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Chapter 2

Artificial intelligence, machine learning, and deep learning for enabling smart and sustainable cities and infrastructure

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Abstract: The development of smart and sustainable cities and infrastructure with the integrated use of artificial intelligence (AI), machine learning (ML), and deep learning (DL) has emerged as a key transformative progress in the urban planning and management. As key drivers of efficiency, sustainability, and liveability, these technologies have emerged in response to recent trends within urban landscapes. Real-time AI-driven analytics allows cities to capture insights to adapt to the behaviour of cities, this includes policies like predictive maintenance of infrastructure, energy uses optimization as well as traffic management. ML algorithms provide resilient approaches for waste management, water distribution, pollution control, etc., which ultimately enriches adaptive behaviour of urban systems. DL especially with their pattern matching help aid the creation of intelligent system monitoring and management of city resources and make it sustainable and resilient against environmental threats. The amalgamation of Internet of things (IoT) devices with AI, ML and DL models has the ability to gather data, helps in taking advantage of data-driven city governance. Integrated solutions for the creation of smart grids, self-sustained urban transportation network and effective public service mechanisms are increasingly possible, seeking to contribute to the sustainability of urban development in the long run. The intersection of these technologies not only will aid cities in their day-to-day operational challenges brought on by urbanization, but also enable cities in their longer-term strategic planning, foster economic growth and improve general quality of life for residents.

Keywords: Smart city, Internet of things, Sustainable development, Artificial intelligence, Machine learning, Deep learning, Industry 4.0

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2.1 Introduction

The rapid rate of urbanization and population increase in metropolitan areas are among the leading causes for sustainable city management with corresponding infrastructure. Indeed, traditional approaches to city management and infrastructure development have been increasingly inadequate in retaining sustenance for issues like traffic congestion, pollution, energy consumption, and waste management (Neo et al., 2023; Ghazal et al., 2023). There is, hence, a need that is developing to provide new solutions that would enable the creation of intelligent and sustainable cities. Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) technologies can become powerful tools in this context, offering advanced solutions for data analysis, predictive modeling, and decision-making procedures (De Las Heras et al., 2020; Ahmed et al., 2022; Szpilko et al., 2023; Rane et al., 2024a). Awe-inspiring capabilities have already been shown in many areas, from healthcare to finance, by AI, ML, and DL, and the interest in their application to urban management has already gained ground (Varshney et al., 2021; Prabakar et al., 2023; Paramesha et al., 2024a). These could be technologies to optimize the functioning of critical infrastructure systems and improve resource utilization, thereby improving the quality of life among urban residents (Nosratabadi et al., 2019; Singh et al., 2020; Paramesha et al., 2024b). For instance, AI can drive intelligent traffic management systems where there is congestion and emission reduction, ML algorithms predict and mitigate infrastructural failures, and DL models enable more efficient energy use in smart grids (David, & Koch, 2019; Chen, & Zhang, 2022; Jafari et al., 2023). Such innovations become essential in developing resilient urban environments that can adapt to change and operate sustainably in the long term. Drawing from these observations, the study attempts to fill these lacunae by providing an in-depth literature review, co-occurrence analysis of relevant keywords, and cluster analysis for detecting emerging trends and research priorities.

Contributions of the research work:

1) This research provides an overview of the literature available on AI, ML, and DL applications in developing innovative and sustainable cities. Significant findings, challenges, and future directions are identified.
2) Helps to identify and analyse the most relevant keywords in a field, outlining patterns and relations that may indicate current research focuses and emerging areas of interest.
3) Applies advanced clustering techniques to group-related studies and themes, aiding insights into dominant research clusters and giving the depth to plunge deeper into the understanding of interdisciplinary connections within such a domain.

2.2 Methodology

Literature review, keyword analysis, co-occurrence analysis, and cluster analysis have been used in this study to analyse the roles of AI, ML, and DL in developing innovative and sustainable cities and infrastructure. The literature review covers an in-depth survey of academic journals, conference papers, and industrial reports published in the last ten years. Key sources utilized in article collection include IEEE Xplore, ScienceDirect, and Google Scholar. These would be guided by keywords such as "artificial intelligence," "machine learning," "deep learning," "smart cities," and "sustainable infrastructure" that guide the search process. The literature gathered is fed into bibliometric tool VOSviewer for keyword and co-occurrence analysis. The tools identify all the most frequently occurring terms and their interrelations, which are useful in showing emergent trends and research gaps. Co-occurrence analysis charts the connections of keywords with each other, outlining at a glance the strong interdisciplinary character of research in this area. This will involve cluster analysis in the grouping of literature into well-defined themes. Applying algorithms like k-means, the study groups articles with similar characteristics and thematic similarities.

2.3 Results and discussions

Co-occurrence and cluster analysis of the keywords

This Fig. 2.1 illustrates the interconnected web of various terms, whereby the term "smart city" is located at the heart, and therefore indicates the centrality of "smart city" in the field of smart cities. The extensive network of connotations with the concept of smart city accurately reveals its centrality in discussions about AI, machine learning, and deep learning in urban settings. Smart cities are a complex system of systems, characterized by this central placement, which weaves together a wide range of technological, environmental and socio-economic components that makes the smart city domain so important.

Cluster 1: Smart cities and urban development

Sustainable development goals, urban planning, smart cities, big data, machine learning is the symbol of the fusion of the city development along with the state-of-the-art technologies. Although the addition of "machine learning" and "big data" highlight the need to utilize data in strengthening the decision-making process in smart city projects. It promotes "sustainable development," calling for cities to be smart not just for literal sake, but to be environmentally conscious, durable and resource-stingy. In this cluster, urban planning, urban development, AI and machine learning creating and managing urban places. While prediction is using predictive analytics for forecasting and responding to urban challenges, decision-making looks at the role of AI as a tool for better, smarter governance.

Cluster 2: Internet of Things (IoT) and connectivity

The blue cluster just descripted encloses the high-impact concepts: "internet of things (IoT)", "learning systems", "edge computing", and "5G mobile communication system". This cluster underscores the very high value of connectivity and the ability to share real-time data to better manage smart cities. The reason largely to do with overflow of data that a system of IoT devices is capable of providing and transmitting, data that is vital to the performance of many urban services. Low-latency data processing and communication – is the priority for real-time applications like traffic management and emergency response, edge computing and 5G are the aggregation of all of this. This is testified by the very presence of security systems and the need for quality service provision but the report stresses that the high quality of services and the ability to maintain secure networks are vital, to be named among the best of the best in creating and maintaining a smart city infrastructure.

Cluster 3: Machine learning and decision support

The green cluster focuses on application of AI to enhance analysis and prediction covering features like ML, decision, support vector machine and future forecasting. Support vector machines are machine learning algorithms that are necessary for data analysis on big data holding millions of datasets. Meanwhile, cluster describes how these technologies are deployed in forecasting (predicting trends and the future) and can help in planning urban life proactively. The cluster indicates the deployment of AI enabled public health care in smart urban areas. Automatic data acquisition covers real-time monitoring and control of urban system which increases safety and productivity with the help of AI.

Purple cluster creates an overview of the environmental outlook of smart cities, relates it to sustainability and energy management, including smart grid and energy consumption. Noteworthy- AI is necessary for attaining the fundamental goal, which is sustainability, as it leverages resources better and reduces the environmental impact. Smart grid technology is very important to ensure the efficiency and sustainability of the energy, and healthy delivery and consumption, smart grid management with energy management are very necessary. Utilisation of AI technology to monitor and ameliorate environmental conditions and the relevant field is air quality and waste management. The use of AI is particularly crucial in the framework of promoting environmental sustainability practices through the exposure of the concept of learning (e-learning) to the residents of the city.

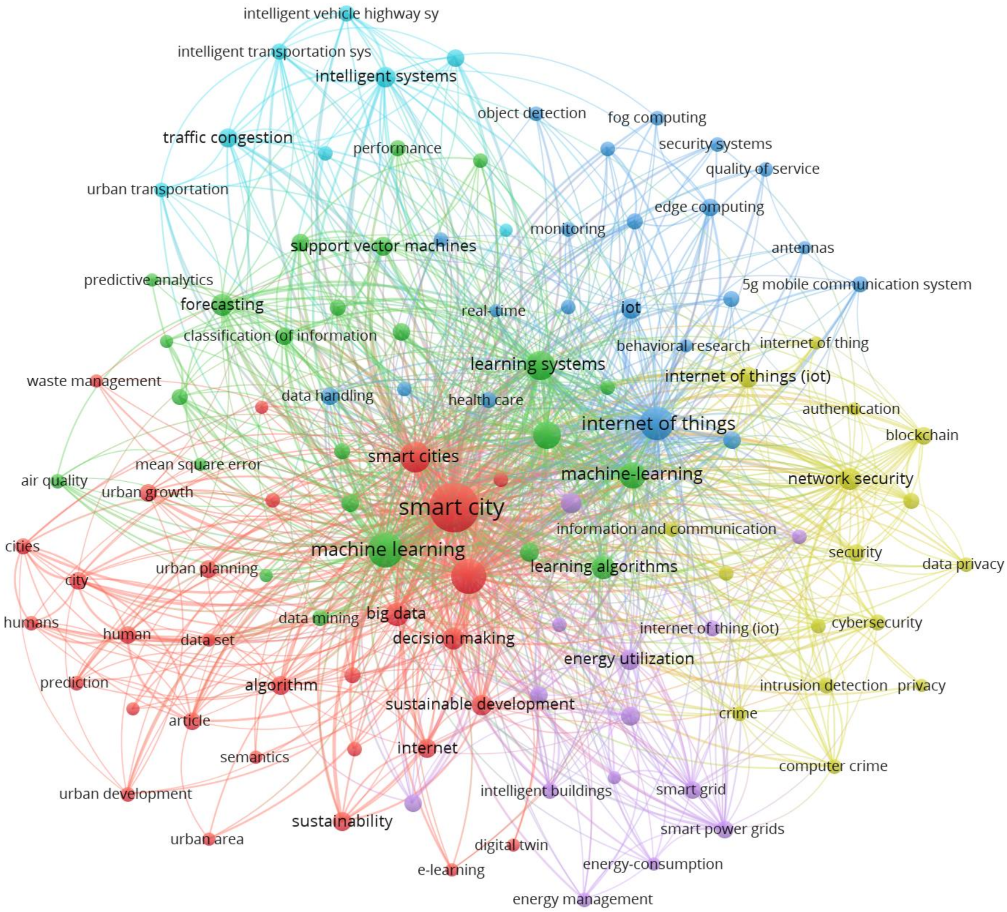

Fig. 2.1 Co-occurrence analysis of the keywords in literature

Cluster 4: Sustainability and environmental management

Cluster 5: Security and privacy

The presence of terms such as network security, cybersecurity, data privacy, authentication and more indicates the strong emphasis on ensuring the security of smart city infrastructures. As the world continues to grow more connected and more reliant on data within our urban areas, the security and privacy of the data within our systems have become incredibly important. The result is that the city's systems are secure, with cyber threats to the city detected and counteracted through AI and machine learning. "Blockchain," means the use of decentralized technologies to make data transactions more secure and more transparent. "Computer crime" highlights the subtleties of cyber threats, and the seriousness of ensuring adequate safety measures are in place. The intricate weave of cluster connections displays the interdisciplinary character of smart city initiatives. In diverse contexts, words such as "internet", "big data" and "decision making" are more often than not being used, to underline their momentous importance. This cross-cutting between "machine learning" and urban relevant environmental, and security concern exemplifies the broad range of urban challenges that "machine learning" can address. In response to the use of support vector machines and learning algorithms, the integration of AI in the planning and operational parts of smart cities has not been far behind of predictive analytics applications in real-time scenarios. We need to harmonize the strategies of urban expanding with the objectives of sustainable urban development in order to build a connection between the spatial planning and the sustainable development.

Applications of Artificial intelligence, machine learning, and deep learning in smart and sustainable cities and infrastructure

The rapid urbanization has brought new and unprecedented challenges to city management and infrastructure development (De Las Heras et al., 2020; Ahmed et al., 2022; Ghazal et al., 2023; Rane et al., 2024b). Therefore, the concepts of smart cities and sustainable infrastructure have emerged with manifold technologies that enable efficient, livable, and resilient urban environments. Of these, AI, ML, and DL have been prominent transformation tools (Varshney et al., 2021; Prabakar et al., 2023; Paramesha et al., 2024c). They provide innovative solutions for optimizing city operations, enhancing quality of life, and promoting sustainability.

Urban planning and management

AI is integral to the stages of planning and management involved in urban planning by way of analysing large data sets that would inform decision-making processes (Ullah et al., 2020; Luckey, 2021; Varshney 2021). AI-driven systems may, therefore process data from sources such as satellite imagery, social media, and sensor networks, providing insight into the dynamics of urban areas. AI algorithms can be used in population growth, traffic patterns, and environmental impact prediction of immense utility to city planners in developing more efficient and sustainable designs for urban areas (Luckey, 2021; Varshney 2021; Ahmed et al., 2022; Paramesha et al., 2024d). Second, AI-driven tools can improve resource allocation, for example, energy and water distribution, using demand pattern prediction and areas for better identification.

Enhancing public safety and security

AI, ML, and DL contributing to public safety and security in smart cities (Deep, & Verma, 2023; Zhao, 2023; Rane et al., 2024c). Activities that seem out of the ordinary can be detected and analysed in real-time by AI-infused surveillance systems, improving response times to impending dangers. DL algorithms that come with facial recognition technology identify people in crowded places and help in crime prevention and the tracking of suspects or missing persons. AI-driven predictive policing models can hence be trained on historical crime data to predict possible hotspots, thus providing law enforcers with better resource allocation and the ability to engage in proactive efforts against criminal activities.

Intelligent Transportation Systems (ITS)

AI, ML, and DL technologies show massive promise in the transport sector (Majumdar et al., 2021; Chen, & Zhang, 2022). ITS incorporates all those technologies in managing and streamlining traffic flow, hence reducing congestion and improving transportation efficiency. Traffic signals can assess the real-time traffic situation with AI algorithms, thereby reducing wait time and conserving fuel. ML models will be able to predict traffic conditions and provide the best routes to commuters to improve their travel experience (Ei Leen et al., 2023; Abdullah et al., 2023; Paramesha et al., 2024e). Besides, self-driving cars, perceivably based on DL for perception and decision-making, become an avenue towards a better tomorrow in urban mobility; this means offering users safer and more efficient modes of transport.

Energy management and sustainability

One of the most critical parts of sustainable city initiatives is energy management (Selvaraj et al., 2023). AI and ML technologies can make possible smart grids that shall help with optimization processes associated with energy distribution and consumption very effectively (Pham, et al., 2021; Chui et al., 2018). The analysis of energy usage patterns by ML algorithms brings the ability to predict fluctuations in demand and adjust supply accordingly, reducing energy wastage and, thus, costs. AI-driven systems can integrate solar and wind power, from renewables, into the grid much better than now in predicting their output and making appropriate storage arrangements (Farmanbar et al., 2019; David, & Koch, 2019; Jafari et al., 2023). This provides greater resilience and sustainability for urban energy systems.

Table 2.1 Applications of AI, ML, and DL in smart and sustainable cities and infrastructure

References	**Application Area**	**AI**	**ML**	**DL**
Majumdar et al., (2021); Chen, & Zhang, (2022); Ei	Traffic Management	Traffic signal control, congestion prediction	Traffic pattern analysis, anomaly detection	Real-time traffic flow prediction, autonomous

Leen et al., (2023); Abdullah et al., (2023)				vehicle navigation
Selvaraj et al., (2023); Pham, et al., (2021); Chui et al., (2018)	Energy Management	Smart grid optimization, demand response	Energy consumption prediction, anomaly detection in energy usage	Predictive maintenance for energy infrastructure, renewable energy forecasting
Chen, et al., (2022); Szpilko et l., (2023); Udupiet al., (2024)	Waste Management	Route optimization for waste collection, waste sorting	Predictive waste generation models, recycling rate improvement	Image recognition for waste classification, smart bins
Punia, & Mor, (2021); Krishnan et al., (2022); Adedeji et al., (2022)	Water Management	Leak detection, water quality monitoring	Water usage prediction, anomaly detection	Real-time flood prediction, advanced water quality prediction
França et al., (2021); Deep, & Verma, (2023); Zhao, (2023)	Public Safety	Crime prediction, emergency response optimization	Crime pattern analysis, anomaly detection in surveillance	Real-time video analysis for public safety, facial recognition
Szpilko et al., (2023); Alahi et al., (2023); Bibri et al., (2024)	Environmental Monitoring	Pollution tracking, climate change impact analysis	Air quality prediction, anomaly detection	High-resolution environmental monitoring, species identification
Gonçalves et al., (2020); Rodríguez-Gracia et al., (2023)	Building Management	Smart HVAC systems, lighting control	Energy efficiency optimization, fault detection	Predictive maintenance for building systems, occupant behavior modeling

Gangwani, D., & Gangwani, P. (2021); Szpilko (2023); Ullah et al., (2020)	Transportation	Autonomous public transport systems, route optimization	Demand prediction for public transport, service optimization	Real-time passenger flow prediction, autonomous vehicle operations
Ullah et al., (2020); Mehta et al., (2022); Szpilko et al., (2023)	Healthcare Services	Telemedicine, health monitoring	Disease outbreak prediction, patient data analysis	Real-time health monitoring, advanced medical imaging analysis
Ullah et al., (2020); Luckey, (2021); Varshney (2021)	Urban Planning	Land use optimization, infrastructure development	Predictive urban growth models, infrastructure demand analysis	High-resolution urban simulation, real-time construction site monitoring
França et al., (2021); Younus et al., (2022); Alahakoon et al., (2023)	Education	Personalized learning, administrative automation	Student performance prediction, resource allocation	Intelligent tutoring systems, automatic grading
Monteiro et al., (2021); Grimaldia et al., (2021); Alahi, et al., (2023)	Public Services	Chatbots for citizen services, smart kiosks	Service demand prediction, process optimization	Voice recognition for public service access, advanced document analysis
Kishen et al., (2021); Cao, (2021); Oosthuizen et al., (2021)	Retail	Personalized shopping experiences, inventory management	Customer behaviour prediction, sales forecasting	Real-time image recognition for stock management, personalized advertising

Ryman-Tubb et al., (2018); Kunwar, (2019); Mahalakshmi et al., (2022)	Finance	Fraud detection, automated customer service	Credit scoring, risk assessment	Real-time market prediction, advanced financial analysis
Gajdošík, & Marciš, (2019); Bulchand-Gidumal, (2022); Doborjeh et al., (2022)	Tourism and Hospitality	Personalized travel recommendations, smart booking systems	Demand prediction, guest preference analysis	Advanced sentiment analysis, real-time customer feedback processing
Jose et al., (2021); Shaikh et al., (2022); Rahman, & Ravi, (2022)	Agriculture	Crop monitoring, pest detection	Yield prediction, soil quality analysis	Real-time crop health monitoring, advanced image analysis for plant diseases
Çınar et al., (2020); Fahle et al., (2020); Rai et al., (2021)	Manufacturing	Predictive maintenance, quality control	Process optimization, defect detection	Real-time anomaly detection in production, advanced robotics control
Kibria et al., (2018); Balmer et al., (2020); Ouyang et al., (2021)	Telecommunications	Network optimization, customer service automation	Service demand prediction, fault detection	Real-time network traffic analysis, advanced signal processing
Sun et al., (2020); Abid et al., (2021)	Disaster Management	Emergency response coordination, resource allocation	Disaster prediction models, damage assessment	Real-time damage detection from satellite imagery, advanced risk modeling

Recuero Virto, & López, (2019); Zhao et al., (2020)	Cultural Heritage Preservation	Digitization of artifacts, virtual tours	Predictive analysis of deterioration, visitor pattern analysis	High-resolution image restoration, real-time monitoring of heritage sites
Frolova, & Ermakova, (2021); Rosili et al., (2021); Zeleznikow, (2023)	Legal Services	Document analysis, case outcome prediction	Legal research optimization, workload prediction	Real-time transcription services, advanced legal analytics
Guo et al., (2019); Sepasgozar et al., (2020); Alzoubi, (2022)	Housing	Smart home systems, automated maintenance	Property value prediction, tenant behaviour analysis	Real-time security monitoring, advanced home automation
Araújo, et al., 2021); Ghosh et al., (2023)	Sports and Recreation	Performance analysis, event management	Player behaviour analysis, fan engagement prediction	Real-time game analysis, advanced motion tracking

Waste management and recycling

Effective waste management is the means to clean and sustainable urban environments. A range of innovations enabled by AI, ML, and DL technologies can enhance waste collection, sorting, and recycling processes (Chen, et al., 2022; Udupiet al., 2024). For example, AI-powered sensors and cameras that monitor fill levels in waste bins and create collection routes on their own can help to reduce operational costs while at the same time reducing the impact on the environment. ML algorithms analyse waste composition to identify recyclable materials more effectively. Besides, DL models do so by automating identification and sorting procedures for different types of waste materials as part of improving recycling processes (Szpilko et al., 2023; Udupiet al., 2024).

Smart buildings and infrastructure

AI, ML, and DL have become intrinsic parts of intelligent buildings and related infrastructures (Chew et al., 2020; Das et al., 2023). Smart buildings harness the power of these technologies in optimizing energy use, improving occupant comfort, and increasing efficiency in general. AI-driven building management systems can track and control HVAC, lighting, and other utilities against real-time occupancy data to reduce energy consumption and operational costs (Gonçalves et al., 2020; Rodríguez-Gracia et al., 2023). In this regard, ML algorithms can leverage the data obtained from sensors to predict maintenance needs, thus preventing equipment failures and elongating building infrastructure life. Moreover, DL models can enhance building security through improved monitoring of possible access points to the building's interior, which is attained by effective detection of unauthorized activities.

Environmental monitoring and management

A sustainable city needs environmental solid monitoring and management systems for people's and ecosystems' well-being. AI, ML, and DL technologies can constantly track parameters such as air/water quality or other environmental indicators (Szpilko et al., 2023; Alahi et al., 2023). AI algorithms will allow one to analyse sensor data to detect sources of pollution and predict environmental trends; hence, timely interventions are possible (Alahi et al., 2023; Bibri et al., 2024). AI/ML can help optimize water and green space management, anticipating patterns of use and detecting opportunities for conservation. Moreover, DL models are improving climate modeling and prediction, helping cities be better prepared to deal with and mitigate the effects of climatic change.

Smart healthcare systems

Health is one of the critical components of innovative city initiatives; AI, ML, and DL technological innovations contribute to strengthening healthcare services (Ullah et al., 2020; Szpilko et al., 2023). The AI-enabled systems can singly analyse patient data from which customized treatment recommendations can be made. ML algorithms learn patterns from health records and social media data to predict the outbreak of diseases, thereby supporting early interventions and control measures. Moreover, DL models can analyse medical imaging to increase the chances of detecting diseases-especially fatal ones like cancer at an early stage when effective treatment is possible. These technologies thus enable innovative healthcare systems to ensure access by urban populations to high-quality and efficient healthcare services.

Citizen engagement and participation

AI, ML, and DL technologies further raise the level of engagement and participation from citizens living in smart cities. Artificially intelligent platforms can allow for the extraction and analysis of public feedback from social media and other sources to understand the pulse of citizens better and identify areas of concern. ML models finally make it possible to personalize communication with residents by informing them about relevant information and updates on city services and events. DL algorithms can further facilitate natural language processing and sentiment analysis, aiding city authorities to understand residents better for effective and responsive interaction. It enhances the sense of citizen participation with this kind of technology, hence creating urban settings that are more inclusive and responsive.

AI based crack detection system

Table 2.2 shows the AI based crack detection system. The AI-based crack detection system combines advanced techniques of data collection, replete sets of diverse datasets, and better preprocessing methods for both ML and DL models. This multifaceted approach embeds high accuracy with the robustness to crack detection for the existence of a wide range of industrial applications. This constitutes progress in automated structural health monitoring and predictive maintenance, harbouring cutting-edge AI-based technologies.

Table 2.2 AI based crack detection system

Stage	**Details**			
Data Collection	CCD / CMOS Sensors, Laser Scanner			
Datasets	CFD, GAPS384, AigleRN, EdmCrack600, CRACK500, DEEPCRACK, RDD			
Pre-Processing	Histogram Equalization, Filtering, Morphological Operations			
AI Based Crack Classification	**Machine Learning Approach**	**Deep Learning Approach**		
	- Support Vector Machine	**Image patch classification**	**Boundary box regression**	**Semantic segmentation**
	- K Nearest Neighbour - Naive Bayes	**-DCNN** **-VGG16** **-ALEXNET** **-RESNET**	**-Faster R-CNN** **-SSD** **-YOLO**	**-RNN** **-U NET** **-FCN** **-ZF NET**

Emerging technologies and their potential impact on smart and sustainable cities and infrastructure

Technologies that are more into action and play a very significant role in developing a city are related to the Internet of Things (IoT) (Jin, et al., 2014; Zanella et al., 2014; Rejeb et al., 2022). IoT enables the interconnection of devices surrounding a person, letting them transfer and receive data (Jin, et al., 2014; Rejeb et al., 2022). Under the concept of a smart city, IoT devices can include simple devices like street lights and traffic signals and complex devices like water meters and waste bins. Interconnected devices will collect an enormous amount of data, which, after analysis, can be used to optimize the city's operations. For example, sensor power adjustment at smart streetlights can be turned on/off automatically depending on the time of day or by sensing pedestrian presence, thereby saving energy. Case of intelligent traffic signals, on the other hand, operate their timing in real-time according to the situation of the comfort and reduce congestion and emissions (Chen, & Zhang, 2022; Ei Leen et al., 2023; Abdullah et al., 2023). These facilitate leveraging IoT to make cities urban environments more responsive and efficient. Table 2.3 shows the emerging technologies and their potential impact on smart and sustainable cities.

AI and ML also join in as significant components in the making of smart cities (Ahmed et al., 2022; Szpilko et al., 2023). AI can digest these vast volumes of data IoT devices produce and analyse them to make learned decisions and inferences. For example, in transportation, AI can be used to control traffic flows, pre-diagnose infrastructure maintenance, and even manage autonomous vehicles. A set of AI algorithms applied in energy management guarantees that energy is optimally distributed and consumed; renal energy sources are seamlessly fitted into the grid, reducing total energy consumption. AI-driven solutions can also help make a contribution towards enhancing public safety through the execution of predictive policing, wherein sets of data on crimes are analysed to foresee and prevent activities relating to crimes. Big data analytics constitutes another critical technology that underlies intelligent city initiatives (Khan et al., 2017; Soomro et al., 2019). Available capacities in the collection, processing, and analysis of large data are promising a deeper understanding of urban dynamics by city planners and managers. For example, through big data, it can be possible to deduce patterns of energy use, water consumption, or transportation habits, which are also valuable for resource allocation. Data analysis in public health can involve sources tracking diseases to allow a response.

Table 2.3 Emerging technologies and their potential impact on smart and sustainable cities

References	Technology	Description	Impact on Smart Cities	Impact on Sustainable Cities
Jin, et al., (2014); Zanella et al.,	IoT	Interconnected devices exchanging data	Enhances city services, traffic	Real-time resource

(2014); Rejeb et al., (2022)			management, efficiency	monitoring, reduces waste
Ahmed et al., (2022); Szpilko et al., (2023)	AI	Machines learning and decision-making	Optimizes operations, enhances public safety, improves services	Increases energy efficiency, supports monitoring, urban planning
Strohbach et al., (2015); Khan et al., (2017); Soomro et al., (2019)	Big Data Analytics	Analysis of large datasets	Improves urban planning, transport systems, services	Supports impact assessments, tracks consumption
Rao, & Prasad, (2018); Shehab et al., (2021)	5G Networks	High-speed, low-latency connectivity	Real-time communication, supports autonomous vehicles	Facilitates energy management, environmental monitoring
Kundu, (2019); Karale, & Ranaware, (2019); Huang, et al., (2022)	Blockchain	Secure, transparent transactions	Enhances security, governance, supply chain	Secure energy trading, waste management tracking
Farmanbar et al., (2019); David, & Koch, (2019); Jafari et al., (2023)	Smart Grids	Digital technology in electrical grids	Optimizes energy, integrates renewables	Reduces waste, supports renewables
Burns et al., (2020); Biloria, (2023)	Autonomous Vehicles	Self-navigating vehicles	Reduces congestion, improves public transport, road safety	Lowers emissions, reduces parking needs
Thellufsen et al., (2020); Lewandowska et al., (2020); Hoang, & Nguyen, (2021)	Renewable Energy	Harnessing renewable energy sources	Increases renewables, lowers carbon footprint	Promotes sustainable energy, reduces emissions
Chew et al., (2020); Das et al., (2023)	Smart Buildings	Tech-enhanced buildings	Enhances efficiency, occupant comfort	Reduces energy consumption, promotes efficiency

White et al., (2021); Cureton, & Dunn, (2021); Qian et al., (2022)	Digital Twins	Virtual replicas for simulation	Improves planning, infrastructure management	Efficient resource management, impact assessments
Jain et al., (2021); Gohari et al., (2022)	Urban Drones	UAVs for delivery, surveillance, inspection	Enhances logistics, emergency response	Reduces congestion, supports monitoring

Blockchain technology has exciting applications in replicability, security, and transparency for city services (Kundu, 2019; Karale, & Ranaware, 2019). New decentralized and immutable ledger blockchain technology can be used to perform very secure transactions and manage frequently changing data. It ensures secure, transparent voting systems that help to uphold electoral integrity in intelligent cities. Blockchain can also be applied in supply chain management to track down the origin and movement of goods, promoting sustainability and reducing fraud. That also mean that blockchain supports the development of smart contracts-self-executing contracts with the terms directly written into code. These contracts can automate and streamline various administrative processes, reducing bureaucracy and increasing efficiency. The deployment of 5G networks will be the game-changer in intelligent cities connectivity. The inherent features and functionalities of 5G, high speed, very low latency, and huge capacity, have turned it into an enabler of seamless operation for IoT devices, real-time data analytics, and highly developed communication services. From autonomous vehicles to intelligent grids, telemedicine, or even remote education, the protean applications supported by 5G have made it hugely successful (Rao, & Prasad, 2018; Shehab et al., 2021). For instance, in the transport sector, 5G can facilitate vehicle-to-everything communication and vehicle-to-everything (V2X), vehicle interactions with other vehicles and infrastructures to improve safety and efficiency. In health, 5G can help with remote surgery and real-time monitoring of patients to increase access to medical care.

This can contribute to sustainable urban environments and is integrated within such emerging technologies. On the one hand, IoT and AI techniques will make smart grids ensure optimization in energy production and consumption, incorporate renewable energy sources, and bring down carbon footprints (Lewandowska et al., 2020; Hoang, & Nguyen, 2021). Intelligent water management systems can monitor water usage, detect leaks, and ensure efficient distribution, thereby saving this resourceful element. The IoT can facilitate better waste management by making IoT-enabled sensors track waste levels and optimize collection routes to reduce fuel consumption and gas emissions in the long term. Among the significant components of urban infrastructure, one area that will benefit greatly from these technologies is transportation. AI and 5G-driven autonomous vehicles can become a panacea for traffic accidents, congestion reduction, and emissions reduction. Intelligent public transit systems, with traveller information provided in real-time, will make traveling by transit much more efficient and user-friendly. In addition, intelligent digital platforms enable electric and shared mobility solutions that foster sustainable modes of transport.

Another area of impact for emerging technologies is intelligent buildings and infrastructure (Chew et al., 2020; Das et al., 2023). IoT sensors in an intelligent building could significantly monitor and control lighting, heating, ventilation, and air conditioning (HVAC), and other similar systems to optimize energy use and comfort. Such buildings can exploit renewable sources of energy like solar panels and utilize energy storage systems for demand management. Digital twin technologies can create replicas in the virtual space for physical assets in construction. Therefore, they can increase the sustainability and resilience of built infrastructure by improving design, construction, and maintenance activities. Digital technologies also contribute to public safety and security. For instance, AI-enabled surveillance devices can analyse video feeds in real time to identify any suspicious activity and alert the concerned authority of any threat. IoT devices helpful during disaster management by sending early warnings to different authorities so that emergency responses can be initiated on time. Furthermore, blockchain will ensure integrity and security for critical data against cyber threats.

Fig. 2.2 summarizes the various industrial systems: robotics and automation systems, advanced sensing and monitoring systems, programmable logic controllers, building management systems, human-machine interface, and predictive maintenance systems. In this research, each technology has been taken into consideration with its associated benefits and drawbacks. The advantages include increased productivity, cost reduction, quality control, and energy optimization. Contrasted to these benefits are the drawbacks related to huge upfront investment costs, maintenance, and integration problems. Such a detailed comparison would go on to highlight the critical factors that need consideration while deciding on the implementation of these industrial systems.

The participants follow an experimental procedure for performing some tasks and then answer evaluation questionnaires. This information is detailed in Table 2.4. The experiment will first be introduced, followed by signing consent forms by the participants as shown. After that, the collaboration process is explained, and training of the participants is conducted. Upon completing the training, a detailed explanation of the first task is presented, and the participants carry out the task. On completion of the first task, the NASA-TLX questionnaire is administered to obtain information about the perceived workload about the task. Afterward, instructions concerning the second task are presented, and the participants perform this task too. At the end of the second task, participants are requested to fill in the NASA-TLX and an acceptability questionnaire, thus ending the procedure. This is a step-by-step procedure for the systematic assessment of participants' performances on tasks, as well as their perceptions relevant to these tasks.

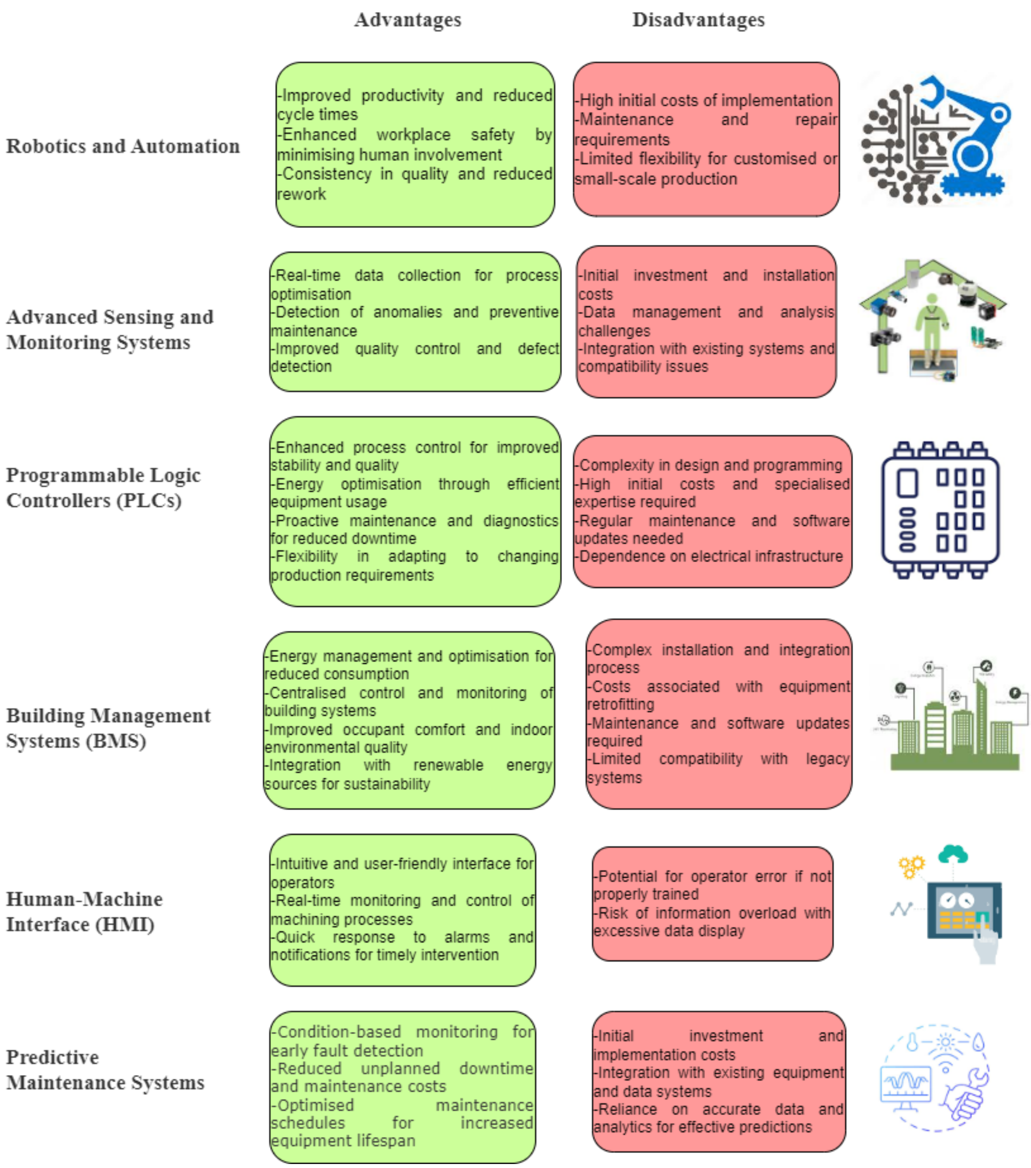

Fig. 2.2 The role of industrial devices in sustainable machining: advantages and disadvantages

Table 2.4 Illustration of the experimental approach

Steps	The experimental procedure
1	Presentation of the experiment
2	Signing of consentments
3	Explanation of the collaboration
4	Training period
5	Explanation of the first task.
6	Realization of Task 1
7	Answering NASA-TLX
8	Explanation of the second task
9	Realization of the second task
10	The participant will then respond to the NASA-TLX and acceptability questionnaire.

2.4 Conclusions

The significance of AL, ML, and DL technologies in strengthening urban performance in terms of efficiency, sustainability, and livability has been accentuated by recent advancements. AI-based software helps analyse data in real-time as well as creates predictive models that are vital for promoting smart-use of urban resources. For example, it prevents traffic jams by means of intelligent traffic management systems, making an important contribution to environmental protection. ML algorithms play a vital role in managing the energy consumption of smart grids, maintaining an equilibrium of the energy resources with the energy demand, and also to deal with renewable energy resources, without any obstacles. Thanks to DL, the discipline that can process lots of data, the intelligent structure in human/municipal services or infrastructure initiated earlier, also may become more sophisticated. DL models can process satellite imagery and sensor data for real-time tracking of the health of infrastructure, enabling predictive maintenance to ensure the resilience of an urban infrastructure. This technology also helps a lot in the field of waste management where intelligent bots can sort the waste products more effectively, leading to better recycling initiatives and lesser use of landfills. A recent emphasis on the integration of ethical AI principles is what should prevent these advancements from being made at the detriment of privacy and security. To earn citizen trust and to protect sensitive information, they are now adopting more transparent AI frameworks, more substantial safeguards for data. This interdependence of technology developers with urban planners and policymakers needs to continue if we are to tap into the full potential of these technologies to create liveable, just, and environmentally sustainable cities.

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