteristics resource components, like collections of OFMDA tones.

5.2.4. Industry 5.0

Power for running a smart city is a fundamental necessity. However, there is no detailed research on the different power sources such as nuclear, wind, hydro, and thermal energies to light up smart cities. The researchers propose a detailed comparative analysis of power sources in the coming future work. Smart cities are ways considered to be revolutionizing in technical ways, but the trends in smart cities govern some non-technical ways. The objects' art and design are some of the most highly neglected topics being reviewed by the researchers when doing literature work on smart cities. Art and design significantly impact smart cities' visualization regarding the buildings, architecture, and interior. The progress of smart cities is highly dependent on satellites for IoT and inter-connectivity around the world. However, the operational medium of the satellites is also in space outside the planet Earth. Thus, the researchers intend to conduct future research on the effects of astronomy on human-made things and how they can be more efficient for future smart cities. The need for Industry 5.0 arises when it is observed that efficiency in the workflow can be further extended to an ultimate optimum level when HCI is incorporated in industries. The robustness of smart systems in the cities also arouses threats to precious information. The research directions must be primarily sketched in cyber defense mechanisms, i.e., intrusion detection systems and intrusion prevention systems.

5.2.5. Advanced robotic systems

Next-generation software in robotics and mechatronics will demand essential, adaptive, streamlined, and significantly more economical technology. Technologies can be accessible due to the digital removal of small-level opinions controller, sensors, and cabling computers. Conventional electrical motors, for example, terminal motors and drivetrain, are not very appropriate for Boolean technology, even though, due to the fact they get intricate, cumbersome in addition to high priced. These kinds of automation were not recognized and therefore have been struck with chief topics of usability. Thus in the upcoming creation, the most current fad, the Web of stuff, will undoubtedly be utilized with those technologies and devices that we utilize inside our daily lives to do our job better with hardly any relief. Two-way communication might be said as full-duplex communication, exactly wherever the system interacts with still yet another apparatus of its work and own so. It continues to be referred to as the Web of objects and will certainly be known as an interconnection of devices or items.

5.2.6. Advanced cyber-security

Security is a fundamental requirement of every aspect of life. Thus, to enhance the security of the proposed literature, a suitable environment shall be developed to test out the loopholes in current state-of-the-art models. Furthermore, the work will be extended to assess the vulnerabilities of that critical system that are not reviewed so far. Also, it is noted that the side-channel attacks are highly neglected in the smart cities literature frameworks (Javed et al., 2021f). For this deficiency, the researchers intend first to identify the exposed systems in public that can cause a data breach. Current state-of-the-art techniques and newly devised proposed approaches shall be tested on that cybersecurity threat to testify to the strength of the approaches.

5.2.7. ECO-friendly technologies

Smart plantation and cross-product vegetation are commonly practiced techniques in farms for smart revenue. However, there is still a big room for research in making this vegetation nutritious for the residents of smart cities. Thus, the researchers also intend to conduct detailed research on the cross vegetation to envision better health for citizens of a future smart city. In medicine, the researchers intend to review the chemical compositions of medicines and study their side effects on the modern smart city inhabitants according to their activities. To make smart agriculture more robust and dynamic, the use of nanotechnology, specially IoNT devices, can play a vital role in the context of smart cities. This area has huge study requirements to make an intelligent smart environmental protection and improvement system relying on IoNT sensors data.

5.2.8. Artificial intelligence

In the AI-based modernization of smart cities, we identify additional spaces where automation can be done. For this purpose, thorough research shall be conducted to test the conventional methods, current state-of-the-art optimized techniques, and the newly envisioned proposed approaches. The future is about resiliency in ML, context awareness in ML, federated learning, federated deep reinforcement learning, explainable AI, self-supervised learning, quantum computing, context-aware natural Language Processing, transfer learning, and extended reality. Recently, federated learning has been introduced to data privacy and governance. Federated learning train models locally without exchanging data. The local models and global models are working on the same model architecture. To make work efficient, automated, and eco-friendly, electric motors and AI vast open room for research to make life smarter and healthier. In HCI, it is observed that human brain-linked technology is highly under trending research topics, but the connections of this technology are still missing in smart cities. Thus, human brain optimized and controlled automated technologies shall be reviewed in detail to make smart cities even more robust.

5.2.9. Healthcare and lifestyle

The prime purpose of smart cities is to bring comfort to human beings and efficiency in current state-of-the-art techniques and technologies available for humankind to live a better quality of life. Smart cities are initially envisioned to upgrade daily living standards for ease, efficiency, and security. The design has also become a mode of human interaction with the information, making it more engaging. The researchers intend to thoroughly review these fields to study the revolutionizing behavior of art, design, and the fashion industry. The world has been facing calamities and pandemics since the beginning of life.

Therefore, to make the smart cities more sustainable towards disastrous in-comings, an adequately devised backup mechanism should be envi-sioned to encounter uncertain circumstances. This highlights a great field of research when the recent pandemic, COVID-19, is regarded, and no such preventive mechanism had been found at the initial level. The inclusion of IoNT in H-IoT can increase the spread and depth of state-of- the-art technology-based healthcare facilities and medical tasks that were previously considered impossible before the nano-tech age. Effective design, development, and operations of such nano-sized gad-gets is a challenge that needs careful attention to make humans enjoy healthier life in future smart cities.

5.2.10. Context and situation awareness

Situational awareness is the critical intelligence within future smart city systems that can benefit endless implementation. Situational awareness is most utilizable for law enforcement and crime control. It can also help in health care facility monitoring and may act as a positive add-on for smart nursing homes and smart childcare facilities. The ac-tivity tracking, identification, and context-aware monitoring will bring in-depth changes in how many systems in the smart city interact with the city environment. Architecture, analysis, and adoption are the three A's of situational awareness techniques, which will see comprehensive research and development shortly.

5.2.11. Concept transportation

Transportation systems evolve from various perspectives, including eco-friendly characteristics, smart features, and multi-terrain maneu-vering capabilities. It intends to introduce EV systems in heavy vehicles and robust catalytic converters to maintain power while being eco-friendly in future transportation. Moreover, significant research is going on to enable road transportation systems to fly. Moreover, a new routing system for flying vehicles must be devised to maintain a uniform flow.

6. Conclusion

The concept of future smart cities is vital to improving citizens' well-being and quality of life. A smart city is a broad concept that doing in steps is more fruitful for traditional cities. However, planning based on technology to make a smart city from scratch will be a better option for designing a new city. The world is scurrying towards implementing technologies to ease the city's governance, management, control, and ease and quality of life of citizens. This paper briefly discussed re-quirements for future smart cities, application frameworks, 360-degree coverage requirements, technology challenges, and implementation strategies to make them a baseline standard for future smart cities. We reviewed the latest state-of-the-art studies and their crucial point of interest. This paper also combines the vital technologies/areas related to smart cities in a single paper to provide a way to look into the smart cities as a single system of systems instead of separate independent systems, as current research focuses on a single aspect of a smart city. This 360-degree viewing/covering of smart cities will eventually result in more research in the area while viewing the smart cities as a whole single system composed of different complex systems as mentioned in the taxonomy presented in this paper. Furthermore, we compared the proposed future smart city architecture with current state-of-the-art studies. We notice that state-of-the-art lacks in several areas of research which majorly include 6G networks, WiFi-7, industry 5.0, ro-botic systems, human well-being, HVAC, pantry backup, calamity backup that are inevitable for future smart cities. We also discussed the different technological challenges of future smart cities.

Funding Statement

The work has been partially supported by Australian Research Council under grants DP220103717, DP200101374, LP170100891, and LE220100078.

CRediT authorship contribution statement

Abdul Rehman Javed: Conceptualization, Writing – original draft, Methodology, Validation. **Faisal Shahzad:** Methodology, Writing – original draft, Visualization, Investigation. **Saif ur Rehman:** Method-ology, Data curation, Writing – original draft. **Yousaf Bin Zikria:** Su-pervision, Writing – review & editing. **Imran Razzak:** Supervision, Validation, Writing – review & editing. **Zunera Jalil:** Writing – review & editing. **Guandong Xu:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Aceleanu, M. I., Serban, A. C., Suciu, M.-C., & Bitoiu, T. I. (2019). The management of municipal waste through circular economy in the context of smart cities development. *IEEE Access, 7*, 133602–133614.

Afzal, S., Asim, M., Javed, A. R., Beg, M. O., & Baker, T. (2021). Urldeepdetect: A deep learning approach for detecting malicious urls using semantic vector models. *Journal of Network and Systems Management, 29*(3), 1–27.

Ahmad, T., Zhang, D., Huang, C., Zhang, H., Dai, N., Song, Y., & Chen, H. (2021). Artificial intelligence in sustainable energy industry: Status quo, challenges and opportunities. *Journal of Cleaner Production, 289*, Article 125834. https://doi.org/10.1016/j.jclepro.2021.125834. https://www.sciencedirect.com/science/article/pii/S0959652621000548

Ahmad, W., Rasool, A., Javed, A. R., Baker, T., & Jalil, Z. (2021). Cyber security in iot-based cloud computing: A comprehensive survey. *Electronics, 11*(1), 16.

Ahmed, S. S., Fountas, G., Eker, U., Still, S. E., & Anastasopoulos, P. C. (2021). An exploratory empirical analysis of willingness to hire and pay for flying taxis and shared flying car services. *Journal of Air Transport Management, 90*, Article 101963. https://doi.org/10.1016/j.jairtraman.2020.101963. http://www.sciencedirect.com/science/article/pii/S0969699720305469

Ahmed, S. S., Hulme, K. F., Fountas, G., Eker, U., Benedyk, I. V., Still, S. E., & Anastasopoulos, P. C. (2020). The flying car—challenges and strategies toward future adoption. *Frontiers in Built Environment, 6*, 106. https://doi.org/10.3389/fbuil.2020.00106. https://www.frontiersin.org/article/10.3389/fbuil.2020.00106

Ahmed, U., Srivastava, G., Djenouri, Y., & Lin, J. C.-W. (2022). Knowledge graph based trajectory outlier detection in sustainable smart cities. *Sustainable Cities and Society, 78*, Article 103580.

Ahmed, W., Rasool, A., Javed, A. R., Kumar, N., Gadekallu, T. R., Jalil, Z., & Kryvinska, N. (2021). Security in next generation mobile payment systems: A comprehensive survey. *IEEE Access*.

Ahmed, W., Shahzad, F., Javed, A. R., Iqbal, F., & Ali, L. (2021). Whatsapp network forensics: Discovering the ip addresses of suspects. In *2021 11th IFIP international conference on new technologies, mobility and security (NTMS)* (pp. 1–7). https://doi.org/10.1109/NTMS49979.2021.9432677

Akram, M. W., Bashir, A. K., Shamshad, S., Saleem, M. A., AlZubi, A. A., Chaudhry, S. A., Alzahrani, B. A., & Zikria, Y. B. (2021). A secure and lightweight drones-access protocol for smart city surveillance. *IEEE Transactions on Intelligent Transportation Systems*.

Al Ridhawi, I., Otoum, S., Aloqaily, M., Jararweh, Y., & Baker, T. (2020). Providing secure and reliable communication for next generation networks in smart cities. *Sustainable Cities and Society, 56*, Article 102080. https://doi.org/10.1016/j.scs.2020.102080. http://www.sciencedirect.com/science/article/pii/S2210670720300676

Alam, M. M., Malik, H., Khan, M. I., Pardy, T., Kuusik, A., & Le Moullec, Y. (2018). A survey on the roles of communication technologies in iot-based personalized healthcare applications. *IEEE Access, 6*, 36611–36631.

Alam, M. M., Malik, H., Khan, M. I., Pardy, T., Kuusik, A., & Le Moullec, Y. (2018). A survey on the roles of communication technologies in iot-based personalized healthcare applications. *IEEE Access, 6*, 36611–36631. https://doi.org/10.1109/ACCESS.2018.2853148

Alam, T., Khan, M. A., Gharaibeh, N. K., & Gharaibeh, M. K. (2021). In *Big data for smart cities: A case study of NEOM City, Saudi Arabia* (pp. 215–230). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-60922-1_11. URL doi: 10.1007/978-3-030-60922-1_11.

Alawadhi, S., & Scholl, H. J. (2016). Smart governance: A cross-case analysis of smart city initiatives. In *2016 49th Hawaii international conference on system sciences (HICSS)* (pp. 2953–2963). https://doi.org/10.1109/HICSS.2016.370

Albreem, M. A. M., El-Saleh, A. A., Isa, M., Salah, W., Jusoh, M., Azizan, M. M., & Ali, A. (2017). Green internet of things (iot): An overview. In *2017 IEEE 4th international conference on smart instrumentation, measurement and application (ICSIMA)* (pp. 1–6). https://doi.org/10.1109/ICSIMA.2017.8312021

Aldaej, A. (2019). Enhancing cyber security in modern internet of things (iot) using intrusion prevention algorithm for iot (ipai). *IEEE Access*.

Al-Garadi, M. A., Mohamed, A., Al-Ali, A. K., Du, X., Ali, I., & Guizani, M. (2020). A survey of machine and deep learning methods for internet of things (iot) security. *IEEE Communications Surveys Tutorials, 22*(3), 1646–1685. https://doi.org/10.1109/COMST.2020.2988293

Alghamdi, A., Hammad, M., Ugail, H., Abdel-Raheem, A., Muhammad, K., Khalifa, H. S., & El-Latif, A. A. A. (2020). Detection of myocardial infarction based on novel deep transfer learning methods for urban healthcare in smart cities. *Multimedia Tools and Applications*, 1–22.

Ali, R., Zikria, Y. B., Bashir, A. K., Garg, S., & Kim, H. S. (2021). Urllc for 5g and beyond: Requirements, enabling incumbent technologies and network intelligence. *IEEE Access*. https://doi.org/10.1109/ACCESS.2021.3073806, 1-1.

Ali, R., Zikria, Y. B., Garg, S., Bashir, A. K., Obaidat, M. S., & Kim, H. S. (2021). A federated reinforcement learning framework for incumbent technologies in beyond 5g networks. *IEEE Network, 35*(4), 152–159.

Ali, R., Zikria, Y. B., Kim, B.-S., & Kim, S. W. (2020). Deep reinforcement learning paradigm for dense wireless networks in smart cities. In *Smart cities performability, cognition, & security* (pp. 43–70). Springer.

Ali, T., Irfan, M., Alwadie, A. S., & Glowacz, A. (2020). Iot-based smart waste bin monitoring and municipal solid waste management system for smart cities. *Arabian Journal for Science and Engineering, 45*, 10185–10198.

Allam, Z. (2021). In *Big data, artificial intelligence and the rise of autonomous smart cities* (pp. 7–30). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-59448-0_2. URL doi:10.1007/978-3-030-59448-0_2.

Aloqaily, M., Otoum, S., Al Ridhawi, I., & Jararweh, Y. (2019). An intrusion detection system for connected vehicles in smart cities. *Ad Hoc Networks, 90*, Article 101842.

Alpaydin, E. (2020). *Introduction to machine learning*. MIT press.

Alqahtani, F., Al-Makhadmeh, Z., Tolba, A., & Said, W. (2020). Internet of things-based urban waste management system for smart cities using a cuckoo search algorithm. *Cluster Computing, 23*, 1769–1780.

Al-Turjman, F. (2020). Intelligence and security in big 5g-oriented iont: An overview. *Future Generation Computer Systems, 102*, 357–368. https://doi.org/10.1016/j.future.2019.08.009. http://www.sciencedirect.com/science/article/pii/S0167739X19301074

Andharia, J. (2020). Blurred boundaries, shared practices: Disaster studies as an emerging discipline and disaster management as a field of practice. *Disaster Studies*, 33–76.

Aqib, M., Mehmood, R., Alzahrani, A., & Katib, I. (2020). A smart disaster management system for future cities using deep learning, gpus, and in-memory computing. In *Smart infrastructure and applications* (pp. 159–184). Springer.

Ardagna, D., Cappiello, C., Samá, W., & Vitali, M. (2018). Context-aware data quality assessment for big data. *Future Generation Computer Systems, 89*, 548–562. https://doi.org/10.1016/j.future.2018.07.014. https://www.sciencedirect.com/science/article/pii/S0167739X17329151

Arumugam, C., & Shunmuganathan, S. (2021). Digital forensics: Essential competencies of cyber-forensics practitioners. In *Advances in machine learning and computational intelligence* (pp. 843–851). Springer.

Aslam, F., Aimin, W., Li, M., & Ur Rehman, K. (2020). Innovation in the era of iot and industry 5.0: Absolute innovation management (aim) framework. *Information, 11*(2), 124.

Aslam, M. S., Khan, A., Atif, A., Hassan, S. A., Mahmood, A., Qureshi, H. K., & Gidlund, M. (2020). Exploring multi-hop lora for green smart cities. *IEEE Network, 34*(2), 225–231. https://doi.org/10.1109/MNET.001.1900269

Asman, W. A. (1992). *Ammonia emission in Europa: Updated emission and emission variations, RIVM Rapport 228471008*.

Baali, H., Djelouat, H., Amira, A., & Bensaali, F. (2017). Empowering technology enabled care using iot and smart devices: A review. *IEEE Sensors Journal, 18*(5), 1790–1809.

Baig, Z. A., Szewczyk, P., Valli, C., Rabadia, P., Hannay, P., Chernyshev, M., Johnstone, M., Kerai, P., Ibrahim, A., Sansurooah, K., Syed, N., & Peacock, M. (2017). Future challenges for smart cities: Cyber-security and digital forensics. *Digital Investigation, 22*, 3–13. https://doi.org/10.1016/j.diin.2017.06.015. https://www.sciencedirect.com/science/article/pii/S1742287617300579

Baker, J. W., Schubert, M., & Faber, M. H. (2008). On the assessment of robustness. *Structural Safety, 30*(3), 253–267.

Bakioglu, G., & Atahan, A. O. (2021). Ahp integrated topsis and vikor methods with pythagorean fuzzy sets to prioritize risks in self-driving vehicles. *Applied Soft Computing, 99*, Article 106948. https://doi.org/10.1016/j.asoc.2020.106948. https://www.sciencedirect.com/science/article/pii/S1568494620308863

Banjo, S., Bolaji, B., Osagie, I., Fayomi, O., Fakehinde, O., Olayiwola, P., Oyedepo, S., & Udoye, N. (2019). Experimental analysis of the performance characteristic of an eco-friendly hc600a as a retrofitting refrigerant in a thermal system. In *, Vol. 1378. Journal of physics: conference series* (p. 042033). IOP Publishing.

Barns, S. (2018). Smart cities and urban data platforms: Designing interfaces for smart governance. URL *City, Culture and Society, 12*, 5–12. https://doi.org/10.1016/j.ccs.2017.09.006 http://www.sciencedirect.com/science/article/pii/S1877916617302047.

Basit, A., Zafar, M., Liu, X., Javed, A. R., Jalil, Z., & Kifayat, K. (2020). A comprehensive survey of ai-enabled phishing attacks detection techniques. *Telecommunication Systems*, 1–16.

Belhadi, A., Djenouri, Y., Srivastava, G., Djenouri, D., Lin, J. C.-W., & Fortino, G. (2021). Deep learning for pedestrian collective behavior analysis in smart cities: A model of group trajectory outlier detection. *Information Fusion, 65*, 13–20.

Bellalta, B., Bononi, L., Bruno, R., & Kassler, A. (2016). Next generation ieee 802.11 wireless local area networks: Current status, future directions and open challenges. *Computer Communications, 75*, 1–25. https://doi.org/10.1016/j.comcom.2015.10.007. http://www.sciencedirect.com/science/article/pii/S0140366415003874

Bénaben, F., Lauras, M., Truptil, S., & Salatgé, N. (2016). A metamodel for knowledge management in crisis management. In *2016 49th Hawaii international conference on system sciences (HICSS)* (pp. 126–135). https://doi.org/10.1109/HICSS.2016.24

Bhattacharya, S., Somayaji, S. R. K., Gadekallu, T. R., Alazab, M., & Maddikunta, P. K. R. (2020). A review on deep learning for future smart cities. *Internet Technology Letters*, Article e187.

Bhattacharya, S., Somayaji, S. R. K., Gadekallu, T. R., Alazab, M., & Maddikunta, P. K. R. (2020). A review on deep learning for future smart cities. URL *Internet Technology Letters*. , Article e187. https://doi.org/10.1002/itl2.187 https://onlinelibrary.wiley.com/doi/abs/10.1002/itl2.187.

Bibri, S. E. (2020). In *The IoT and big data analytics for smart sustainable cities: Enabling technologies and practical applications* (pp. 191–226). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-41746-8_8. URL doi:10.1007/978-3-030-41746-8_8.

Bilal, M., Usmani, R. S. A., Tayyab, M., Mahmoud, A. A., Abdalla, R. M., Marjani, M., … Hashem, I. A. T. (2020). *Smart cities data: Framework, applications, and challenges*. In (pp. 1–29). Handbook of Smart Cities.

Bondi, A. B. (2000). Characteristics of scalability and their impact on performance. In *Proceedings of the 2nd international workshop on software and performance* (pp. 195–203).

Bourguet, M.-L. (2003). Designing and prototyping multimodal commands. In *, Vol. 3. Interact* (pp. 717–720). Citeseer.

Buquerin, K. K. G., Corbett, C., & Hof, H.-J. (2021). A generalized approach to automotive forensics, forensic science international. *Digital Investigation, 36*, Article 301111.

Cao, L. (2020). *Ai in fintech: A research agenda*. arXiv:2007.12681. arXiv preprint. arXiv:2007.12681.

Cao, W., Zhang, J., Cai, C., Chen, Q., Zhao, Y., Lou, Y., Jiang, W., & Gui, G. (2021). Cnn-based intelligent safety surveillance in green iot applications. *China Communications, 18*(1), 108–119. https://doi.org/10.23919/JCC.2021.01.010

Cappa, F., Oriani, R., Peruffo, E., & McCarthy, I. (2021). Big data for creating and capturing value in the digitalized environment: Unpacking the effects of volume, variety, and veracity on firm performance. *Journal of Product Innovation Management, 38*(1), 49–67.

Cardullo, P., & Kitchin, R. (2019). Being a 'citizen'in the smart city: Up and down the scaffold of smart citizen participation in Dublin, Ireland. *GeoJournal, 84*(1), 1–13.

Chaabouni, N., Mosbah, M., Zemmari, A., Sauvignac, C., & Faruki, P. (2019). Network intrusion detection for iot security based on learning techniques. *IEEE Communications Surveys Tutorials, 21*(3), 2671–2701. https://doi.org/10.1109/COMST.2019.2896380

Chang, M.-C., Chiang, C.-K., Tsai, C.-M., Chang, Y.-K., Chiang, H.-L., Wang, Y.-A., Chang, S.-Y., Li, Y.-L., Tsai, M.-S., & Tseng, H.-Y. (2020). Ai city challenge 2020 - Computer vision for smart transportation applications. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition (CVPR) workshops*.

Chaudhari, M. S., Patil, B., & Raut, V. (2019). Iot based waste collection management system for smart cities: An overview. In *2019 3rd international conference on computing methodologies and communication (ICCMC), IEEE* (pp. 802–805).

Chaudhry, S. A., Nebhen, J., Irshad, A., Bashir, A. K., Kharel, R., Yu, K., & Zikria, Y. B. (2021). A physical capture resistant authentication scheme for the internet of drones. *IEEE Communications Standards Magazine, 5*(4), 62–67.

Chaudhry, S. A., Yahya, K., Garg, S., Kaddoum, G., Hassan, M., & Zikria, Y. B. (2022). Las-sg: An elliptic curve based lightweight authentication scheme for smart grid environments. *IEEE Transactions on Industrial Informatics*.

Chaudhry, S. A., Yahya, K., Karuppiah, M., Kharel, R., Bashir, A. K., & Zikria, Y. B. (2021). Gcacs-iod: A certificate based generic access control scheme for internet of drones. *Computer Networks, 191*, Article 107999. https://doi.org/10.1016/j.comnet.2021.107999. https://www.sciencedirect.com/science/article/pii/S1389128621001195

Chaudhuri, A. (2021). Transformation with trustworthy digital: Policy desiderata for businesses in post covid-19 world. *EDPACS, 63*(1), 1–8.

Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M., & Yin, B. (2018). Smart factory of industry 4.0: Key technologies, application case, and challenges. *IEEE Access, 6*, 6505–6519. https://doi.org/10.1109/ACCESS.2017.2783682

Chen, C., Li, K., Ouyang, A., Zeng, Z., & Li, K. (2018). Gflink: An in-memory computing architecture on heterogeneous cpu-gpu clusters for big data. *IEEE Transactions on Parallel and Distributed Systems, 29*(6), 1275–1288.

Chen, D., Wawrzynski, P., & Lv, Z. (2020). Cyber security in smart cities: A review of deep learning-based applications and case studies. *Sustainable Cities and Society*, Article 102655.

Chen, N., Wang, M., Zhang, N., & Shen, X. (2020). Energy and information management of electric vehicular network: A survey. *IEEE Communications Surveys Tutorials, 22*(2), 967–997. https://doi.org/10.1109/COMST.2020.2982118

Chen, Q., Wang, L., Chen, P., & Chen, G. (2019). Optimization of component elements in integrated coding systems for green communications: A survey. *IEEE Communications Surveys Tutorials, 21*(3), 2977–2999. https://doi.org/10.1109/COMST.2019.2894154

Chen, X., Eder, M. A., Shihavuddin, A., & Zheng, D. (2021). A human-cyber-physical system toward intelligent wind turbine operation and maintenance. *Sustainability, 13*(2). https://doi.org/10.3390/su13020561. https://www.mdpi.com/2071-1050/13/2/561

Chen, Y., Zou, X., Li, K., Li, K., Yang, X., & Chen, C. (2021). Multiple local 3d cnns for region-based prediction in smart cities. *Information Sciences, 542*, 476–491.

Chithaluru, P., Al-Turjman, F., Kumar, M., & Stephan, T. (2020). I-areor: An energy-balanced clustering protocol for implementing green iot in smart cities. *Sustainable Cities and Society, 102254*.

Choi, W., Kim, J., Lee, S., & Park, E. (2021). Smart home and internet of things: A bibliometric study. *Journal of Cleaner Production, 301*, Article 126908.

Corporation, I. D.. Worldwide wearables market forecast to maintain double-digit growth in 2020 and through 2024, according to idc. URL https://www.idc.com/getdoc.jsp?containerId=prUS46885820.

Cowley, R., Joss, S., & Dayot, Y. (2018). The smart city and its publics: insights from across six uk cities. *Urban Research & Practice, 11*(1), 53–77. https://doi.org/10.1080/17535069.2017.1293150. arXiv:doi:10.1080/17535069.2017.1293150, doi:10.1080/17535069.2017.1293150. URL.

Curtis, A., Küppers, B., Möllnitz, S., Khodier, K., & Sarc, R. (2021). Real time material flow monitoring in mechanical waste processing and the relevance of fluctuations. *Waste Management, 120*, 687–697. https://doi.org/10.1016/j.wasman.2020.10.037. https://www.sciencedirect.com/science/article/pii/S0956053X20306085

Dahir, A. L. (2020). 'instead of coronavirus, the hunger will kill us'.A global food crisis looms. *The New York Times, 22*.

Datta, A. (2018). The digital turn in postcolonial urbanism: Smart citizenship in the making of india's 100 smart cities. URL *Transactions of the Institute of British Geographers, 43*(3), 405–419. https://doi.org/10.1111/tran.12225 https://rgs-ibg.onlinelibrary.wiley.com/doi/abs/10.1111/tran.12225.

de Haan, F., & Butot, V. (2021). In *Finding safety in the smart city: A discourse analysis with strategic implications* (pp. 225–242). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-42523-4_16. URL doi:10.1007/978-3-030-42523-4_16.

Dong, S., Esmalian, A., Farahmand, H., & Mostafavi, A. (2020). An integrated physical-social analysis of disrupted access to critical facilities and community service-loss tolerance in urban flooding. URL *Computers, Environment and Urban Systems*.

Dowling, R., McGuirk, P., & Gillon, C. (2019). Strategic or piecemeal? Smart city initiatives in Sydney and Melbourne. *Urban Policy and Research, 37*(4), 429–441. https://doi.org/10.1080/08111146.2019.1674647. arXiv:doi:10.1080/08111146.2019.1674647, doi:10.1080/08111146.2019.1674647. URL.

Ecclestone, B. R., Bell, K., Abbasi, S., Dinakaran, D., Taher, M., Mackey, J. R., & Reza, P. H. (2021). Histopathology for mohs micrographic surgery with photoacoustic remote sensing microscopy. *Biomedical Optics Express, 12*(1), 654–665. https://doi.org/10.1364/BOE.405869. http://www.osapublishing.org/boe/abstract.cfm?URI=boe-12-1-654

Ejaz, W., & Anpalagan, A. (2019). Internet of things enabled electric vehicles in smart cities. In *Internet of things for smart cities* (pp. 39–46). Springer.

ElFar, O. A., Chang, C.-K., Leong, H. Y., Peter, A. P., Chew, K. W., & Show, P. L. (2020). Prospects of industry 5.0 in algae: Customization of production and new advance technology for clean bioenergy generation. *Energy Conversion and Management: X*, Article 100048.

Elsaeidy, A. A., Jagannath, N., Sanchis, A. G., Jamalipour, A., & Munasinghe, K. S. (2020). Replay attack detection in smart cities using deep learning. *IEEE Access, 8*, 137825–137837.

Fagbola, F. I., & Venter, H. (2022). Smart digital forensic readiness model for shadow iot devices. *Applied Sciences, 12*(2), 730.

Fan, C., Zhang, C., Yahja, A., & Mostafavi, A. (2021). Disaster city digital twin: A vision for integrating artificial and human intelligence for disaster management. *International Journal of Information Management, 56*, Article 102049.

Fard, S. M. H., Karimimpour, H., Dehghantanha, A., Jahromi, A. N., & Srivastava, G. (2020). Ensemble sparse representation-based cyber threat hunting for security of smart cities. *Computers & Electrical Engineering, 88*, Article 106825.

Fayyaz, M., Farhan, A. A., & Javed, A. R. (2021). Thermal comfort model for hvac buildings using machine learning. *Arabian Journal for Science and Engineering*, 1–16.

FEIBUSTech, Q. T.. Wi-fi 6 industry impact report. URL https://www.qualcomm.com/media/documents/files/wi-fi-6-industry-impact-report.pdf.

Fernandez, J.-C., Mounier, L., & Pachon, C. (2005). A model-based approach for robustness testing. URL. In *IFIP international conference on testing of communicating systems* (pp. 333–348). Springer.

Fernandez-Anez, V., Fernández-Güell, J. M., & Giffinger, R. (2018). Smart city implementation and discourses: An integrated conceptual model. The case of Vienna. *Cities, 78*, 4–16. https://doi.org/10.1016/j.cities.2017.12.004. http://www.sciencedirect.com/science/article/pii/S0264275117306558

Ferrag, M. A., Maglaras, L., Moschoyiannis, S., & Janicke, H. (2020). Deep learning for cyber security intrusion detection: Approaches, datasets, and comparative study. *Journal of Information Security and Applications, 50*, Article 102419.

Ferrag, M. A., Shu, L., Yang, X., Derhab, A., & Maglaras, L. (2020). Security and privacy for green iot-based agriculture: Review, blockchain solutions, and challenges. *IEEE Access, 8*, 32031–32053. https://doi.org/10.1109/ACCESS.2020.2973178

Ferrara, A., Jakubek, S., & Hametner, C. (2021). Energy management of heavy-duty fuel cell vehicles in real-world driving scenarios: Robust design of strategies to maximize the hydrogen economy and system lifetime. *Energy Conversion and Management*, Article 113795.

Finogeev, A. E. A. (2019). Intelligent monitoring system for smart road environment. *Journal of Industrial Information Integration, 15*, 15–20.

Garca-Sanz-Calcedo, J., de Sousa Neves, N., & Fernandes, J. P. A. (2020). Measurement of embodied carbon and energy of hvac facilities in healthcare centers. *Journal of Cleaner Production*, Article 125151.

Garg, A., Mittal, N., et al. (2020). A security and confidentiality survey in wireless internet of things (iot). In *Internet of things and big data applications* (pp. 65–88). Springer.

Gavrilović, N., & Mishra, A. (2020). Software architecture of the internet of things (iot) for smart city, healthcare and agriculture: Analysis and improvement directions. *Journal of Ambient Intelligence and Humanized Computing*, 1–22.

Ghose, B., & Rehena, Z. (2021). A deep learning approach for predicting air pollution in smart cities. URL. In *Computational intelligence and machine learning* (pp. 29–38). Springer.

Goh, G., Sing, S., & Yeong, W. (2021). A review on machine learning in 3d printing: Applications, potential, and challenges. *Artificial Intelligence Review, 54*(1), 63–94.

Gonzalez, G. T., Kaur, U., Rahman, M., Venkatesh, V., Sanchez, N., Hager, G., Xue, Y., Voyles, R., & Wachs, J. (2021). From the dexterous surgical skill to the battlefield—a robotics exploratory study. *Military Medicine, 186*(Supplement_1), 288–294.

Govada, S. S., Rodgers, T., Cheng, L., & Chung, H. (2020). Smart environment for smart and sustainable hong kong. arXiv:2007.12681. In *Smart environment for Smart Cities* (pp. 57–90). Springer. arXiv:2007.12681.

Govindan, K., Shankar, K. M., & Kannan, D. (2020). Achieving sustainable development goals through identifying and analyzing barriers to industrial sharing economy: A framework development. *International Journal of Production Economics, 227*, Article 107575. https://doi.org/10.1016/j.ijpe.2019.107575. https://www.sciencedirect.com/science/article/pii/S0925527319304177

Guo, Y., Zhang, B., Sun, Y., Jiang, K., & Wu, K. (2021). Machine learning based feature selection and knowledge reasoning for cbr system under big data. *Pattern Recognition, 112*, Article 107805.

Gupta, M., Abdelsalam, M., Khorsandroo, S., & Mittal, S. (2020). Security and privacy in smart farming: Challenges and opportunities. *IEEE Access, 8*, 34564–34584. https://doi.org/10.1109/ACCESS.2020.2975142

Gupta, S., & Sundar, B. (2020). A computer vision based approach for automated traffic management as a smart city solution. In *2020 IEEE international conference on electronics, computing and communication technologies (CONECCT)* (pp. 1–6). https://doi.org/10.1109/CONECCT50063.2020.9198588

Gyawali, S., Xu, S., Qian, Y., & Hu, R. Q. (2021). Challenges and solutions for cellular based v2x communications. *IEEE Communications Surveys & Tutorials, 23*(1), 222–255. https://doi.org/10.1109/COMST.2020.3029723

Habibi, M. A., Nasimi, M., Han, B., & Schotten, H. D. (2019). A comprehensive survey of ran architectures toward 5g mobile communication system. *IEEE Access, 7*, 70371–70421.

Hajjaji, Y., Boulila, W., Farah, I. R., Romdhani, I., & Hussain, A. (2021). Big data and iot-based applications in smart environments: A systematic review. *Computer Science Review, 39*, Article 100318.

Hamad, S. A., Sheng, Q. Z., Zhang, W. E., & Nepal, S. (2020). Realizing an internet of secure things: A survey on issues and enabling technologies. *IEEE Communications Surveys Tutorials, 22*(2), 1372–1391. https://doi.org/10.1109/COMST.2020.2976075

Han, B., Jiang, W., Habibi, M. A., & Schotten, H. D. (2021). *An abstracted survey on 6g: Drivers, requirements, efforts, and enablers*. arXiv:2101.01062.

Han, H., Hsu, L.-T. J., Lee, J.-S., & Sheu, C. (2011). Are lodging customers ready to go green? An examination of attitudes, demographics, and eco-friendly intentions. *International Journal of Hospitality Management, 30*(2), 345–355.

Han, M. J. N., & Kim, M. J. (2021). A critical review of the smart city in relation to citizen adoption towards sustainable smart living. URL *Habitat International, 108*, Article 102312. https://doi.org/10.1016/j.habitatint.2021.102312 https://www.sciencedirect.com/science/article/pii/S0197397521000011.

Haque, A. B., Bhushan, B., & Dhiman, G. (2021). Conceptualizing smart city applications: Requirements, architecture, security issues, and emerging trends. *Expert Systems*.

Hashem, I. A. T., Ezugwu, A. E., Al-Garadi, M. A., Abdullahi, I. N., Otegbeye, O., Ahman, Q. O., Mbah, G. C., Shukla, A. K., & Chiroma, H. (2020). *A machine learning solution framework for combatting covid-19 in smart cities from multiple dimensions*. medRxiv. arXiv:doi:10.1080/00207543.2017.1326643, doi:10.1080/00207543.2017.1326643. URL.

Hassan, M. A., Javed, A. R., Hassan, T., Band, S. S., Sitharthan, R., & Rizwan, M. (2022). Reinforcing communication on the internet of aerial vehicles. *IEEE Transactions on Green Communications and Networking*.

Helmold, M. (2020). Total revenue management (trm). In *Total Revenue Management (TRM)* (pp. 1–12). Springer.

Hill, M. D. (1990). What is scalability? *ACM SIGARCH Computer Architecture News, 18*(4), 18–21.

Hu, B., Feng, Y., Sun, J., Gao, Y., & Tan, J. (2019). Driving preference analysis and electricity pricing strategy comparison for electric vehicles in smart city. *Information Sciences, 504*, 202–220.

Hu, Y., Yang, A., Li, H., Yuyan, S., & Sun, L. (2018). On smart city and safe city concepts : A survey of intrusion detection on industrial control systems. *International Journal of Distributed Sensor Networks, 14*(8), 836–845. https://doi.org/10.1177/1550147718794615. https://journals.sagepub.com/doi/abs/10.1177/1550147718794615

Huang, K., Subedi, D., Mitra, R., Yung, I., Boyd, K., Aldrich, E., & Chitrakar, D. (2021). Telelocomotion—remotely operated legged robots. *Applied Sciences, 11*(1), 194.

Hussain, R., & Zeadally, S. (2019). Autonomous cars: Research results, issues, and future challenges. *IEEE Communications Surveys Tutorials, 21*(2), 1275–1313. https://doi.org/10.1109/COMST.2018.2869360

I. E. A. (IEA). Global demand for pure hydrogen, 1975-2018. URL https://www.iea.org/data-and-statistics/charts/global-demand-for-pure-hydrogen-1975-2018.

I. L.A. (2017). Digital business model and smart economy sectoral development trajectories substantiation. Jun. In *, Vol. 10531. Internet of things, smart spaces, and next generation networks and systems* (pp. 13–28). Springer International Publishing. https://doi.org/10.1007/978-3-319-67380-6_2. URL doi:10.1145/3057266.

Idwan, S., Mahmood, I., Zubairi, J. A., & Matar, I. (2020). Optimal management of solid waste in smart cities using internet of things. *Wireless Personal Communications, 110* (1), 485–501.
Imtiaz, S. I., Rehman, S. U., Javed, A. R., Jalil, Z., Liu, X., & Alnumay, W. S. (2020). Deepamd: Detection and identification of android malware using high-efficient deep artificial neural network. *Future Generation Computer Systems, 115*, 844–856.
Iqbal, A., & Al-Ghamdi, K. A. (2018). Energy-efficient cellular manufacturing system: Eco-friendly revamping of machine shop configuration. *Energy, 163*, 863–872.
Irshad, A., Chaudhry, S. A., Alazab, M., Kanwal, A., Zia, M. S., & Zikria, Y. B. (2021). A secure demand response management authentication scheme for smart grid. *Sustainable Energy Technologies and Assessments, 48*, Article 101571.
Iskandaryan, D., Ramos, F., & Trilles, S. (2020). Air quality prediction in smart cities using machine learning technologies based on sensor data: A review. *Applied Sciences, 10*(7), 2401.
Ismagilova, E., Hughes, L., Rana, N. P., & Dwivedi, Y. K. (2020). Security, privacy and risks within smart cities: Literature review and development of a smart city interaction framework. *Information Systems Frontiers*, 1–22.
ISO/IEC. Iso/iec 30182:2017(en) smart city concept model — guidance for establishing a model for data interoperability. https://www.iso.org/obp/ui#iso:std:iso-iec:30182:ed-1:v1:en. URL doi:10.1007/978-3-030-59448-0_2.
Issac, T., Silas, S., & Rajsingh, E. B. (2020). Dynamic and static system modeling with simulation of an eco-friendly smart lighting system. In *Systems simulation and modeling for cloud computing and big data applications* (pp. 81–97). Elsevier.
Iwendi, C., Jalil, Z., Javed, A. R., Reddy, T., Kaluri, R., Srivastava, G., & Jo, O. (2020). Keysplitwatermark: Zero watermarking algorithm for software protection against cyber-attacks. *IEEE Access, 8*, 72650–72660.
Janarthanan, T., Bagheri, M., & Zargari, S. (2021). Iot forensics: An overview of the current issues and challenges, digital forensic investigation of internet of things (IoT). *Devices*, 223–254.
Javadzadeh, G., & Rahmani, A. M. (2020). Fog computing applications in smart cities: A systematic survey. *Wireless Networks, 26*(2), 1433–1457.
Javed, A. R., Abid, R., Aslam, B., Khalid, H. A., Khan, M. Z., Alhazmi, O. H., & Rizwan, M. (2021). Green5g: Enhancing capacity and coverage in device-to-device communication. *CMC*.
Javed, A. R., Beg, M. O., Asim, M., Baker, T., & Al-Bayatti, A. H. (2020). Alphalogger: Detecting motion-based side-channel attack using smartphone keystrokes. *Journal of Ambient Intelligence and Humanized Computing*, 1–14.
Javed, A. R., Fahad, L. G., Farhan, A. A., Abbas, S., Srivastava, G., Parizi, R. M., & Khan, M. S. (2021). Automated cognitive health assessment in smart homes using machine learning. *Sustainable Cities and Society, 65*, Article 102572.
Javed, A. R., Faheem, R., Asim, M., Baker, T., & Beg, M. O. (2021). A smartphone sensors-based personalized human activity recognition system for sustainable smart cities. *Sustainable Cities and Society, 71*, Article 102970.
Javed, A. R., & Jalil, Z. (2020). Byte-level object identification for forensic investigation of digital images. In *2020 International conference on cyber warfare and security (ICCWS), IEEE* (pp. 1–4).
Javed, A. R., Jalil, Z., Zehra, W., Gadekallu, T. R., Suh, D. Y., & Piran, M. J. (2021). A comprehensive survey on digital video forensics: Taxonomy, challenges, and future directions. *Engineering Applications of Artificial Intelligence, 106*, Article 104456.
Javed, A. R., Rehman, S. U., Khan, M. U., Alazab, M., & Khan, H. U. (2021). Betalogger: Smartphone sensor-based side-channel attack detection and text inference using language modeling and dense multilayer neural network. *Transactions on Asian and Low-Resource Language Information Processing, 20*(5), 1–17.
Javed, A. R., Sarwar, M. U., Beg, M. O., Asim, M., Baker, T., & Tawfik, H. (2020). A collaborative healthcare framework for shared healthcare plan with ambient intelligence. *Human-centric Computing and Information Sciences, 10*(1), 1–21.
Javed, A. R., Sarwar, M. U., Khan, H. U., Al-Otaibi, Y. D., Alnumay, W. S., et al. (2021). Pp-spa: Privacy preserved smartphone-based personal assistant to improve routine life functioning of cognitive impaired individuals. *Neural Processing Letters*, 1–18.
Javed, A. R., Sarwar, M. U., Khan, S., Iwendi, C., Mittal, M., & Kumar, N. (2020). Analyzing the effectiveness and contribution of each axis of tri-axial accelerometer sensor for accurate activity recognition. *Sensors, 20*(8), 2216.
Javed, A. R., Usman, M., Rehman, S. U., Khan, M. U., & Haghighi, M. S. (2020). Anomaly detection in automated vehicles using multistage attention-based convolutional neural network. *IEEE Transactions on Intelligent Transportation Systems*, 4291–4300.
Jeong, Y.-S., & Park, J. H. (2020). Security, privacy, and efficiency of sustainable computing for future smart cities. *Journal of Information Processing Systems, 16*, 1–5.
Ji, T., Chen, J.-H., Wei, H.-H., & Su, Y.-C. (2021). Towards people-centric smart city development: Investigating the citizens' preferences and perceptions about smart-city services in Taiwan. *Sustainable Cities and Society, 67*, Article 102691. https://doi.org/10.1016/j.scs.2020.102691. https://www.sciencedirect.com/science/article/pii/S2210670720309069
Jiang, H. (2020). Smart urban governance in the 'smart' era: Why is it urgently needed? *Cities.* , Article 103004. https://doi.org/10.1016/j.cities.2020.103004. http://www.sciencedirect.com/science/article/pii/S0264275120313524
Joss, S., Sengers, F., Schraven, D., Caprotti, F., & Dayot, Y. (2019). The smart city as global discourse: Storylines and critical junctures across 27 cities. *Journal of Urban Technology, 26*(1), 3–34. https://doi.org/10.1080/10630732.2018.1558387. arXiv: doi:10.1080/10630732.2018.1558387, doi:10.1080/10630732.2018.1558387. URL.
K. D, Harshavardhan, A., Kumar, V. M., Sunitha, D., & Korra, S. N. (2021). Ble in iot: Improved link stability and energy conservation using fuzzy approach for smart homes automation. URL *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.12.378 https://www.sciencedirect.com/science/article/pii/S221478532040094X.
Kamble, S. S., Gunasekaran, A., Ghadge, A., & Raut, R. (2020). A performance measurement system for industry 4.0 enabled smart manufacturing system in smmes- a review and empirical investigation. *International Journal of Production Economics, 229*, Article 107853. https://doi.org/10.1016/j.ijpe.2020.107853. http://www.sciencedirect.com/science/article/pii/S0925527320302176
Karvonen, A., Cugurullo, F., & Caprotti, F. (2019). *Inside Smart Cities : Place, politics and urban innovation*. Taylor & Francis Group.
Kebande, V. R., Karie, N. M., Choo, K.-K. R., & Alawadi, S. (2021). Digital forensic readiness intelligence crime repository. *Security and Privacy, 4*(3), Article e151.
Kettebekov, S., & Sharma, R. (2001). Toward natural gesture/speech control of a large display. In *IFIP international conference on engineering for human-computer interaction* (pp. 221–234). Springer.
Khalil, E. E. (2021). 12 - distributed energy in smart cities and the infrastructure. arXiv: 2007.12681. In J. R. Vacca (Ed.), *Solving urban infrastructure problems using smart city technologies* (pp. 249–268). Elsevier. https://doi.org/10.1016/B978-0-12-816816-5.00012-7. arXiv:2007.12681 https://www.sciencedirect.com/science/article/pii/B9780128168165000127.
Khan, L. U., Yaqoob, I., Tran, N. H., Kazmi, S. A., Dang, T. N., & Hong, C. S. (2020). Edge computing enabled smart cities: A comprehensive survey. *IEEE Internet of Things Journal*.
Khan, M. U., Javed, A. R., Ihsan, M., & Tariq, U. (2020). A novel category detection of social media reviews in the restaurant industry. *Multimedia Systems*, 1–14.
Khan, R., Kumar, P., Jayakody, D. N. K., & Liyanage, M. (2020). A survey on security and privacy of 5g technologies: Potential solutions, recent advancements, and future directions. *IEEE Communications Surveys & Tutorials, 22*(1), 196–248. https://doi.org/10.1109/COMST.2019.2933899
Khan, S., Nazir, S., & Anwar, H. (2021). Deep learning-based urban big data fusion in smart cities: Towards traffic monitoring and flow-preserving fusion. *Computers & Electrical Engineering, 89*, Article 106906.
Khorov, E., Levitsky, I., & Akyildiz, I. F. (2020). Current status and directions of ieee 802.11be, the future wi-fi7. *IEEE Access, 8*, 88664–88688. https://doi.org/10.1109/ACCESS.2020.2993448
Kim, H., & Ben-Othman, J. (2020). Toward integrated virtual emotion system with ai applicability for secure cps-enabled smart cities: Ai-based research challenges and security issues. *IEEE Network, 34*(3), 30–36.
Kim, H., Choi, H., Kang, H., An, J., Yeom, S., & Hong, T. (2021). A systematic review of the smart energy conservation system: From smart homes to sustainable smart cities. *Renewable and Sustainable Energy Reviews, 140*, Article 110755.
Kim, M. J., & Jun, H. J. (2021). Towards a sustainable life: Smart and green design in buildings and community. *Sustainability, 13*(3). https://doi.org/10.3390/su13031022. https://www.mdpi.com/2071-1050/13/3/1022
Kim, S., Jo, W., Lee, J., & Shon, T. (2022). Ai-enabled device digital forensics for smart cities. *The Journal of Supercomputing, 78*(2), 3029–3044.
Kiran, D., Sharma, I., & Garg, I. (2020). Industry 5.0 and smart cities: A futuristic approach. *European Journal of Molecular & Clinical Medicine, 7*(8), 2750–2756.
Kirimtat, A., Krejcar, O., Kertesz, A., & Tasgetiren, M. F. (2020). Future trends and current state of smart city concepts: A survey. *IEEE Access, 8*, 86448–86467.
Kitchin, R., & Dodge, M. (2019). The (in)security of smart cities: Vulnerabilities, risks, mitigation, and prevention. *Journal of Urban Technology, 26*(2), 47–65. https://doi.org/10.1080/10630732.2017.1408002. arXiv:doi:10.1080/10630732.2017.1408002, doi:10.1080/10630732.2017.1408002. URL.
Knowles, B., Bates, O., & Håkansson, M. (2018). This changes sustainable hci. In *Proceedings of the 2018 CHI conference on human factors in computing systems* (pp. 1–12).
Konstantinou, C. (2021). Towards a secure and resilient all-renewable energy grid for smart cities. *IEEE Consumer Electronics Magazine*. https://doi.org/10.1109/MCE.2021.3055492, 1-1.
Kowalkiewicz, M., & Dootson, P. (2019). *Government 5.0: the future of public services*. URL. Australia: The Chair in Digital Economy https://eprints.qut.edu.au/133743/.
Kowalkiewicz, M., Rosemann, M., & Dootson, P. (2017). *Retail 5.0: Check-out the future*. URL. Australia: PwC Chair in Digital Economy https://eprints.qut.edu.au/110377/.
Krishna, K. R. (2021). *Aerial robotics in agriculture: Parafoils, blimps, aerostats, and kites*. CRC Press.
Kulkarni, P., & Akhilesh, K. (2020). Big data analytics as an enabler in smart governance for the future smart cities. In *Smart technologies* (pp. 53–65). Springer.
Kumar, P., Gupta, G. P., & Tripathi, R. (2020). Tp2sf: A trustworthy privacy-preserving secured framework for sustainable smart cities by leveraging blockchain and machine learning. *Journal of Systems Architecture*, Article 101954.
Kumar, S., Yadav, D., Gupta, H., Verma, O. P., Ansari, I. A., & Ahn, C. W. (2021). A novel yolov3 algorithm-based deep learning approach for waste segregation: Towards smart waste management. *Electronics, 10*(1). https://doi.org/10.3390/electronics10010014. https://www.mdpi.com/2079-9292/10/1/14
Kumar, T. M. V., & Dahiya, B. (2017). In *Smart economy in smart cities* (pp. 3–76). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-10-1610-3_1. URL doi:10.1007/978-981-10-1610-3_1.
Kumaran, K. M., & Chinnadurai, M. (2020). Cloud-based robotic system for crowd control in smart cities using hybrid intelligent generic algorithm. *Journal of Ambient Intelligence and Humanized Computing*, 1–14.
Lai, C. S., Jia, Y., Dong, Z., Wang, D., Tao, Y., Lai, Q. H., Wong, R. T., Zobaa, A. F., Wu, R., & Lai, L. L. (2020). A review of technical standards for smart cities. *Clean Technologies, 2*(3), 290–310.
Lai, C. S., Lai, L. L., & Lai, Q. H. (2021). In *Smart City* (pp. 1–171). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-52155-4_1.
Laroui, M., Dridi, A., Afifi, H., Moungla, H., Marot, M., & Cherif, M. A. (2019). Energy management for electric vehicles in smart cities: A deep learning approach. In *2019*

15th International Wireless Communications & Mobile Computing Conference (IWCMC), IEEE (pp. 2080–2085).
Latham, J. (2021). The myth of a food crisis. In *Rethinking food and agriculture* (pp. 93–111). Elsevier.
Latifi, R., Dong, X. D., Abouezzi, Z., Kaul, A., Caine, A., Bergamaschi, R., … Gandhi, C. D. (2021). In *Surgical telementoring and teleproctoring* (pp. 431–453). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-56917-4_27. URL doi: 10.1007/978-3-030-56917-4_27.
Laudante, G., Musone, V., Rak, M., Venticinque, S., & Salzillo, G. (2020). A cloud-edge smart infrastructures for road safety. In *2020 IEEE 20th Mediterranean electrotechnical conference (MELECON)* (pp. 147–152). https://doi.org/10.1109/MELECON48756.2020.9140506
Lee, J., Lee, Y. C., & Kim, J. T. (2021). Migration from the traditional to the smart factory in the die-casting industry: Novel process data acquisition and fault detection based on artificial neural network. *Journal of Materials Processing Technology, 290*, Article 116972. https://doi.org/10.1016/j.jmatprotec.2020.116972. https://www.sciencedirect.com/science/article/pii/S0924013620303939
Li, D., Deng, L., Lee, M., & Wang, H. (2019). Iot data feature extraction and intrusion detection system for smart cities based on deep migration learning. *International Journal of Information Management, 49*, 533–545.
Li, M., Lal, C., Conti, M., & Hu, D. (2021). Lechain: A blockchain-based lawful evidence management scheme for digital forensics. *Future Generation Computer Systems, 115*, 406–420. https://doi.org/10.1016/j.future.2020.09.038. https://www.sciencedirect.com/science/article/pii/S0167739X1933167X
Li, W., Koo, C., Hong, T., Oh, J., Cha, S. H., & Wang, S. (2020). A novel operation approach for the energy efficiency improvement of the hvac system in office spaces through real-time big data analytics. *Renewable and Sustainable Energy Reviews, 127*, Article 109885.
Lian, Z., Wang, W., Huang, H., & Su, C. (2022). Layer-based communication-efficient federated learning with privacy preservation. *IEICE Transactions on Information and Systems, 105*(2), 256–263.
Liu, C., Li, K., Li, K., & Buyya, R. (2017). A new service mechanism for profit optimizations of a cloud provider and its users. *IEEE Transactions on Cloud Computing, 9*(1), 14–26.
Liu, C., Li, K., Tang, Z., & Li, K. (2018). Bargaining game-based scheduling for performance guarantees in cloud computing. *ACM Transactions on Modeling and Performance Evaluation of Computing Systems (TOMPECS), 3*(1), 1–25.
Liu, D., Zhang, Y., Wang, W., Dev, K., & Khowaja, S. A. (2021). Flexible data integrity checking with original data recovery in iot-enabled maritime transportation systems. *IEEE Transactions on Intelligent Transportation Systems*.
Liu, X., & Ansari, N. (2019). Toward green iot: Energy solutions and key challenges. *IEEE Communications Magazine, 57*(3), 104–110. https://doi.org/10.1109/MCOM.2019.1800175
Liu, X., Reddi, K., Elgowainy, A., Lohse-Busch, H., Wang, M., & Rustagi, N. (2020). Comparison of well-to-wheels energy use and emissions of a hydrogen fuel cell electric vehicle relative to a conventional gasoline-powered internal combustion engine vehicle. *International Journal of Hydrogen Energy, 45*(1), 972–983.
Liu, Y. (2018). The application of human-computer interaction in smart city planning and design. In *International conference of design, user experience, and usability* (pp. 101–111). Springer.
Liu, Y., Yang, C., Jiang, L., Xie, S., & Zhang, Y. (2019). Intelligent edge computing for iot-based energy management in smart cities. *IEEE Network, 33*(2), 111–117. https://doi.org/10.1109/MNET.2019.1800254
Losavio, M. M., Chow, K. P., Koltay, A., & James, J. (2018). The internet of things and the smart city: Legal challenges with digital forensics, privacy, and security. *Security and Privacy, 1*(3), Article e23. https://doi.org/10.1002/spy2.23. https://onlinelibrary.wiley.com/doi/abs/10.1002/spy2.23
Luong, N. C., Hoang, D. T., Gong, S., Niyato, D., Wang, P., Liang, Y., & Kim, D. I. (2019). Applications of deep reinforcement learning in communications and networking: A survey. *IEEE Communications Surveys Tutorials, 21*(4), 3133–3174. https://doi.org/10.1109/COMST.2019.2916583
Macrorie, R., Marvin, S., & While, A. (2019). Robotics and automation in the city: a research agenda. *Urban Geography, 0*(0), 1–21. https://doi.org/10.1080/02723638.2019.1698868. arXiv:doi:10.1080/02723638.2019.1698868, doi: 10.1080/02723638.2019.1698868. URL.
Magaia, N., Fonseca, R., Muhammad, K., Segundo, A. H. F. N., Neto, A. V. L., & de Albuquerque, V. H. C. (2020). Industrial internet of things security enhanced with deep learning approaches for smart cities. *IEEE Internet of Things Journal*.
Mahmood, I., & Zubairi, J. A. (2019). Efficient waste transportation and recycling: Enabling technologies for smart cities using the internet of things. *IEEE Electrification Magazine, 7*(3), 33–43.
Majid, M., Habib, S., Javed, A. R., Rizwan, M., Srivastava, G., Gadekallu, T. R., & Lin, J. C.-W. (2022). Applications of wireless sensor networks and internet of things frameworks in the industry revolution 4.0: A systematic literature review. *Sensors, 22*(6), 2087.
Malek, J. A., Lim, S. B., & Yigitcanlar, T. (2021). Social inclusion indicators for building citizen-centric smart cities: A systematic literature review. *Sustainability, 13*(1). https://doi.org/10.3390/su13010376. https://www.mdpi.com/2071-1050/13/1/376
Mamchenko, M., Ananyev, P., Kontsevoy, A., Plotnikova, A., & Gromov, Y. (2021). The concept of robotics complex for transporting special equipment to emergency zones and evacuating wounded people. In *Proceedings of 15th international conference on electromechanics and robotics" Zavalishin's readings"* (pp. 211–223). Springer.
Manogaran, G., Varatharajan, R., Lopez, D., Kumar, P. M., Sundarasekar, R., & Thota, C. (2018). A new architecture of internet of things and big data ecosystem for secured smart healthcare monitoring and alerting system. *Future Generation Computer Systems, 82*, 375–387. https://doi.org/10.1016/j.future.2017.10.045. http://www.sciencedirect.com/science/article/pii/S0167739X17305149
Marchetti, A., Dio, C. D., Manzi, F., & Massaro, D. (2022). Robotics in clinical and developmental psychology. In *Reference module in neuroscience and biobehavioral psychology*.
Mazumdar, S., Seybold, D., Kritikos, K., & Verginadis, Y. (2019). A survey on data storage and placement methodologies for cloud-big data ecosystem. *Journal of Big Data, 6*(1), 1–37.
Mei, J., Li, K., Tong, Z., Li, Q., & Li, K. (2018). Profit maximization for cloud brokers in cloud computing. *IEEE Transactions on Parallel and Distributed Systems, 30*(1), 190–203.
Mingaleva, Z., Vukovic, N., Volkova, I., & Salimova, T. (2020). Waste management in green and smart cities: A case study of Russia. *Sustainability, 12*(1), 94.
Mirnaghi, M. S., & Haghighat, F. (2020). Fault detection and diagnosis of large-scale hvac systems in buildings using data-driven methods: A comprehensive review. *Energy and Buildings*, Article 110492.
Mishra, R. A., Kalla, A., Braeken, A., & Liyanage, M. (2021). Privacy protected blockchain based architecture and implementation for sharing of students' credentials. *Information Processing & Management, 58*(3), Article 102512. https://doi.org/10.1016/j.ipm.2021.102512. https://www.sciencedirect.com/science/article/pii/S0306457321000212
Mitchell, D., Zaki, O., Blanche, J., Roe, J., Kong, L., Harper, S., Robu, V., Lim, T., & Flynn, D. (2021). *Symbiotic system design for safe and resilient autonomous robotics in offshore wind farms*. arXiv preprint. arXiv:2101.09491.
Mittal, M., Iwendi, C., Khan, S., & Rehman Javed, A. (2020). Analysis of security and energy efficiency for shortest route discovery in low-energy adaptive clustering hierarchy protocol using levenberg-marquardt neural network and gated recurrent unit for intrusion detection system. *Transactions on Emerging Telecommunications Technologies*, Article e3997.
Mkansi, M. (2021). E-business adoption costs and strategies for retail micro businesses. *Electronic Commerce Research*, 1–41.
Mofolasayo, A. (2020). Potential policy issues with flying car technology. URL *Transportation Research Procedia, 48*, 8–22. https://doi.org/10.1016/j.trpro.2020.08.002 http://www.sciencedirect.com/science/article/pii/S2352146520304130.
Mohammad, N. (2019). A multi-tiered defense model for the security analysis of critical facilities in smart cities. *IEEE Access, 7*, 152585–152598.
Mohasseb, A., Aziz, B., Jung, J., & Lee, J. (2020). Cyber security incidents analysis and classification in a case study of korean enterprises. *Knowledge and Information Systems, 62*(7), 2917–2935.
Mrdovic, S. (2021). In *IoT forensics* (pp. 215–229). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-10591-4_13. URL doi:10.1007/978-3-030-10591-4_13.
Mughal, H., Javed, A. R., Rizwan, M., Almadhor, A. S., & Kryvinska, N. (2022). Parkinson's disease management via wearable sensors: A systematic review. *IEEE Access*, 35219–35237.
Muhammad, A. N., Aseere, A. M., Chiroma, H., Shah, H., Gital, A. Y., & Hashem, I. A. T. (2020). Deep learning application in smart cities: Recent development, taxonomy, challenges and research prospects. *Neural Computing and Applications*, 1–37.
Nagpal, R., Mehrotra, D., Sehgal, R., Srivastava, G., & Lin, J. C.-W. (2022). Overcoming smart city barriers using multi-modal interpretive structural modeling. *Journal of Signal Processing Systems*, 1–17.
Nahavandi, S. (2019). Industry 5.0—a human-centric solution. *Sustainability, 11*(16). https://doi.org/10.3390/su11164371. https://www.mdpi.com/2071-1050/11/16/4371
Neto, A. R., Silva, T. P., Batista, T. V., Delicato, F. C., Pires, P. F., & Lopes, F. (2020). An architecture for distributed video stream processing in iomt systems. *Open Journal of Internet Of Things (OJIOT), 6*(1), 89–104.
Niemann, J., & Pisla, A. (2021). URL. In *Smart life cycle services* (pp. 107–121). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-56449-0_9.
Okai, E., Feng, X., & Sant, P. (2018). Smart cities survey. In *2018 IEEE 20th international conference on high performance computing and communications; IEEE 16th international conference on smart city; IEEE 4th international conference on data science and systems (HPCC/SmartCity/DSS)* (pp. 1726–1730). https://doi.org/10.1109/HPCC/SmartCity/DSS.2018.00282
Olabi, A., Wilberforce, T., & Abdelkareem, M. A. (2021). Fuel cell application in the automotive industry and future perspective. *Energy, 214*, Article 118955.
Oladapo, B. I., Ismail, S. O., Afolalu, T. D., Olawade, D. B., & Zahedi, M. (2021). Review on 3d printing: Fight against covid-19. *Materials Chemistry and Physics, 258*, Article 123943.
Olowononi, F. O., Rawat, D. B., & Liu, C. (2021). Resilient machine learning for networked cyber physical systems: A survey for machine learning security to securing machine learning for cps. *IEEE Communications Surveys Tutorials, 23*(1), 524–552. https://doi.org/10.1109/COMST.2020.3036778
Orosz, D. (2021). Examining the contribution of smart homes to the smart performance of cities. In *, 17. Theory methodology practice: club of economics in miskolc* (pp. 23–30) (SI).
Oueida, S., Aloqaily, M., & Ionescu, S. (2019). A smart healthcare reward model for resource allocation in smart city. *Multimedia Tools and Applications, 78*(17), 24573–24594.
Pafnoiu, L. (2020). Food crisis-global priority. In *, Economic Sciences Series: 20 (1). Ovidius university annals* (pp. 232–236).
Palanca, J., Jordán, J., Bajo, J., & Botti, V. (2020). An energy-aware algorithm for electric vehicle infrastructures in smart cities. *Future Generation Computer Systems, 108*, 454–466.

Pardini, K., Rodrigues, J. J., Diallo, O., Das, A. K., de Albuquerque, V. H. C., & Kozlov, S. A. (2020). A smart waste management solution geared towards citizens. *Sensors, 20*(8), 2380.

Park, J. B., Craggs, R. J., & Tanner, C. C. (2018). Eco-friendly and low-cost enhanced pond and wetland (epw) system for the treatment of secondary wastewater effluent. *Ecological Engineering, 120*, 170–179.

Pereira, G. V., Parycek, P., Falco, E., & Kleinhans, R. (2018). Smart governance in the context of smart cities: A literature review. *Information Polity, 23*(2).

Perera, C., Qin, Y., Estrella, J. C., Reiff-Marganiec, S., & Vasilakos, A. V. (2017). Fog computing for sustainable smart cities: A survey. Jun *ACM Computing Surveys, 50*(3). https://doi.org/10.1145/3057266. URL doi:10.1145/3057266.

Petersen, L., Fallou, L., Reilly, P., & Serafinelli, E. (2020). Public expectations of critical infrastructure operators in times of crisis. *Sustainable and Resilient Infrastructure, 5* (1–2), 62–77.

Pinna, F., Masala, F., & Garau, C. (2017). Urban policies and mobility trends in italian smart cities. *Sustainability, 9*(4), 494. https://doi.org/10.3390/su9040494. doi: 10.3390/su9040494.

Popa, R. A., Redfield, C. M. S., Zeldovich, N., & Balakrishnan, H. (2011). Cryptdb: Protecting confidentiality with encrypted query processing. In *Proceedings of the twenty-third ACM symposium on operating systems principles, SOSP '11* (pp. 85–100). New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/2043556.2043566.

Porambage, P., Okwuibe, J., Liyanage, M., Ylianttila, M., & Taleb, T. (2018). Survey on multi-access edge computing for internet of things realization. *IEEE Communications Surveys & Tutorials, 20*(4), 2961–2991. https://doi.org/10.1109/COMST.2018.2849509

Postorino, M. N., & Sarné, G. M. L. (2020). Reinventing mobility paradigms: Flying car scenarios and challenges for urban mobility. *Sustainability, 12*(9), 3581. https://doi.org/10.3390/su12093581. doi: 10.3390/su12093581.

Qadri, Y. A., Nauman, A., Zikria, Y. B., Vasilakos, A. V., & Kim, S. W. (2020). The future of healthcare internet of things: A survey of emerging technologies. *IEEE Communications Surveys & Tutorials, 22*(2), 1121–1167.

Qureshi, A. M., Lymer, J., & Dougherty, S. (2021). Robotic small sat servicing: A next generation servicing architecture incorporating advanced robotics. In *AIAA Scitech 2021 forum* (p. 0073). arXiv:doi:10.1080/00207543.2017.1326643, doi:10.1080/00207543.2017.1326643. URL.

Qureshi, K. N., Rana, S. S., Ahmed, A., & Jeon, G. (2020). A novel and secure attacks detection framework for smart cities industrial internet of things. *Sustainable Cities and Society, 61*, Article 102343.

Qureshi, K. N., Tayyab, M. Q., Rehman, S. U., & Jeon, G. (2020). An interference aware energy efficient data transmission approach for smart cities healthcare systems. *Sustainable Cities and Society, 62*, Article 102392. https://doi.org/10.1016/j.scs.2020.102392. http://www.sciencedirect.com/science/article/pii/S2210670720306132

Rademacher, T. (2020). In *Artificial intelligence and law enforcement* (pp. 225–254). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-32361-5_10. URL doi:10.1007/978-3-030-32361-5_10.

Radu, L.-D. (2020). Disruptive technologies in smart cities: A survey on current trends and challenges. *Smart Cities, 3*(3), 1022–1038.

Rahman, M. A., Asyhari, A. T., Leong, L., Satrya, G., Tao, M. H., & Zolkipli, M. (2020). Scalable machine learning-based intrusion detection system for iot-enabled smart cities. *Sustainable Cities and Society, 61*, Article 102324.

Ramadan, R. A. (2020). Efficient intrusion detection algorithms for smart cities-based wireless sensing technologies. *Journal of Sensor and Actuator Networks, 9*(3), 39.

Rana, M., Shafiq, A., Altaf, I., Alazab, M., Mahmood, K., Chaudhry, S. A., & Zikria, Y. B. (2021). A secure and lightweight authentication scheme for next generation iot infrastructure. *Computer Communications, 165*, 85–96. https://doi.org/10.1016/j.comcom.2020.11.002. https://www.sciencedirect.com/science/article/pii/S0140366420319745

Ranaweera, P., Jurcut, A. D., & Liyanage, M. (2021). Survey on multi-access edge computing security and privacy. *IEEE Communications Surveys & Tutorials*. https://doi.org/10.1109/COMST.2021.3062546, 1-1.

Rashid, M. M., Kamruzzaman, J., Hassan, M. M., Imam, T., & Gordon, S. (2020). Cyberattacks detection in iot-based smart city applications using machine learning techniques. *International Journal of Environmental Research and Public Health, 17*(24), 9347.

Ravi, V., Alazab, M., Srinivasan, S., Arunachalam, A., & Soman, K. (2021). Adversarial defense: Dga-based botnets and dns homographs detection through integrated deep learning. *IEEE Transactions on Engineering Management*.

Rehman, A., Rehman, S. U., Khan, M., Alazab, M., & Reddy, T. (2021). Canintelliids: Detecting in-vehicle intrusion attacks on a controller area network using cnn and attention-based gru. *IEEE Transactions on Network Science and Engineering*, 1456–1466.

Rehman Javed, A., Jalil, Z., Atif Moqurrab, S., Abbas, S., & Liu, X. (2020). Ensemble adaboost classifier for accurate and fast detection of botnet attacks in connected vehicles. *Transactions on Emerging Telecommunications Technologies*, Article e4088.

Rehman, S. U., Javed, A. R., Khan, M. U., Nazar Awan, M., Farukh, A., & Hussien, A. (2020). Personalisedcomfort: A personalised thermal comfort model to predict thermal sensation votes for smart building residents. *Enterprise Information Systems*, 1–23.

Ren, Y., Xie, R., Yu, F. R., Huang, T., & Liu, Y. (2021). Potential identity resolution systems for the industrial internet of things: A survey. *IEEE Communications Surveys Tutorials, 23*(1), 391–430. https://doi.org/10.1109/COMST.2020.3045136

Resman, M., Turk, M., & Herakovič, N. (2021). Methodology for planning smart factory. *Procedia CIRP, 97*, 401–406. https://doi.org/10.1016/j.procir.2020.05.258. https://www.sciencedirect.com/science/article/pii/S2212827120314803

Ristvej, J., Lacinák, M., & Ondrejka, R. (2020). On smart city and safe city concepts. *Mobile Networks and Applications, 25*(3), 836–845.

Rocha Neto, A., Silva, T. P., Batista, T., Delicato, F. C., Pires, P. F., & Lopes, F. (2021). Leveraging edge intelligence for video analytics in smart city applications. *Information, 12*(1), 14.

Roldán-Gómez, J. J., González-Gironda, E., & Barrientos, A. (2021). A survey on robotic technologies for forest firefighting: Applying drone swarms to improve firefighters' efficiency and safety. *Applied Sciences, 11*(1), 363.

Rose, J., Persson, J. S., & Heeager, L. T. (2015). How e-government managers prioritise rival value positions: The efficiency imperative. *Information polity, 20*(1), 35–59.

Rosemann, M., Becker, J., & Chasin, F. (2020). City 5.0. *Business & Information Systems Engineering*, 1–7.

Růžička, J., & Navrátilová, K. (2020). Crisis management as the part of smart traffic control in cities. In *2020 Smart City symposium Prague (SCSP)* (pp. 1–5). https://doi.org/10.1109/SCSP49987.2020.9133818

Saharan, S., Kumar, N., & Bawa, S. (2020). An efficient smart parking pricing system for smart city environment: A machine-learning based approach. *Future Generation Computer Systems, 106*, 622–640. https://doi.org/10.1016/j.future.2020.01.031. http://www.sciencedirect.com/science/article/pii/S0167739X19322496

Saif, W. S., Esmail, M. A., Ragheb, A. M., Alshawi, T. A., & Alshebeili, S. A. (2020). Machine learning techniques for optical performance monitoring and modulation format identification: A survey. *IEEE Communications Surveys Tutorials, 22*(4), 2839–2882. https://doi.org/10.1109/COMST.2020.3018494

Sanjeevikumar, P. (2021). *Green energy: Solar energy, photovoltaics, and smart cities*. Wiley.

Sarker, I. H. (2021). Machine learning: Algorithms, real-world applications and research directions. *SN Computer Science, 2*(3), 1–21.

Serban, A. C., & Lytras, M. D. (2020). Artificial intelligence for smart renewable energy sector in europe—smart energy infrastructures for next generation smart cities. *IEEE Access, 8*, 77364–77377.

Sgarbossa, F., Peron, M., Lolli, F., & Balugani, E. (2021). Conventional or additive manufacturing for spare parts management: An extensive comparison for poisson demand. *International Journal of Production Economics, 233*, Article 107993. https://doi.org/10.1016/j.ijpe.2020.107993. https://www.sciencedirect.com/science/article/pii/S092552732030342X

Shabbir, M., Shabbir, A., Iwendi, C., Javed, A. R., Rizwan, M., Herencsar, N., & Lin, J. C.-W. (2021). Enhancing security of health information using modular encryption standard in mobile cloud computing. *IEEE Access, 9*, 8820–8834.

Shafeer, T., Arumugam, M. S., & Sasikala, A. (2021). On the design and applications of an integrated smart home automation. In I. J. Jacob, S. K. Shanmugam, S. Piramuthu, & P. Falkowski-Gilski (Eds.), *Data intelligence and cognitive informatics* (pp. 35–52). Singapore: Springer Singapore.

Shafiq, M., Tian, Z., Bashir, A. K., Jolfaei, A., & Yu, X. (2020). Data mining and machine learning methods for sustainable smart cities traffic classification: A survey. *Sustainable Cities and Society, 60*, Article 102177.

Shahzad, F., Iqbal, W., & Bokhari, F. S. (2015). On the use of cryptdb for securing electronic health data in the cloud: A performance study. URL. In *2015 17th international conference on E-health networking, application services (HealthCom)* (pp. 120–125). https://doi.org/10.1109/HealthCom.2015.7454484.

Shahzad, F., Javed, A. R., Jalil, Z., & Iqbal, F. (2022). Cyber forensics with machine learning. In D. Phung, G. I. Webb, & C. Sammut (Eds.), *Encyclopedia of machine learning and data science* (pp. 1–6). New York, NY: Springer US. https://doi.org/10.1007/978-1-4899-7502-7_987-1. URL doi:10.1007/978-3-030-32361-5_10.

Shanahan, J. G., & Dai, L. (2020). Introduction to computer vision and real time deep learning-based object detection. In *Proceedings of the 26th ACM SIGKDD international conference on knowledge discovery & data mining, KDD '20* (pp. 3523–3524). New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3394486.3406713.

Sharma, G., Tripathi, V., & Srivastava, A. (2021). Recent trends in big data ingestion tools: A study. In *Research in intelligent and computing in engineering* (pp. 873–881). Springer.

Sharma, M., Joshi, S., Kannan, D., Govindan, K., Singh, R., & Purohit, H. (2020). Internet of things (iot) adoption barriers of smart cities' waste management: An indian context. *Journal of Cleaner Production, 270*, Article 122047.

Shehab, N., Badawy, M., & Arafat, H. (2021). Big data analytics and preprocessing. In *Machine learning and big data analytics paradigms: Analysis, applications and challenges* (pp. 25–43). Springer.

Shorfuzzaman, M., Hossain, M. S., & Alhamid, M. F. (2021). Towards the sustainable development of smart cities through mass video surveillance: A response to the covid-19 pandemic. *Sustainable Cities and Society, 64*, Article 102582.

Siddiqa, S. K. H. M., Apurva, K., Nandan, D., & Kumar, S. (2021). Documentation on smart home monitoring using internet of things. In A. Kumar, & S. Mozar (Eds.), *Iccce 2020* (pp. 1115–1124). Singapore: Springer Singapore.

Simonofski, A., Vallé, T., Serral, E., & Wautelet, Y. (2021). Investigating context factors in citizen participation strategies: A comparative analysis of Swedish and Belgian smart cities. *International Journal of Information Management, 56*, Article 102011. https://doi.org/10.1016/j.ijinfomgt.2019.09.007. https://www.sciencedirect.com/science/article/pii/S0268401219302439

Singh, S., Kumar, R., Panchal, R., & Tiwari, M. K. (2020). Impact of covid-19 on logistics systems and disruptions in food supply chain. *International Journal of Production Research*, 1–16.

Singh, S. K., Jeong, Y.-S., & Park, J. H. (2020). A deep learning-based iot-oriented infrastructure for secure smart city. *Sustainable Cities and Society, 60*, Article 102252.

Song, J., Han, Z., Wang, W., Chen, J., & Liu, Y. (2022). A new secure arrangement for privacy-preserving data collection. *Computer Standards & Interfaces, 80*, Article 103582.

Songhorabadi, M., Rahimi, M., Farid, A. M. M., & Kashani, M. H. (2020). *Fog computing approaches in smart cities: A state-of-the-art review*. arXiv preprint.
Sorlei, I.-S., Bizon, N., Thounthong, P., Varlam, M., Carcadea, E., Culcer, M., Iliescu, M., & Raceanu, M. (2021). Fuel cell electric vehicles—a brief review of current topologies and energy management strategies. *Energies, 14*(1), 252.
Soyata, T., Habibzadeh, H., Ekenna, C., Nussbaum, B., & Lozano, J. (2019). Smart city in crisis: Technology and policy concerns. *Sustainable Cities and Society, 50*, Article 101566.
Srinivasan, S., Ravi, V., Alazab, M., Ketha, S., Ala'M, A.-Z., & Padannayil, S. K. (2021). Spam emails detection based on distributed word embedding with deep learning. In *Machine intelligence and big data analytics for cybersecurity applications* (pp. 161–189). Springer.
Sriram, S., Vinayakumar, R., Alazab, M., & Soman, K. (2020). Network flow based iot botnet attack detection using deep learning. In *IEEE INFOCOM 2020-IEEE conference on computer communications workshops (INFOCOM WKSHPS)* (pp. 189–194). IEEE.
Srivastava, D., Gayathri, N., Al-Turjman, F., & Kumar, S. R. (2021). Chapter 10 - security aspects and uavs in socialized regions. URL. In F. Al-Turjman, & B. Deebak (Eds.), *Security in IoT social networks, intelligent data-centric systems* (pp. 229–245). Academic Press. https://doi.org/10.1016/B978-0-12-821599-9.00010-8 https://www.sciencedirect.com/science/article/pii/B9780128215999000108.
Starnawska, S. E. (2020). Sustainability in the banking industry through technological transformation. In *The Palgrave handbook of corporate sustainability in the digital era* (pp. 429–453). Springer.
Stoyanova, M., Nikoloudakis, Y., Panagiotakis, S., Pallis, E., & Markakis, E. K. (2020). A survey on the internet of things (iot) forensics: Challenges, approaches, and open issues. *IEEE Communications Surveys Tutorials, 22*(2), 1191–1221. https://doi.org/10.1109/COMST.2019.2962586
Strozzi, F., Colicchia, C., Creazza, A., & Noè, C. (2017). Literature review on the 'smart factory' concept using bibliometric tools. *International Journal of Production Research, 55*(22), 6572–6591. https://doi.org/10.1080/00207543.2017.1326643. arXiv:doi:10.1080/00207543.2017.1326643, doi:10.1080/00207543.2017.1326643. URL.
Studley, M. E., & Little, H. (2020). Robots in smart cities. In *How Smart is your city?* (pp. 75–88). Springer.
Svobodová, L., & Bednarska-Olejniczak, D. (2020). Smart city and economy: Bibliographic coupling and co-occurrence. In *Conference on e-business, e-services and e-society* (pp. 102–113). Springer.
T. Group. Building a 5g world we can all trust. URL https://www.thalesgroup.com/sites/default/files/database/document/2020-12/tel-Trusted-5G_2.pdf.
Tahir, S. F., Fahad, L. G., & Kifayat, K. (2020). Key feature identification for recognition of activities performed by a smart-home resident. *Journal of Ambient Intelligence and Humanized Computing, 11*(5), 2105–2115.
Tandon, A., Dhir, A., Islam, A. N., & Mäntymäki, M. (2020). Blockchain in healthcare: A systematic literature review, synthesizing framework and future research agenda. *Computers in Industry, 122*, Article 103290. https://doi.org/10.1016/j.compind.2020.103290. http://www.sciencedirect.com/science/article/pii/S0166361520305248
Tanveer, M., Alkhayyat, A., Chaudhry, S. A., Zikria, Y. B., Kim, S. W., et al. (2022). Reas-tmis: Resource-efficient authentication scheme for telecare medical information system. *IEEE Access, 10*, 23008–23021.
Tataria, H., Shafi, M., Molisch, A. F., Dohler, M., Sjöland, H., & Tufvesson, F. (2020). *6g wireless systems: Vision, requirements, challenges, insights, and opportunities*. URL. arXiv preprint.
Tekouabou, S. C. K., Cherif, W., & Silkan, H. (2020). Improving parking availability prediction in smart cities with iot and ensemble-based model. *Journal of King Saud University-Computer and Information Sciences*.
Tharwat, M., & Khattab, A. (2021). In *Clustering techniques for smart cities: An artificial intelligence perspective* (pp. 113–134). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-60922-1_6. URL doi:10.1007/978-3-030-60922-1_6.
Tien, P. W., Wei, S., & Calautit, J. (2021). A computer vision-based occupancy and equipment usage detection approach for reducing building energy demand. *Energies, 14*(1), 156.
Tookanlou, P. B., & Wong, H. (2020). Determining the optimal customization levels, lead times, and inventory positioning in vertical product differentiation. *International Journal of Production Economics, 221*, Article 107479.
Topaloglu, M., Yarkin, F., & Kaya, T. (2018). Solid waste collection system selection for smart cities based on a type-2 fuzzy multi-criteria decision technique. *Soft Computing, 22*(15), 4879–4890.
U. N. O. F. T. C. O. H. A. (OCHA). (2018). Ocha strategic plan, 2018-21. URL https://www.unocha.org/sites/unocha/files/OCHA.
U. N. O. F. T. C. O. H. A. (OCHA). (2021). Ocha global humantarian overview 2021 - abridged version. URL https://www.unocha.org/sites/unocha/files/GHO-2021-Abridged-EN.pdf.
Ullah, Z., Al-Turjman, F., Mostarda, L., & Gagliardi, R. (2020). Applications of artificial intelligence and machine learning in smart cities. *Computer Communications*.
Union, I. T.. Report itu-r m.2370-0 : Imt traffic estimates for the years 2020 to 2030. https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2370-2015-PDF-E.pdf.
Union, I. T.. Itu ai/ml in 5g challenge. https://www.itu.int/en/ITU-T/AI/challenge/2020/Pages/default.aspx.
ur Rehman, S., Khaliq, M., Imtiaz, S. I., Rasool, A., Shafiq, M., Javed, A. R., Jalil, Z., & Bashir, A. K. (2021). Diddos: An approach for detection and identification of distributed denial of service (ddos) cyberattacks using gated recurrent units (gru). *Future Generation Computer Systems, 118*, 453–466.
Urooj, S., Alrowais, F., Teekaraman, Y., Manoharan, H., & Kuppusamy, R. (2021). Iot based electric vehicle application using boosting algorithm for smart cities. *Energies, 14*(4), 1072.
Usman Sarwar, M., Rehman Javed, A., Kulsoom, F., Khan, S., Tariq, U., & Kashif Bashir, A. (2021). Parciv: Recognizing physical activities having complex interclass variations using semantic data of smartphone. *Software: Practice and Experience, 51* (3), 532–549.
Valdez, A.-M., Cook, M., & Potter, S. (2018). Roadmaps to utopia: Tales of the smart city. *Urban Studies, 55*(15), 3385–3403. https://doi.org/10.1177/0042098017747857. URL.
Vamsi, B., Doppala, B. P., Rao, N. T., & Bhattacharyya, D. (2021). Comparative analysis of prevalent disease by preprocessing techniques using big data and machine learning: An extensive review. *Machine Intelligence and Soft Computing*, 27–38.
van Beek, H., van den Bos, J., Boztas, A., van Eijk, E., Schramp, R., & Ugen, M. (2020). Digital forensics as a service: Stepping up the game. *Forensic Science International: Digital Investigation, 35*, Article 301021. https://doi.org/10.1016/j.fsidi.2020.301021. https://www.sciencedirect.com/science/article/pii/S2666281720300706
Vinayakumar, R., Alazab, M., Srinivasan, S., Pham, Q.-V., Padannayil, S. K., & Simran, K. (2020). A visualized botnet detection system based deep learning for the internet of things networks of smart cities. *IEEE Transactions on Industry Applications, 56*(4), 4436–4456.
Vogt, J. (2021). *Where is the human got to go? Artificial intelligence, machine learning, big data, digitalisation, and human–robot interaction in industry 4.0 and 5.0*.
Wang, H., Zhao, H., Zhang, J., Ma, D., Li, J., & Wei, J. (2019). Survey on unmanned aerial vehicle networks: A cyber physical system perspective. *IEEE Communications Surveys & Tutorials, 22*(2), 1027–1070.
Wang, H., Zhao, H., Zhang, J., Ma, D., Li, J., & Wei, J. (2020). Survey on unmanned aerial vehicle networks: A cyber physical system perspective. *IEEE Communications Surveys Tutorials, 22*(2), 1027–1070. https://doi.org/10.1109/COMST.2019.2962207
Wang, J., Spicher, N., Warnecke, J. M., Haghi, M., Schwartze, J., & Deserno, T. M. (2021). Unobtrusive health monitoring in private spaces: The smart home. *Sensors, 21*(3). https://doi.org/10.3390/s21030864. https://www.mdpi.com/1424-8220/21/3/864
Wang, X., & Xu, F. (2021). A theory of fintech and trade finance, SSRN. URL https://ssrn.com/abstract=3777250.
Wani, M. A., Bhat, F. A., Afzal, S., & Khan, A. I. (2020). *Advances in deep learning*. Springer.
WEF, W. E. F.. The impact of 5g: Creating new value across industries and society. URL http://www3.weforum.org/docs/WEF_The_Impact_of_5G_Report.pdf.
Wegner, P. (1996). Interoperability. *ACM Computing Surveys (CSUR), 28*(1), 285–287.
Wilke, C. O. A. W. C. J.. A drone program taking flight. https://www.aboutamazon.com/news/transportation/a-drone-program-taking-flight.
Wu, Y., Zhang, W., Shen, J., Mo, Z., & Peng, Y. (2018). Smart city with chinese characteristics against the background of big data: Idea, action and risk. *Journal of Cleaner Production, 173*, 60–66. https://doi.org/10.1016/j.jclepro.2017.01.047. URL doi:10.1007/978-3-030-42523-4_16 http://www.sciencedirect.com/science/article/pii/S0959652617300549.
Xhafa, F., Kilic, B., & Krause, P. (2020). Evaluation of iot stream processing at edge computing layer for semantic data enrichment. *Future Generation Computer Systems, 105*, 730–736. https://doi.org/10.1016/j.future.2019.12.031. http://www.sciencedirect.com/science/article/pii/S0167739X19321296
Xu, B., Li, L., Hu, D., Wu, B., Ye, C., & Cai, H. (2018). Healthcare data analysis system for regional medical union in smart city. *Journal of Management Analytics, 5*(4), 334–349. https://doi.org/10.1080/23270012.2018.1490211. arXiv:doi:10.1080/23270012.2018.1490211, doi:10.1080/23270012.2018.1490211. URL.
Yaacoub, J.-P. A., Salman, O., Noura, H. N., Kaaniche, N., Chehab, A., & Malli, M. (2020). Cyber-physical systems security: Limitations, issues and future trends. *Microprocessors and Microsystems, 77*, Article 103201.
Yan, J., Liu, J., & Tseng, F.-M. (2020). An evaluation system based on the self-organizing system framework of smart cities: A case study of smart transportation systems in China. *Technological Forecasting and Social Change, 153*, Article 119371. https://doi.org/10.1016/j.techfore.2018.07.009. http://www.sciencedirect.com/science/article/pii/S0040162518301021
Yang, L., Elisa, N., & Eliot, N. (2019). Privacy and security aspects of e-government in smart cities. URL. In *Smart cities cybersecurity and privacy* (pp. 89–102). Elsevier.
Yaqoob, T., Abbas, H., & Atiquzzaman, M. (2019). Security vulnerabilities, attacks, countermeasures, and regulations of networked medical devices—A review. *IEEE Communications Surveys Tutorials, 21*(4), 3723–3768. https://doi.org/10.1109/COMST.2019.2914094
Yu, H., Afzal, M. K., Zikria, Y. B., Rachedi, A., & Fitzek, F. H. (2020). Tactile internet: Technologies, test platforms, trials, and applications. *Future Generation Computer Systems, 106*, 685–688. https://doi.org/10.1016/j.future.2020.01.057. https://www.sciencedirect.com/science/article/pii/S0167739X20304192
Yu, L., Sun, Y., Xu, Z., Shen, C., Yue, D., Jiang, T., & Guan, X. (2020). Multi-agent deep reinforcement learning for hvac control in commercial buildings. *IEEE Transactions on Smart Grid, 12*(1), 407–419.
Zaki, O., Dunnigan, M., Robu, V., & Flynn, D. (2021). Reliability and safety of autonomous systems based on semantic modelling for self-certification. *Robotics, 10* (2021), 10.
Zarecor, K. E., Peters, D. J., & Hamideh, S. (2021). In *Ruralsmart shrinkage and perceptions of quality of life in the American Midwest* (pp. 395–415). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-50540-0_20. URL doi:10.1007/978-3-030-50540-0_20.
Zehra, W., Javed, A. R., Jalil, Z., Khan, H. U., & Gadekallu, T. R. (2021). Cross corpus multi-lingual speech emotion recognition using ensemble learning. *Complex & Intelligent Systems*, 1–10.

Zekić-Sušac, M., Mitrović, S., & Has, A. (2020). Machine learning based system for managing energy efficiency of public sector as an approach towards smart cities. *International Journal of Information Management*, Article 102074.

Zhang, J., Yue, W., Fan, P., & Gao, J. (2021). Measuring the accessibility of public green spaces in urban areas using web map services. *Applied Geography, 126*, Article 102381. https://doi.org/10.1016/j.apgeog.2020.102381. https://www.sciencedirect.com/science/article/pii/S0143622820314806

Zhao, R., Stincescu, T., Ballantyne, E. E., & Stone, D. A. (2020). Sustainable city: Energy usage prediction method for electrified refuse collection vehicles. *Smart Cities, 3*(3), 1100–1116.

Zhou, Y., Yu, F. R., Chen, J., & Kuo, Y. (2019). Cyber-physical-social systems: A state-of-the-art survey, challenges and opportunities. *IEEE Communications Surveys & Tutorials, 22*(1), 389–425.

Zikria, Y. B., Afzal, M. K., Kim, S. W., Marin, A., & Guizani, M. (2020). Deep learning for intelligent iot: Opportunities, challenges and solutions. *Computer Communications, 164*, 50–53. https://doi.org/10.1016/j.comcom.2020.08.017. https://www.sciencedirect.com/science/article/pii/S0140366420319046