Volume 15 • Issue 4 • 2023

received: 1 May 2023
accepted: 10 November 2023

pages: 53-75

Artificial intelligence in the smart city — a literature review

Danuta Szpilko
Felix Jimenez Naharro
George Lăzăroiu
Elvira Nica
Antonio de la Torre Gallegos

Danuta Szpilko
Bialystok University of Technology, Poland
ORCID 0000-0002-2866-8059
Corresponding author:
d.szpilko@pb.edu.pl

Felix Jimenez Naharro
University of Seville, Spain
ORCID 0000-0001-9217-2624

George Lăzăroiu
Curtin University, Australia
Toronto Metropolitan University/ICCL, Canada
ORCID 0000-0002-3422-6310

Elvira Nica
Bucharest University of Economic Studies, Romania
ORCID 0000-0002-7383-2161

Antonio de la Torre Gallegos
University of Seville, Spain
ORCID 0000-0001-7839-0385

A B S T R A C T
The influence of artificial intelligence (AI) in smart cities has resulted in enhanced efficiency, accessibility, and improved quality of life. However, this integration has brought forth new challenges, particularly concerning data security and privacy due to the widespread use of Internet of Things (IoT) technologies. The article aims to provide a classification of scientific research relating to artificial intelligence in smart city issues and to identify emerging directions of future research. A systematic literature review based on bibliometric analysis of Scopus and Web of Science databases was conducted for the study. Research query included TITLE-ABS-KEY ("smart city" AND "artificial intelligence") in the case of Scopus and TS = ("smart city" AND "artificial intelligence") in the case of the Web of Sciences database. For the purpose of the analysis, 3101 publication records were qualified. Based on bibliometric analysis, seven research areas were identified: safety, living, energy, mobility, health, pollution, and industry. Urban mobility has seen significant innovations through AI applications, such as autonomous vehicles (AVs), electric vehicles (EVs), and unmanned aerial vehicles (UAVs), yet security concerns persist, necessitating further research in this area. AI's impact extends to energy management and sustainability practices, demanding standardised regulations to guide future research in renewable energy adoption and developing integrated local energy systems. Additionally, AI's applications in health, environmental management, and the industrial sector require further investigation to address data handling, privacy, security, and societal implications, ensuring responsible and sustainable digitisation in smart cities.

K E Y   W O R D S
smart city, artificial intelligence, energy, safety, living, pollution, mobility, transport, industry, health, Internet of Things, big data, blockchain, machine learning, European Green Deal, bibliometric analysis

10.2478/emj-2023-0028

Introduction

With increasing urbanisation worldwide, cities are turning to innovative, specialised technologies to address social, economic, environmental, and other challenges. Artificial intelligence (AI) has been increasingly recognised as a transformative tool, holding the potential to revolutionise city development. With its capabilities to learn, predict, and potentially operate autonomously, AI offers a wealth of opportunities for developing and managing smart cities. Its applications span various areas, from pre-

Szpilko, D., & Jimenez Naharro, F., Lăzăroiu, G., Nica, E., & de la Torre Gallegos, A. (2023). Artificial intelligence in the smart city — a literature review. *Engineering Management in Production and Services, 15*(4), 53-75. doi: 10.2478/emj-2023-0028

dictive maintenance and enhanced citizen services to improved sustainability initiatives. However, despite its growing prevalence, a comprehensive understanding of AI's role, its range of applications in smart cities, and the potential implications are currently lacking.

As a technological tool, AI can significantly contribute to integrating pivotal smart city dimensions, such as living, people, economy, mobility, environment, and government. AI and other advanced techniques have shown great promise in developing optimal policies to tackle complex issues intrinsic to the evolution of smart cities, ranging from intelligent transportation systems and cybersecurity to energy-efficient smart grids and smart healthcare systems.

However, the application of AI in smart cities has its risks. The same power that allows AI to drive urban transformations also presents a slew of challenges. Ensuring ethical AI application, maintaining data privacy, and mitigating the potential for AI misuse are among the top concerns in this emerging field. It is also critical to remember that the shift towards an AI-driven city can exacerbate social inequalities and create a digital divide among citizens if not managed thoughtfully.

Given the topic's relevance related to the application of artificial intelligence in a smart city, this article aims to classify scientific research relating to artificial intelligence in smart city issues and identify emerging directions for future research. The methodology used in this study combines a systematic literature review to identify the most relevant studies and new topics to be developed in the future. The research shows the scope and importance of AI in smart city development and the challenges it brings to cities and citizens.

1. Literature review

As the global urban population is projected to surge to 66 % or 70 % by 2050 (O'Dwyer et al., 2019), there are escalating concerns about the environmental, managerial, and security impacts. In response to this challenge, smart cities which heavily rely on information and communication technologies (ICTs) have been proposed and realised in various nations (Aguilera et al., 2017; Alifi & Supangkat, 2016; Al_Turjman & Baali, 2022; Galindo, 2014; Yamakami, 2017; Szpilko et al., 2020). Smart cities integrate different technologies, such as the Internet of Things, blockchain, artificial intelligence, machine learning (ML), and deep reinforcement learning (DRL), to provide comprehensive solutions (Alam et al., 2017; Ali et al., 2020; Allam et al., 2019; Allam & Dhunny, 2019; Chen et al., 2021; Liu et al., 2019; Bilan et al., 2022).

AI emerged in 1956 but developed slowly because of immature computational technologies. Now, it is deployed at a scale of cities (Yigitcanlar et al., 2020). Its diverse computational technologies range from rule-based systems to deep learning systems, and these technologies play increasingly critical roles in the delivery of public services (Ma et al., 2020; Wirtz et al., 2019). For instance, Robotic Process Automation (RPA) projects are automating mundane, repetitive, and costly tasks, freeing up valuable resources (Mendling et al., 2018; Siderska et al., 2023).

The AI role in managing the massive amounts of data generated by IoT, a crucial component of smart city applications, cannot be overstated (Al-Turjman et al., 2021; Ullah, Al-Turjman, Mostarda et al., 2020). By employing AI, ML, and DRL techniques, cities can harness and analyse this data to make optimal decisions (Allam et al., 2019; Allam & Dhunny, 2019; Liu et al., 2019). It is important to note that the accuracy and precision of these technologies can be further enhanced by increasing the amount of training data, thereby strengthening their learning capabilities and improving automated decision efficiencies (Ullah, Al-Turjman, Mostarda et al., 2020).

Significant strides have been made in such different sectors as intelligent transportation, cybersecurity, smart grids, and UAVs-assisted next-generation communication in smart cities (Allam & Newman, 2018). AI, ML, and DRL technologies play a transformative role in these sectors by enhancing their efficiency and scalability (Ferdowsi et al., 2019).

Intelligent transportation systems have integrated ML and DRL-based technologies in various applications, including self-driving vehicles, ensuring the security of connected vehicles, efficient passenger hunting, and safe travels (Ang et al., 2022; Ferdowsi et al., 2019; Wences et al., 2017). Similarly, the role of AI, ML, and DRL technologies in cybersecurity is outstanding, with significant impacts on almost all sectors of a smart city (Ullah, Al-Turjman, Mostarda et al., 2020). Furthermore, AI continues to revolutionise energy generation, management, and consumption within smart cities, underscoring its far-reaching implications for societal and economic development (Golinska-Dawson & Sethanan, 2023; Muhammad et al., 2019; Pramod et al., 2023).

Autonomous vehicles are also explored as a modernisation tool for public transport infrastructure

(Gaber et al., 2020; Toglaw et al., 2018). Furthermore, smart cities are venturing into using robotics for law enforcement to lower conflict incident rates and free up human resources (Galindo, 2014; Hu & Jiang, 2019; Ma et al., 2018). The utilisation of AI and ML in predicting and preventing incidents is also gaining traction. For example, an efficient crime detection system for smart cities has been proposed utilising DRL and neural networks to identify and analyse criminal activity (Castelli et al., 2017; Diro & Chilamkurti, 2018; David et al., 2023). Likewise, an ML-based architecture has been put forward to predict incidents and generate responses before their occurrence (Aqib et al., 2020). As AI and ML become increasingly integrated into urban governance, there is the potential for more sustainable, safe, inclusive, and resilient cities (Allam & Newman, 2018; Choudhary & Sarthy, 2022; Lourenco et al., 2018).

Through AI and associated technologies like ML and DRL, cities can harness and analyse big data, improve decision-making, enhance public services, and foster more sustainable and resilient urban environments. However, it is crucial to consider the societal implications of such technologies to avoid potential pitfalls and maximise the benefits. Ethical considerations surrounding the use of artificial intelligence in smart cities are also crucial, particularly regarding data privacy, bias, and potential impacts on citizen rights and autonomy. Balancing technological advancements with ethical guidelines is essential to ensure responsible and inclusive AI integration in urban environments.

2. Research methods

The literature on artificial intelligence in smart cities was examined using a bibliometric analysis approach. This method is frequently employed by researchers, especially when first exploring a specific research topic. With a vast number of publications available, it facilitates the identification, synthesis, analysis, and critical evaluation of their contents (Bornmann & Haunschild, 2017; Keathley-Herring et al., 2016). Utilising quantitative techniques allows for the identification of the current state and developmental trends in the research area under consideration. The results provide insights into the main research directions, trends, and changes in the number of publications over a specific period. Moreover, it enables the creation of rankings for the most productive authors, journals, research units, and countries within the field of research (Niñerola et al., 2019; Szum, 2021). Bibliometric analysis is applicable to well-established research areas in the literature (Winkowska et al., 2019; Gudanowska, 2017; Glińska & Siemieniako, 2018; Halicka, 2017), as well as emerging ones (Siderska & Jadaan, 2018; Szpilko, 2017).

Table 1 illustrates the operationalisation of the process employed in this article using the bibliometric analysis method.

The research process was conducted following a methodology comprising seven distinct phases. These phases encompassed the selection of bibliographic databases (I), the choice of keywords (II), and the criteria to narrow down the search for publications (III). Subsequently, data extraction and selection (IV) was performed, followed by the analysis of the selected publications (V). The last two phases involved identifying research areas (VI) and defining thematic clusters (VII) (Table 1).

In the initial phase of the study, the researchers opted for Scopus and Web of Science bibliographic databases, as they offered a comprehensive array of scientific publications. The selection of these databases was driven by their wide availability and thematic coverage across various scientific disciplines. The bibliometric analysis began by focusing on publications that contained the specific terms “smart city” and “artificial intelligence”. In the first and second samples, the search encompassed publications with this phrase throughout the entire document, while the third sample included titles, abstracts, and keywords.

To refine the search, certain restriction criteria were applied. The search was limited to materials published between 2010 and 2023. For further analysis, articles, conference proceedings, books, book chapters, reviews, editorials, early access and short survey publications were considered eligible. On the other hand, publication types like retracted publications, conference reviews, notes, erratum, and letters were excluded. The outcomes of the search are presented in Table 2.

The initial search for the term “smart city AND artificial intelligence” across the entire set of papers in the first sample yielded 107475 records in Scopus and 3250 records in Web of Science. However, upon the initial analysis, it became evident that many of these publications were not directly relevant to the study area. The search in the second attempt, enclosing the keywords in quotation marks (“smart city” AND

Tab. 1. Methodology of bibliometric analysis

No.	Task	Scope
1.	Database selection	Scopus, Web of Science
2.	Keywords selection	"smart city" AND "artificial intelligence" in topic
3.	Criteria selection	Period: 2010–2023 Document types: articles, proceedings papers, conference papers, books, book chapters, editorial materials, reviews, early access, short survey
4.	Data extraction, removal of duplicates	Criteria for deleting duplicates: DOI, title, authors
5.	Quantitative analysis of the results	Scope: number of publications per year, document types, the most productive authors, institutions, countries, journals
6.	Identification of research areas	Visualisation of the most frequent keywords
7.	Creation of thematic clusters	Visualisation of thematic clusters

Tab. 2. Search results

Stage	Web of Science	Scopus
First search		
Research query	ALL=smart city AND artificial intelligence	ALL (smart city AND artificial intelligence)
Number of articles before inclusion criteria	3250	107475
Number of articles after inclusion criteria	3216	105672
Second search		
Research query	ALL= "smart city" AND "artificial intelligence"	ALL ("smart city" AND "artificial intelligence")
Number of articles before inclusion criteria	1464	69049
Number of articles after inclusion criteria	1463	68660
Third search		
Research query	TS="smart city" AND "artificial intelligence"	TITLE-ABS-KEY ("smart city" AND "artificial intelligence")
Number of articles before inclusion criteria	1237	3014
Number of articles after inclusion criteria	1237	2896

Source: elaborated by the authors based on the Scopus and Web of Science databases.

"artificial intelligence"), also did not yield satisfactory results. As a result, a third attempt was made, restricting the search only to publications containing the specified phrase in their titles, abstracts, and keywords. Subsequently, the refined search produced 3014 records in Scopus and 1237 in Web of Science. After applying the limiting criteria, 2896 records in Scopus and 1237 in Web of Science were obtained. The search results are detailed in Table 2.

Full records in *csv format were downloaded from each database, and these files were aggregated into one, resulting in a total of 4133 records. After eliminating duplicates, a subset of 3101 records was selected for further analysis.

Based on the acquired dataset, various analyses were conducted to examine the number of publications within specific periods and identify the most productive authors, organisations, countries, and journals. The research also focused on identifying the most notable articles with the highest frequency of citations.

Furthermore, a thorough investigation of commonly recurring keywords was conducted, leading to the creation of a map depicting the co-occurrence of keywords associated with the application of artificial intelligence in smart cities. The creation of the keyword co-occurrence map was accomplished using VOSviewer software (version 1.6.19).

To ensure accuracy and relevance, a thesaurus file was additionally prepared (van Eck & Waltman, 2018) to eliminate duplicate terms with similar meanings (e.g., Internet of Things and IoT) or terms not relevant to the study (e.g., article, research, analysis). This file was developed based on keyword analysis and a thorough review of the publication collection. The outcome of this analysis allowed for the identification of thematic clusters representing the main and emerging research directions.

3. Research results

In the initial phase of the study, an examination was carried out to assess the interest in the subject matter over the years. Additionally, the predominant types of publications were identified, along with their connections to the primary subject areas in the Scopus and Web of Science databases.

Between 2018 and 2023, a significant number of publications emerged in both databases (Fig. 1). Prior to this period, references to AI in smart cities were infrequent, representing an "emerging thematic". The total number of citations for publications indexed in the Scopus database was 31 783, while in Web of Science, it amounted to 15 665. There were 865 uncited publications in Scopus and 343 in Web of Science.

In the Web of Science and Scopus databases jointly, the majority of publications consisted of articles (63.5 % and 32.5 %, respectively) and conference papers (50.5 % and 25.1 %). Reviews, editorials, and book chapters made up a smaller portion. The distribution of publications by document type is depicted in Fig. 2.

The preponderance of literature in both databases is primarily allocated to the domains of Engineering,

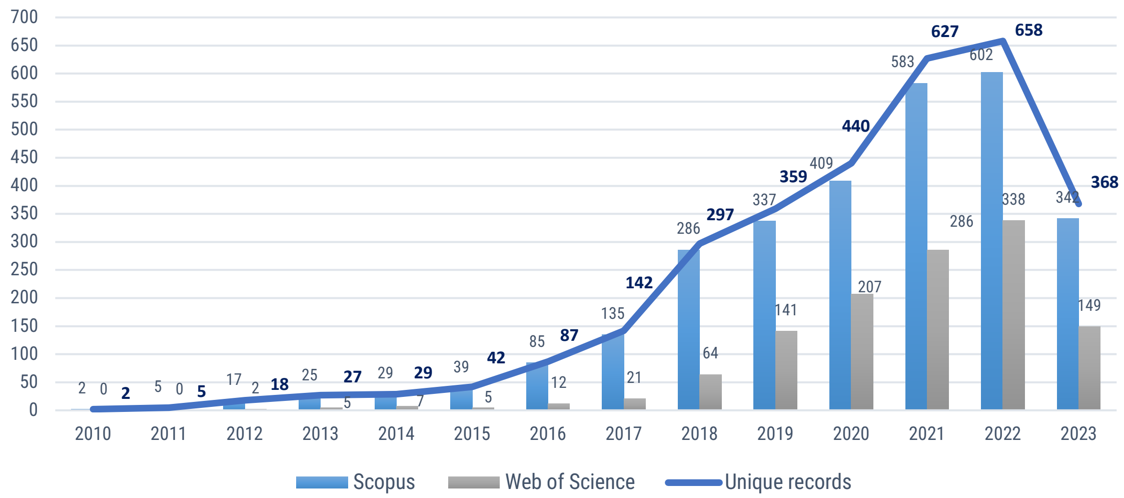

Fig. 1. Number of publications in the field of artificial intelligence in smart cities in the Scopus and Web of Science databases (indexed from January 2010 to July 2023)

Source: elaborated by the authors based on the Scopus and Web of Science databases.

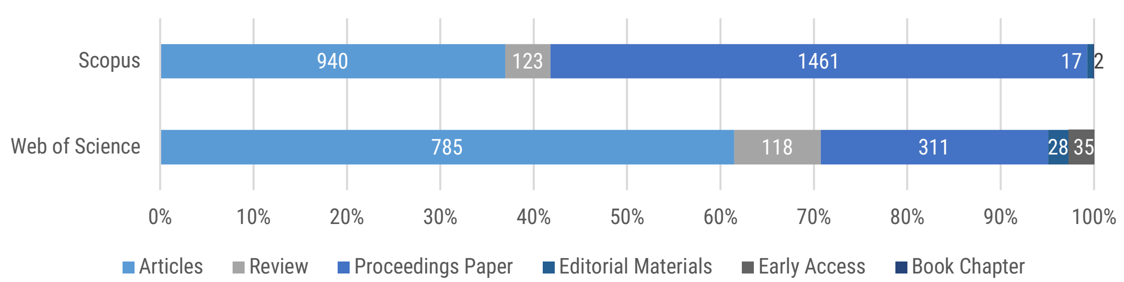

Fig. 2. Type of documents of publications in the field of artificial intelligence in smart cities in the Scopus and Web of Science databases (indexed from January 2010 to July 2023)

Source: elaborated by the authors based on the Scopus and Web of Science databases.

specifically Electrical and Electronic Engineering and Computer Science (Computer Science Information Systems). Specifically, these represent 77.5 % and 44.9 % of all entries in Scopus and 33.1 % and 29.4 % in the Web of Science. Furthermore, a considerable amount of literature in Scopus is also categorised under Social Sciences (17.8 %) and Mathematics (15.9 %), whereas in Web of Science, a significant percentage is attributed to Telecommunications (23.4 %).

The most productive author in this regard is Yigitcanlar, with 16 publications. The most referenced piece by Yigitcanlar et al. is "Contributions and risks of artificial intelligence (AI) in building smarter cities: Insights from a systematic review of the literature" from 2020 and "Can building 'artificially intelligent cities' safeguard humanity from natural disasters, pandemics, and other catastrophes? An urban scholar's perspective" from the same year, amassing 161 and 140 citations in Scopus, respectively. Next is Mehmood, with 14 publications, who held the highest average citation count per publication in both databases. His most cited piece was "Data Fusion and IoT for Smart Ubiquitous Environments: A Survey", published in IEEE Access in 2017, with 254 citations in Scopus and 195 in Web of Science. Allams' (and Dhunny's) most referenced publication was "On big data, artificial intelligence and smart cities", published in Cities in 2019, amassing 456 citations in Web of Science and 305 in Scopus. Table 3 provides a comprehensive list of the most productive authors.

With regard to geographical distribution, the majority of the publications are from China (550), followed by India (495) and the United States (316). Considering author affiliation, King Abdulaziz University produced the highest number of publications (36), followed closely by the Egyptian Knowledge Bank EKB (32) and Universidad de Salamanca (25). Notably, publications from the Queensland University of Technology (Scopus: 36.4, WoS: 28.0), the Chinese Academy of Sciences (Scopus: 25.2, WoS: 45.3), and the King Abdulaziz University (Scopus: 26.9, WoS: 29.2) have been cited most frequently. Compared to other institutions in the ranking, they have a notably high average citation count in both Scopus and the Web of Science databases.

In the ranking of most productive journals, Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes In Bioinformatics took the top spot (134 publications), followed by Advances in Intelligent Systems and Computing with 108 publications, and IEEE Access with 63 publications. However, the journals with the highest average citation count in each database were IEEE Access (Scopus: 38.8, WoS: 26.6) and Sensors (Scopus: 32.9, WoS: 11.3).

The cumulative citation count for publications focusing on artificial intelligence in the context of smart cities amounted to 15665 in the Web of Science and 31783 in Scopus. Among the eleven most cited works, two were published in IEEE Access and Future Generation Computer Systems, while SN Computer Science, Cities, Advanced Materials, Proceedings — 2015 IEEE International Conference on smart city, Healthcare, Computer Communications, and Sustainable Cities and Society each contributed one. Notably, six of these top-cited works originated from the year 2020.

The most cited publication, with 619 citations in Scopus and 392 in the Web of Science, was by Fuller et al. (2020), "Digital Twin: Enabling Technologies, Challenges and Open Research". Next was the article by Diro and Chilamkurti (2018), "Distributed Attack Detection Scheme using Deep Learning Approach for Internet of Things", and the article by Allam and Dhunny (2019), "On Big Data, Artificial Intelligence and Smart Cities". The total citation counts for these articles were somewhat lower than for the first, with Scopus counts of 537 and 456 and Web of Science counts of 402 and 305, respectively (Table 4).

In the context of the bibliometric analysis, keywords recurrently associated with the subject of artificial intelligence in smart cities were extracted. The analytical process employed the use of VOSviewer software. The resulting collection consisted of 380 words or phrases that occurred a minimum of five times in the keywords of the 3101 articles examined. This collection also included words synonymous with abbreviations or repetitions (i.e., "Internet of Things", "internet-of-things", "IoT", "neural-network", and "neural-networks") and terms not intrinsically related to the central theme of analysis (such as "article", "analysis", "model", "knowledge", "literature review"). A thesaurus file was curated and deployed to systematise the word set. Search keywords (e.g., "artificial intelligence", "AI", "smart city", "smart cities") were purposely excluded from this collection. The nomenclature of terms and abbreviations sharing similar meanings was standardised, and terms unrelated to the analysis were discarded. The refined collection included 166 keywords. The most prevalent terms and their interconnections are depicted in Fig. 3.

Tab. 3. Most productive authors, organisations, countries and journals

No.	Item	NP	[%]	Average citation count	
				Scopus	Web of Science
Authors					
1.	Yigitcanlar, T.	16	0.5	48.2	35.4
2.	Mehmood, R.	14	0.5	51.9	143.5
3.	Allam, Z.	12	0.4	113.3	63.2
4.	Al-Turjman, F.	11	0.4	45.4	58.4
5.	Park, J.H.	11	0.4	56.4	39.0
6.	Corchado, J.M.	11	0.4	37.7	36.1
7.	Chui, K.T.	9	0.3	28.9	38.5
8.	Lytras, M.D.	9	0.3	26.3	36.0
9.	Lv, Z.	8	0.3	25.5	19.4
10.	Aloqaily, M.	8	0.3	25.6	17.8
Countries					
1.	China	550	17.7	10.8	15.0
2.	India	495	16.0	8.2	12.5
3.	United States	316	10.2	17.0	17.5
4.	United Kingdom	201	6.5	19.5	18.7
5.	Saudi Arabia	163	5.3	16.2	15.5
6.	Italy	162	5.2	10.8	13.0
7.	Spain	148	4.8	10.4	12.6
8.	South Korea	126	4.1	17.9	17.1
9.	Australia	114	3.7	40.9	24.9
10.	Canada	94	3.0	14.8	14.1
Organisations					
1.	King Abdulaziz University	36	1.2	26.9	29.2
2.	Egyptian Knowledge Bank EKB	32	1.0	N/A	6.6
3.	Universidad de Salamanca	25	0.8	19.0	18.9
4.	King Saud University	23	0.7	12.8	12.3
5.	Amity University	22	0.7	5.7	12.3
6.	Chinese Academy of Sciences	21	0.7	25.2	45.3
7.	Queensland University of Technology	19	0.6	36.4	28.0
8.	University of Ottawa	18	0.6	21.5	14.3
9.	Wuhan University	18	0.6	8.1	4.5
10.	Vellore Institute of Technology	17	0.5	16.7	12.6
11.	Universidade do Minho	17	0.5	3.2	5.6
12.	N8 Research Partnership	17	0.5	N/A	9.9
Journals					
1.	Lecture Notes in Computer Science, Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	134	4.3	6.5	1.8
2.	Advances in Intelligent Systems and Computing	108	3.5	2.6	0.9
3.	IEEE Access	63	2.0	38.8	26.6
4.	ACM International Conference Proceeding Series	59	1.9	3.7	4.0
5.	Sensors (Switzerland)	55	1.8	32.9	11.3
6.	Sustainability (Switzerland)	53	1.7	18.6	13.7
7.	Lecture Notes in Networks and Systems	50	1.6	1.0	0.1
8.	Communications in Computer and Information Science	44	1.4	3.6	1.9
9.	MCCSIS 2018 Multi Conference on Computer Science and Information Systems Proceedings of the International Conferences on Big Data Analytics Data Mining and Computational Intelligence 2018 Theory and Practice in Modern Computing 2018 and Connected Smart Cities 2018	33	1.1	0.4	N/A
10.	Ceur Workshop Proceedings	30	1.0	1.0	1.0
11.	Smart Cities	30	1.0	24.0	12.2

Note: NP — number of publications, [%] — percentage of the total number of publications (3101), N/A — not applicable.

Source: elaborated by the authors based on the Scopus and Web of Science databases.

Tab. 4. Most cited articles on artificial intelligence in the smart city area

No.	Authors	Article title	Journal	Number of citations	
				Scopus	Web of Science
1.	(Fuller et al., 2020)	Digital Twin: Enabling Technologies, Challenges and Open Research	IEEE Access	619	392
2.	(Diro & Chilamkurti, 2018)	Distributed Attack Detection Scheme using Deep Learning Approach for Internet of Things	Future Generation Computer Systems	537	402
3.	(Allam & Dhunny, 2019)	On Big Data, Artificial Intelligence and Smart Cities	Cities	456	305
4.	(J. Shi et al., 2020)	Smart Textile-Integrated Microelectronic Systems for Wearable Applications	Advanced Materials	332	356
5.	(Sarker, 2021)	Machine Learning: Algorithms, Real-World Applications and Research Directions	SN Computer Science	710	N/A
6.	(Tian & Pan, 2015)	Predicting Short-Term Traffic Flow by long Short-Term Memory Recurrent Neural Network	Proceedings - 2015 IEEE International Conference on Smart City	350	281
7.	(Allam & Jones, 2020)	On the Coronavirus (Covid-19) Outbreak and the Smart City Network: Universal Data Sharing Standards Coupled with Artificial Intelligence (AI) to Benefit Urban Health Monitoring and Management	Healthcare	272	187
8.	(Alam et al., 2017)	Data Fusion and IoT for Smart Ubiquitous Environments: A Survey	IEEE Access	254	195
9.	(Ullah et al., 2020)	Applications of Artificial Intelligence and Machine Learning in Smart Cities	Computer Communications	271	176
10.	(S. K. Singh et al., 2020)	BlockIoTIntelligence: A Blockchain-enabled Intelligent IoT Architecture with Artificial Intelligence	Future Generation Computer Systems	241	170
11.	(S. Singh et al., 2020)	Convergence of Blockchain and Artificial Intelligence in IoT Network for the Sustainable Smart City	Sustainable Cities and Society	240	153

Note: N/A — not applicable.

Source: elaborated by the authors based on the Scopus and Web of Science databases.

To clearly present the obtained results, the co-occurrence map was reduced to 86 keywords strictly linked to the area under investigation. Among the most frequent keywords related to artificial intelligence in the context of a smart city are terms associated with technological aspects — Internet of Things (655), machine learning (408), big data (253), deep learning (207), cloud computing (121), blockchain (111). These are interconnected with artificial intelligence and are closely linked with keywords identified in seven clusters, encompassing issues related to the development of a smart city. Within these individual clusters, the most frequently appearing keywords were safety — security (91) and privacy (54); energy — energy (69), smart grid (52); mobility — Intelligent Transport Systems (61) and traffic management (52); health — healthcare (52) and digital twin (49); living — smart building (41) and smart home (35); industry — industry 4.0 (42); pollution — smart waste management (21). The larger the circle in Fig. 6, the more often a given keyword occurs. It should also be highlighted that these terms exhibit the most connections to other terms.

An in-depth analysis of the most frequently occurring keywords allowed for identifying seven thematic clusters and linking them to the eight transformative policies of the European Green Deal (EDG). In the context of smart city development, the European Green Deal strategy, implemented in 2020, plays a significant role. This strategy is the European Union's plan to make the EU climate-neutral by 2050 and to chart a course towards economic development

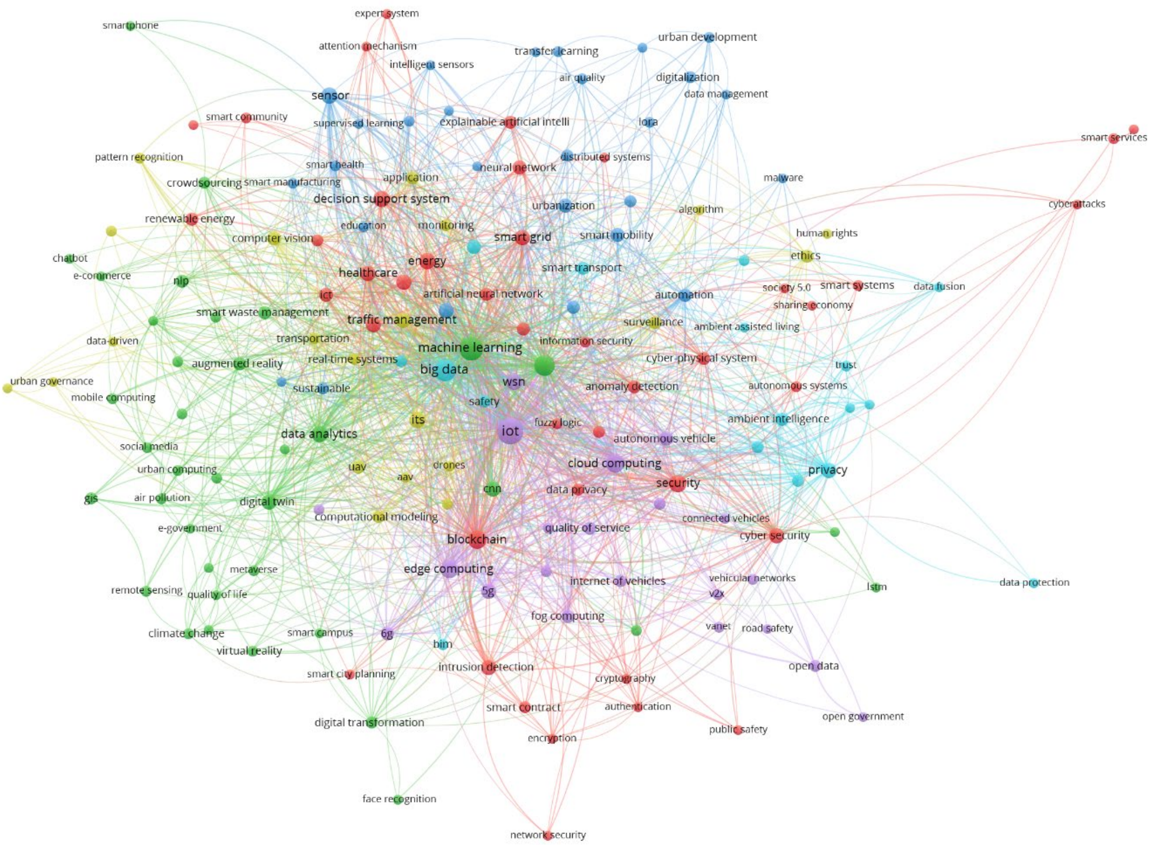

Fig. 3. Keyword co-occurrence map for artificial intelligence in smart cities
Source: elaborated by the authors using VOSviewer software.

that does not increase the consumption of natural resources. The EGD is a key component of the current European Commission's strategy for the fulfilment of the UN 2030 Agenda for Sustainable Development and the Sustainable Development Goals (United Nations, 2015). The European Green Deal serves as a blueprint, outlining the path towards a sustainable European economy. The primary target of the European Green Deal strategy is to achieve a minimum 55 % reduction in net greenhouse gas emissions by 2030, using 1990 levels as a benchmark, and to reach climate neutrality by 2050 (Communication …, 2019). The overarching aim of the European Green Deal strategy is to make sustainable development and human well-being the cornerstone of economic policy, positioning them as a crucial aspect of all policymaking decisions and ensuing actions (Amoroso et al., 2021; Szpilko & Ejdys, 2022). Due to the significant issue of implementing the European Green Deal in EU regions and cities, the identified subareas of artificial intelligence in smart cities were related to its policies (Table 5).

The first cluster, "Safety", primarily refers to areas in which the application of artificial intelligence can ensure safety in smart cities (e.g., privacy, public safety, security, cyber security, cyberattacks, data privacy, data protection, e-commerce, e-government, monitoring, open data, open government, smart environment, smart infrastructure, smart services, intrusion detection, anomaly detection, trust, ethics, human rights). This cluster is closely linked to the transformative policy of the European Green Deal, which involves, among other things, supplying clean, affordable and secure energy and mobilising industry for a clean and circular economy. It is also related to zero pollution and striving for a toxin-free environment.

The second cluster, "Living", focuses on ensuring the highest possible standard of living for residents in smart cities through the use of artificial intelligence. It includes keywords such as quality of life, sharing economy, smart city 5.0, smart community, smart education, smart government, smart home, air quality, smart building, disaster management, society 5.0,

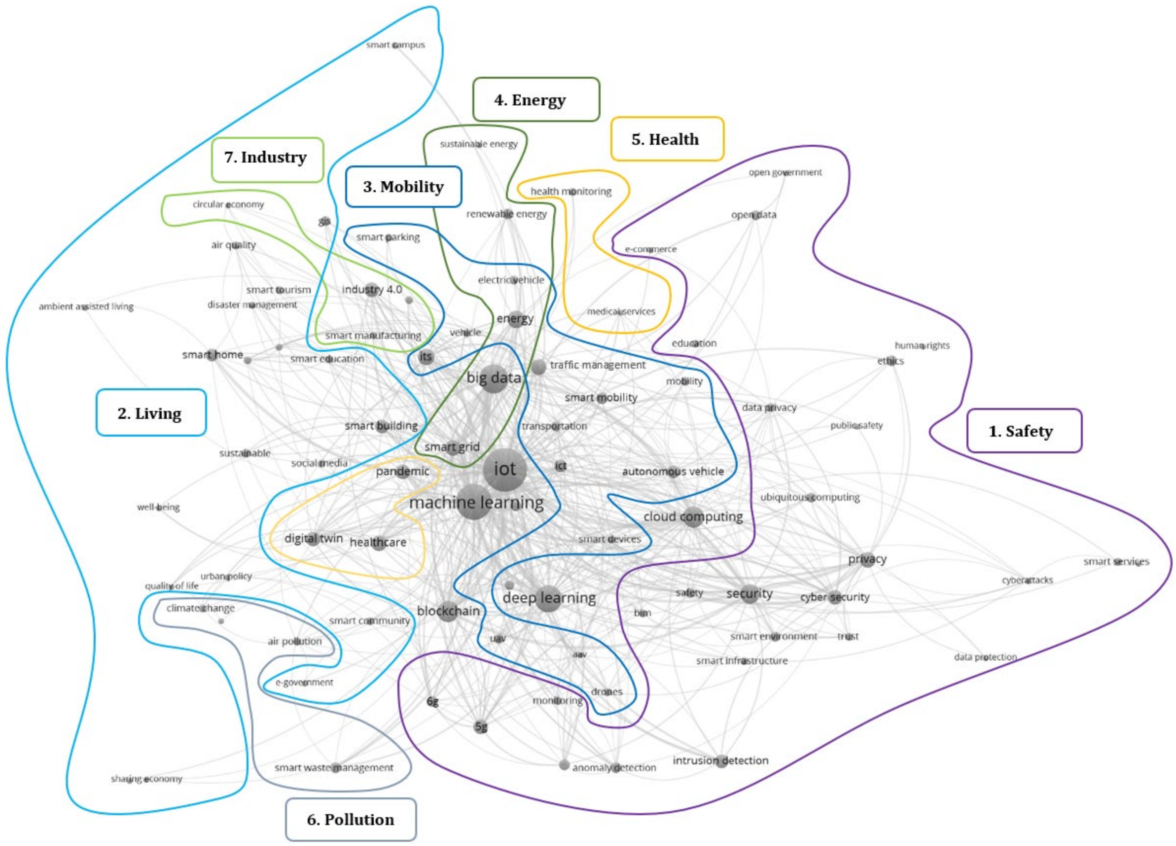

Fig. 4. Thematic clusters of artificial intelligence in smart cities
Source: elaborated by the authors using VOSviewer software.

sustainable, urban policy, and well-being. This cluster is linked to the EGD, which focuses on building and renovation in an energy and resource-efficient way. Striving to provide comfortable living conditions in smart cities also refers to the protection and restoration of ecosystems and biodiversity, which are also subject to EGD transformation policy.

The third cluster, "Mobility", relates to the development of innovative vehicles to enable the most efficient mobility while reducing CO2 emissions. It is associated with the following keywords: vehicle, autonomous vehicle, electric vehicle, ICT, intelligent transport system, smart mobility, smart parking, smart transport, traffic management, transportation, autonomous air vehicles, unmanned aerial vehicles, drones, and smart devices. This cluster is closely linked to the transformative policy of the European Green Deal in terms of transitioning to sustainable and smart mobility.

The fourth cluster, "Energy", primarily refers to technological solutions using AI that enable efficient and safe energy supply and storage, including from renewable sources (e.g., energy, renewable energy, smart energy, sustainable energy, smart grid). This cluster is closely linked to the transformative policy of the European Green Deal aimed at providing clean, affordable, and secure energy.

The fifth cluster, "Health", is oriented towards providing solutions that use artificial intelligence to support residents of smart cities in caring for their health. It is represented by keywords: smart health, healthcare, medical services, digital twin, health monitoring, pandemic. Within the EGD, these topics partially refer to the objective of designing a fair, healthy and environmentally friendly food system.

The sixth cluster, "Pollution", includes keywords related to various pollutants, especially air pollution and waste management (air pollution, climate change, smart waste management). This is closely linked to the goal of zero pollution and a toxin-free environment set out in the EGD.

The last cluster, "Industry", is represented by keywords such as circular economy, digital economy, industry 4.0, RFID, and smart manufacturing. It focuses on Industry 4.0 based on artificial intelligence and simultaneously environmentally friendly production. It appears to be an emerging research area hitherto poorly recognised in the literature. It is

Tab. 5. Sub-areas of artificial intelligence in smart city research in the context of European Green Deal policies

No.	Cluster name	General words	Words	Transformative policies of the European Green Deal	
1.	Safety	Internet of Things, machine learning, big data, deep learning, blockchain, cloud computing	privacy, public safety, quality of service, safety, security, cyber security, cyberattacks, data privacy, data protection, e-commerce, e-government, monitoring, open data, open government, smart environment, smart infrastructure, smart services, intrusion detection, anomaly detection, ubiquitous computing, 5G, 6G, BIM, education, trust, ethics, human rights	2. Supplying clean, affordable and secure energy 3. Mobilising industry for a clean and circular economy 8. A zero pollution ambition for a toxic-free environment	1. Increasing the EU's climate ambition for 2030 and 2050
2.	Living		quality of life, sharing economy, smart campus, smart city 5.0, smart community, smart education, smart government, smart home, smart tourism, air quality, ambient assisted living, smart building, disaster management, GIS, social media, society 5.0, sustainable, urban policy, well-being	2. Supplying clean, affordable and secure energy 4. Building and renovating in an energy and resource-efficient way	
3.	Mobility		mobility, vehicle, autonomous vehicle, electric vehicle, ICT, intelligent transport system, smart mobility, smart parking, smart transport, traffic management, transportation, autonomous air vehicles, unmanned aerial vehicle, drones, smart devices	5. Accelerating the shift to sustainable and smart mobility	
4.	Energy		energy, renewable energy, smart energy, sustainable energy, smart grid	4. Building and renovating in an energy and resource-efficient way	
5.	Health		smart health, healthcare, medical services, digital twin, health monitoring, pandemic	6. From 'Farm to Fork': designing a fair, healthy and environmentally-friendly food system	
6.	Pollution		air pollution, climate change, smart waste management	8. A zero pollution ambition for a toxic-free environment 7. Preserving and restoring ecosystems and biodiversity	
7.	Industry		circular economy, digital economy, industry 4.0, RFID, smart manufacturing	3. Mobilising industry for a clean and circular economy	

closely linked to the EGD goal of mobilising industry for a clean and circular economy. It should also be noted that all the mentioned clusters directly or indirectly also refer to achieving the EU's climate goals for 2030 and 2050.

The application of solutions using artificial intelligence technologies can significantly improve the issue of implementing the European Green Deal assumptions in smart cities.

4. Discussion of results

The bibliometric analysis facilitated the identification of seven thematic domains within international research in connection with artificial intelligence in smart cities. These span a diverse range of subjects, including primarily computer science, engineering and social sciences.

4.1. Safety

Artificial intelligence has emerged as a transformative tool, reshaping the concept and construction of smart cities by enhancing efficiency, accessibility, and quality of life in urban areas (Braun et al., 2018). It is recognised as a crucial instrument in redefining the realms of safety, security, and privacy within these complex urban ecosystems (Allam & Dhunny, 2019; Ullah et al., 2020).

Within the spheres of safety and security, AI has found a range of applications, from traffic management to healthcare and city-wide surveillance (Allam & Jones, 2020; Shi et al., 2020; Ullah et al., 2020; Badura, 2017). Technologies, such as Smart Textile-Integrated Microelectronic Systems (STIMES) and Intelligent Transportation Systems (ITSs), have utilised AI to optimise safety protocols and enhance service quality (Shi et al., 2020; Ullah et al., 2020). AI and machine learning strategies have been employed to enhance health service delivery in the healthcare sector, proving advantageous for urban inhabitants and city management (Ullah et al., 2020).

Despite these advancements, the considerable influx of data facilitated by the Internet of Things introduces significant security and privacy challenges. Issues of centralisation and resource constraints present notable hurdles for AI-driven systems (Singh et al., 2020). With its decentralised architecture, the deployment of blockchain has been proposed as a solution to mitigate these problems (K. Singh et al., 2020; S. Singh et al., 2020; Łasak & Wyciślak, 2023).

Furthermore, federated learning, a distributed collaborative AI approach, enables AI training on distributed IoT devices without data sharing, thereby enhancing data security and privacy (Nguyen et al., 2021; Lv et al., 2021).

Additionally, the convergence of AI and blockchain in smart cities introduces new security challenges, necessitating further investigation (S. Singh et al., 2020). For example, the widespread implementation of IoT, coupled with evolving cyber threats, demands more dynamic and adaptive security measures (Sarker et al., 2022). Innovative approaches such as Holistic Big Data Integrated Artificial Intelligence Modelling (HBDIAIM) aim to address these issues by optimising the scalability and privacy of smart city data management interfaces (Chen et al., 2021).

Preserving privacy, particularly in high-dimensional data collected by IoT devices, poses a significant challenge (Braun et al., 2018). Encrypted data storage on cloud platforms (Anuradha et al., 2021) has been suggested as a solution to this issue, offering secure, remote access to data such as healthcare records. Federated learning approaches can also alleviate these privacy concerns by enabling model training on locally stored data (Liu, Huang et al., 2020).

AI applications also need to consider cultural, metabolic, and governance aspects, necessitating a delicate balance between technological utilisation for economic growth and the maintenance of urban livability (Allam & Dhunny, 2019). Global approaches to AI application control have varied, ranging from a human-centric approach in Western democracies to a techno-centric approach in places like China (Kummitha, 2020).

4.2. Living

The growing trend of urbanisation worldwide has put a tremendous strain on the daily lives of citizens, necessitating solutions to issues such as environmental pollution, public security, and congestion. Smart cities, utilising novel technologies and concepts, aim to create more efficient, technologically advanced, and socially inclusive urban environments, which could potentially alleviate these burdens (Atitallah et al., 2020; Ghazal et al., 2021). The integration of artificial intelligence and the Internet of Things into these urban environments plays a pivotal role in this process.

These technologies generate substantial data, which, upon analysis, provide invaluable insights to enhance the quality of urban life (Atitallah et al., 2020; Ghazal et al., 2021; Skouby & Lynggaard, 2014; Rahman et al., 2023; Gams et al., 2019). The revolutionary progress of AI, driven by advancements in 5G technology, cloud computing, and ICT, forms the foundation for seamless service delivery and the management of interconnected infrastructures, including smart homes (Skouby & Lynggaard, 2014; Gams et al., 2019).

The smart home concept, a vital element of smart cities, has significantly enhanced urban living through the integration of various technological advancements, such as AI, big data, mobile networks, and cloud computing (Li et al., 2022; Shi et al., 2022; Khoa et al., 2020). Such advancements serve as prime examples of the pivotal role AI-powered IoT plays in addressing contemporary societal challenges, like the COVID-19 pandemic, where SDL-based smart health diagnosis systems have been effectively utilised (Shankar et al., 2021). Similarly, AIoT systems have substantially improved safety and air quality monitoring in smart homes, offering potential advancements in hazard detection (Chang et al., 2020).

AI applications in smart cities have also expanded to include emotion-guided interaction architectures, enabling enhanced human–machine interaction while addressing issues such as handling information redundancy in the collected spatiotemporal environment data (Jiang et al., 2020). Nevertheless, despite the promises, concerns about security and privacy remain paramount, necessitating robust security measures and cautious information handling (Khoa et al., 2020; Wu et al., 2023; Braun et al., 2018).

The impact of AI extends beyond smart homes, influencing broader domains, including mobility, logistics, energy, healthcare, and environmental management (Frey et al., 2022; Chang et al., 2020; López-Blanco et al., 2023; Zhi-Xian & Zhang, 2022; Hu et al., 2021; Alsamhi et al., 2019). A prime example of AI integration in urban development is the living lab concept, like the Bauhaus.MobilityLab, which facilitates data processing, analytics, and forecasting for innovative service development (Frey et al., 2022). Moreover, environmental forecasting and urban planning reap significant benefits from AI and IoT combined with big data, enabling the development of future environmental scenarios (López-Blanco et al., 2023).

However, despite these significant advancements, challenges persist. Concerns regarding privacy preservation, network security, and trustworthy data-sharing practices are of utmost importance (Braun et al., 2018). Additionally, social and juristic challenges emerge when individual interests conflict with others, highlighting the necessity for constructive guidelines (Perc et al., 2019).

4.3. Mobility

Artificial intelligence and other digital technologies have been instrumental in shaping mobility within the landscape of smart cities, leading to significant advancements in transportation and sustainability (Ortega-Fernández et al., 2020; Kuźmicz et al., 2022). Implementing AI into various mobility applications has transformed conventional transportation paradigms, prompting further research into this domain.

A pivotal component of this transformation is the utilisation of autonomous vehicles. Enabled by AI and big data analytics, AVs have revolutionised urban mobility, reducing travel times and increasing efficiency. Network calculus (NC) has been proposed to further optimise the Avs' performance by modelling queueing networks, thereby improving the user experience (Cui et al., 2019). Simultaneously, cybersecurity measures, such as blockchain technology and intelligent sensing, are vital for ensuring the safety and reliability of these systems (Reebadiya et al., 2021). Furthermore, AI-driven sensor information fusion systems have enhanced understanding of citizens' mobility patterns, contributing to the development of improved transportation models (Leung et al., 2019; Ejdys & Gulc, 2020; Szpilko et al., 2023).

Electric vehicles also represent a significant commitment to eco-friendly initiatives and the smart city concept, with AI facilitating the management of power within vehicles to optimise energy usage (Aymen & Mahmoudi, 2019). This approach includes collecting and processing data on road conditions and vehicle status.

Moreover, unmanned aerial vehicles have shown promise in various applications, such as wireless coverage and aerial surveillance, with AI and machine learning techniques contributing to their efficiency (Ullah et al., 2020). The growth of the Internet of Things, in conjunction with AI, has been significant in promoting sustainable transitions towards more efficient paradigms in smart city mobility (Nikitas et al., 2020). This integration involves addressing several security challenges (Kim et al., 2021).

An interesting development within this context is the proposition of Autonomous Shuttles (AS) for efficient delivery of goods and last-mile mobility services. The Autonomous Shuttles-as-a-Service (ASaaS) concept, coupled with machine learning techniques for mobility planning and journey tracking certification via AI and blockchain, offers a comprehensive solution for enhancing proximity mobility (Bucchiarone et al., 2021).

Beyond this, Fully Autonomous Ground Vehicles (FAGVs) present an exciting future for smart city development, with real-time data analytics enabling these vehicles to integrate seamlessly with other smart city components, thereby optimising urban environments and promoting sustainable development (Kuru, 2021).

These developments in mobility have been influenced by various factors, including social attitudes, technological innovation, urban politics, and even significant global events such as the COVID-19 pandemic, which has prompted a transformation towards sustainability and smart growth (Kakderi et al., 2021). The introduction of concepts like Mobility-as-a-Service (MaaS), traffic flow optimisation, and reduction in traffic congestion, all underpinned by technologies such as AI, blockchain, and big data, are set to further revolutionise urban environments (Tian & Pan, 2015; Paiva et al., 2021; Wu, 2021).

4.4. Energy

Artificial intelligence continues to exert a transformative influence on smart city development. A major challenge for these cities is energy management, which necessitates the employment of modern technologies for optimal efficiency (Abbas et al., 2020; Kozłowska et al., 2023). Given the complexity and vital role of energy systems, AI and machine learning, in conjunction with the Internet of Things, have emerged as indispensable tools.

AI models, especially those based on artificial neural networks (ANNs) and meta-heuristic algorithms, have been introduced for forecasting and optimising the heating load of buildings' energy efficiency (Le et al., 2019). These innovative approaches contribute significantly to managing and optimising energy usage in buildings, accounting for a considerable proportion of global final energy demand (Vázquez-Canteli et al., 2019; Wu & Chu, 2021). Machine learning algorithms, particularly deep reinforcement learning, are central to this process, fostering adaptive and automated energy controllers for energy savings and demand response (Le et al., 2019).

AI's role extends to promoting energy sustainability, a pivotal aspect of urban development. AI-enabled solutions, such as smart metering and non-intrusive load monitoring (NILM), along with hybrid algorithms like GA-SVM-MKL, are reshaping energy management, enhancing sustainability, and adding a novel dimension to the discourse on energy utilisation (Chui et al., 2018). AI, along with IoT and big data analytics, has been recognised as a potential tool for intelligently prioritising data, thereby fostering more energy-efficient and greener smart cities (Muhammad et al., 2019).

AI also assists in renewable energy adoption within the context of smart cities. AI tools like ANN and statistical analysis have accurately predicted electrical energy consumption while promoting renewable energy generation (Ghadami et al., 2021; Serban & Lytras, 2020).

Moreover, AI contributes to energy consumption prediction and integrated local energy systems (ILES). For instance, the implementation of hybrid networks, such as the "DB-Net", which integrates a dilated convolutional neural network (DCNN) with bidirectional long short-term memory (BiLSTM), has enhanced predictive performance for long- and short-term energy consumption prediction (Khan et al., 2021). Additionally, AI's integration with emerging technologies like electric vehicles optimises energy use in smart cities (Aymen & Mahmoudi, 2019).

Finally, AI is instrumental in short-term photovoltaic (PV) energy generation forecasting (Zhou et al., 2021), optimising energy consumption in infrastructures like Automated Vacuum Waste Collection (AVWC) systems (Fernández et al., 2014), supporting intelligent building energy management systems (BEMSs) (Park et al., 2020), and enhancing the efficiency of critical urban infrastructure sectors, such as sewage treatment and waste management systems (Gaska & Generowicz, 2020).

In conclusion, AI is profoundly influencing the energy sector within smart cities, transforming energy use, improving energy forecasts, and enhancing urban infrastructure operations. As AI and big data technologies continue to evolve, the need for standardised regulations regarding their energy efficiency becomes increasingly important (Anthopoulos & Kazantzi, 2022). Future research and development should address this challenge, ensuring the sustainable growth of these promising technologies.

4.5. Health

The convergence of healthcare and AI within the context of smart cities marks a pivotal juncture in the evolution of health services delivery. This marriage of disciplines holds transformative potential for enhancing well-being, refining healthcare management processes, and strengthening disease control mechanisms (Laamarti et al., 2020; Kamel Boulos et al., 2019; Dong & Yao, 2021).

One of the prime developments within this context is the advent of Digital Twin technology (Fuller et al., 2020), which involves creating digital replicas of living entities. The use of the ISO/IEEE 11073 standardised framework in this regard allows for the collection, analysis, and feedback generation from personal health data accrued from both compliant and non-compliant devices (Laamarti et al., 2020). Additionally, the confluence of GeoAI, the integration of geographic information systems and AI, underscores the significance of location-specific factors in both population and individual health, thus expanding the scope of AI application within healthcare (Kamel Boulos et al., 2019).

The recent COVID-19 pandemic has further magnified the transformative potential of digital solutions within healthcare, paving the way for data-driven smart city models (Hantrais et al., 2021; Dong & Yao, 2021; Allam & Jones, 2020). The effectiveness of AI in managing health emergencies is evident from the different approaches adopted by governments during the COVID-19 pandemic. While Chinese cities and the government used a techno-driven approach, Western governments adopted a human-driven approach to control the transmission of the virus. The analysis suggests that while the techno-driven approach may be more efficient in identifying and isolating infected individuals, it may also suppress and censor citizens' views. Therefore, understanding the human–technology relationship is critical in managing virus transmissions during pandemics (Kummitha, 2020).

One of the technologies that have received attention in the healthcare sector is blockchain, which offers solutions for securing patient and provider identities, managing pharmaceutical and medical device supply chains, clinical research and data monetisation, medical fraud detection, and public health surveillance (Boulos et al., 2018). Coupling blockchain technologies with AI may enhance their power and robustness, leading to more effective healthcare solutions in smart cities.

Healthcare delivery has further been enriched through the integration of telemedicine, telecare, and AI within smart home systems, thereby improving the quality and efficiency of care (Khatoon et al., 2019). Alongside these advancements, the incorporation of cloud computing and deep learning technologies has enabled accurate prediction of diseases based on data collected from IoT sensors embedded within human bodies (Anuradha et al., 2021).

Despite the numerous benefits, several challenges, including privacy and security issues, data handling, and algorithm optimisation, remain and must be addressed to harness the full potential of AI within the healthcare sector (Laamarti et al., 2020; Kamel Boulos et al., 2019; Gad, 2022; Hantrais et al., 2021; Dong & Yao, 2021; Zheng et al., 2022).

The AI technologies, such as deep learning, machine learning, Internet of Things, mobile computing, big data, blockchain, and advanced network systems, are predicted to play a significant role in future smart cities (Javed et al., 2022; Ullah et al., 2020). The amalgamation of AI with big data analytics further enhances the precision of future action plans and improves decision-making strategies (Hariri et al., 2019). Despite the wide array of applications of AI in healthcare, the black-box nature of AI inhibits its widespread acceptance, which necessitates the development of explainable artificial intelligence (XAI) techniques (Loh et al., 2022).

4.6. Pollution

Environmental pollution is one of the major challenges of urban growth, manifesting in multiple forms, such as air, noise, and waste pollution. This pollution, arising from industrial and transportation activities, exacerbates the stress experienced by urban inhabitants (Kaginalkar et al., 2021; Liu et al., 2020; Navarro-Espinoza et al., 2022). AI, IoT, big data, smartphones, and cloud computing offer promising solutions to manage and mitigate these pollution types, thus enhancing urban mobility and quality of life (Kaginalkar et al., 2021; Liu et al., 2020; Bucchiarone et al., 2021; Garcia-Retuerta et al., 2021).

The introduction of predictive and preventative measures has introduced a novel approach to combat pollution. Specifically, deep learning models have demonstrated efficacy in predicting traffic flow at intersections, enabling adaptive traffic control and, consequently, reducing pollution resulting from traffic congestion (Tian & Pan, 2015; Navarro-Espinoza et al., 2022; Yuan et al., 2022). Likewise, IoT devices like drones have been deployed for environmental surveillance, contributing to pollution monitoring and management (Gohari et al., 2022).

Regarding waste management, AI and IoT technologies hold immense potential. They can optimise waste collection, mitigate overflows, and enhance recycling processes, leading to a cleaner urban environment (Ghazal et al., 2021). For instance, smart bins providing real-time data about their status can significantly improve waste collection efficiency (Abuga & Raghava, 2021). Furthermore, AI's implementation in waste management allows for predictive analysis, enabling cities to anticipate and effectively plan for waste accumulation and disposal (Gaska & Generowicz, 2020).

Nonetheless, the adoption of these advanced technologies faces challenges, including inadequate infrastructure, insufficient funding, cybersecurity risks, and a general lack of trust in these technologies (Wang et al., 2021). Understanding and addressing these challenges are crucial to realising the full potential of AI and IoT in developing sustainable smart cities (Rani et al., 2021).

4.7. Industry

Artificial intelligence, in conjunction with other modern technologies, is undoubtedly reshaping various sectors in smart cities. However, the transition to Industry 4.0 is not without its challenges, particularly concerning cloud-based data storage, computation, and communication. Concerns have arisen due to problems such as transmission delay, single points of failure, and privacy disclosure. As a potential solution, blockchain technology has been suggested with its decentralised, tamper-proof, and transparent nature, and it is expected to work alongside AI and 5G to overcome these challenges (Chen et al., 2022).

In the manufacturing sector, AI has played a pivotal role in the development of intelligent systems, enhancing decision-making and increasing flexibility in physical processes to meet the dynamic global market demands (Espina-Romero et al., 2023).

During the era of Industry 4.0 and smart city paradigms, the synergistic application of AI and IoT has proven to be highly effective in monitoring and tracking water consumption, achieving an impressive recognition rate of approx. 98 % (Ktari et al., 2022). Additionally, in the hospitality sector, AI-enabled robots are being deployed to provide personalised services and facilitate seamless guest experiences (Gupta et al., 2022). Notably, these technologies have had a significant impact on the hotel industry by improving service quality and minimising operational costs (Khan et al., 2017; Nam et al., 2021).

Digital Twin technology, recognised as one of the top ten strategic technology trends by Gartner Inc. in 2017, has been integrated into manufacturing and the Industrial Internet of Things. The combination of AI, machine learning, deep learning, and big data within the Industry 4.0 paradigm has facilitated this integration, enabling predictive analysis of potential issues, thus preventing downtime and fostering new opportunities (Augustine, 2020).

Furthermore, the transition from Industry 4.0 to Industry 5.0 has witnessed an increased adoption of metaverse technology, promoting responsible digital transformation. However, this transition is not without challenges, including potential job losses due to automation, increased energy consumption, and the ongoing financial commitments required by AI systems. Therefore, sustainable practices and responsible digitisation must play a central role in managing these challenges (De Giovanni, 2023).

Industry 5.0 signifies a paradigm shift, emphasising collaboration between humans and machines to enhance customer satisfaction. This shift involves the utilisation of advanced technologies, such as big data analytics, IoT, collaborative robots, blockchain, digital twins, and future 6G systems (Adel, 2022). In the transition to a circular economy (CE), the construction industry is notably leveraging these digital technologies for asset tracking, performance optimisation, and increased salvage value, ultimately contributing to a more sustainable industry (Elghaish et al., 2022).

Finally, it is crucial to acknowledge that this increased reliance on AI demands a better understanding and management of potential environmental, social, and economic impacts. Combining tools such as Life Cycle Assessment (LCA) with AI and machine learning can help anticipate uncertainties in the early stages of design, thereby contributing to the comprehensive performance assessment of smart cities (Ragab et al., 2023).

Conclusions

The transformative influence of artificial intelligence within the context of smart cities is undeniable. AI has permeated various sectors, catalysed by complementary technologies, such as the Internet of Things, blockchain, machine learning, deep learning, and federated learning. These benefits include enhanced efficiency, accessibility, and an improved quality of life in urban areas. However, the amalgamation of these advancements brings forth a plethora of new challenges that warrant further research and investigation.

Foremost among these challenges is the issue of data security and privacy. The ubiquitous integration of IoT technologies amplifies the volume of generated data, leading to significant security and privacy concerns (S. K. Singh et al., 2020). These concerns often stem from centralisation and resource constraints, necessitating innovative solutions such as deploying blockchain and federated learning.

Within urban mobility, AI and digital technologies have revolutionised the landscape, bringing forward innovations such as AVs, EVs, and UAVs. Specifically, the application of AI for mobility planning and journey tracking certification via AI and blockchain, along with concepts like Mobility-as-a-Service, form promising areas of exploration. However, these advancements are not devoid of security challenges, highlighting the need for further research in this domain (Kim et al., 2021).

AI's transformative impact extends into the energy sector, where intelligent solutions reshape energy management and sustainability practices. The role of AI in promoting renewable energy adoption, forecasting energy consumption, and developing Integrated Local Energy Systems is increasingly pronounced (Ghadami et al., 2021; Le et al., 2019; Khan et al., 2021). This evolution necessitates standardised regulations regarding energy efficiency as AI and big data technologies advance, signifying another area ripe for future research (Anthopoulos & Kazantzi, 2022).

In the health sector, advancements such as Digital Twin technology and the integration of GeoAI provide opportunities for location-specific health interventions (Laamarti et al., 2020; Kamel Boulos et al., 2019). However, optimising data handling, addressing privacy and security concerns, and improving data sharing protocols require further research. The ethical and societal implications of these applications should also be studied to understand their potential impacts on citizens' rights and trust (Kummitha, 2020).

With regard to environmental management, AI can contribute to mitigating urban growth challenges such as pollution through applications like traffic flow prediction and optimised waste management systems. However, the adoption of these technologies is not without its challenges, including infrastructure development, funding, and cybersecurity risks, pointing towards the need for further research (Wang et al., 2021; Rani et al., 2021).

Finally, the industrial sector, transitioning towards Industry 4.0 and 5.0, heavily depends on AI and blockchain technologies. The potential for job losses due to automation, increased energy consumption, and the financial commitments required by AI systems are challenges that need to be addressed, advocating for further research into sustainable practices and responsible digitisation (De Giovanni, 2023).

In conclusion, while the integration of AI in smart cities holds promising potential for transforming urban life, it is also accompanied by a series of challenges related to data security, privacy, and regulatory compliance. Future research needs to grapple with these issues to unlock the full potential of AI and facilitate sustainable growth and advancement of these technologies.

Acknowledgements

This research was funded under the International Academic Partnership Programme no. BPI/PST/2021/1/00011/U/00001 with the Polish National Agency for Academic Exchange.

Literature

Abbas, S., Khan, M. A., Falcon-Morales, L. E., Rehman, A., Saeed, Y., Zareei, M., Zeb, A., & Mohamed, E. M. (2020). Modeling, Simulation and Optimization of Power Plant Energy Sustainability for IoT Enabled Smart Cities Empowered with Deep Extreme Learning Machine. *IEEE Access*, *8*, 39982-39997. doi: 10.1109/ACCESS.2020.2976452

Abuga, D., & Raghava, N. S. (2021). Real-time smart garbage bin mechanism for solid waste management in smart cities. *Sustainable Cities and Society*, *75*. doi: 10.1016/j.scs.2021.103347

Adel, A. (2022). Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas. *Journal of Cloud Computing-Advances Systems and Applications*, *11*(1). doi: 10.1186/s13677-022-00314-5

Aguilera, U., Peña, O., Belmonte, O., & López-de-Ipiña, D. (2017). Citizen-centric data services for smarter cities. *Future Generation Computer Systems*, *76*, 234-247. doi: 10.1016/j.future.2016.10.031

Alam, F., Mehmood, R., Katib, I., Albogami, N. N., & Albeshri, A. (2017). Data Fusion and IoT for Smart Ubiquitous Environments: A Survey. *IEEE Access*, *5*, 9533-9554. doi: 10.1109/ACCESS.2017.2697839

Alifi, M. R., & Supangkat, S. H. (2016). Information extraction for traffic congestion in social network: Case study: Bekasi city. *2016 International Conference on ICT for Smart Society, ICISS 2016*, 53-58. doi: 10.1109/ICTSS.2016.7792848

Ali, R., Zikria, Y. B., Kim, B.-S., & Kim, S. W. (2020). Deep reinforcement learning paradigm for dense wireless networks in smart cities. In *EAI/Springer Innova-*

tions in Communication and Computing (pp. 43-70). Springer Science and Business Media Deutschland GmbH. doi: 10.1007/978-3-030-14718-1_3

Allam, Z., & Dhunny, Z. A. (2019). On big data, artificial intelligence and smart cities. *Cities*, *89*, 80-91. doi: 10.1016/j.cities.2019.01.032

Allam, Z., & Jones, D. S. (2020). On the coronavirus (Covid-19) outbreak and the smart city network: Universal data sharing standards coupled with artificial intelligence (ai) to benefit urban health monitoring and management. *Healthcare, 8*(1). doi: 10.3390/healthcare8010046

Allam, Z., & Newman, P. (2018). Redefining the Smart City: Culture, Metabolism and Governance. *Smart Cities*, *1*(1), 4-25. doi: 10.3390/smartcities1010002

Allam, Z., Tegally, H., & Thondoo, M. (2019). Redefining the use of big data in urban health for increased liveability in smart cities. *Smart Cities*, *2*(2), 259-268. doi: 10.3390/smartcities2020017

Alsamhi, S. H., Ma, O., Ansari, M. S., & Almalki, F. A. (2019). Survey on collaborative smart drones and internet of things for improving smartness of smart cities. *IEEE Access*, *7*, 128125-128152. doi: 10.1109/ACCESS.2019.2934998

Al-Turjman, F., & Baali, I. (2022). Machine learning for wearable IoT-based applications: A survey. *Transactions on Emerging Telecommunications Technologies*, *33*(8). doi: 10.1002/ett.3635

Al-Turjman, F., Nayyar, A., Devi, A., & Shukla, P. K. (2021). Intelligence of things: AI-IoT based critical-applications and innovations. In *Intelligence of Things: AI-IoT Based Critical-Applications and Innovations*. Springer International Publishing. doi: 10.1007/978-3-030-82800-4

Amoroso, S., Aristodemou, L., Criscuolo, C., Dechezleprete, A., Dernis, H., Grassano, N., Moussiegt, L., Napolitano, L., Nawa, D., Squicciarini, M., & Tuebke, A. (2021). World Corporate Top R&D investors: Paving the way for climate neutrality. *Publications Office of the European Union, Luxembourg, JRC126788, EUR 30884 EN*.

Ang, K. L.-M., Seng, J. K. P., Ngharamike, E., & Ijemaru, G. K. (2022). Emerging Technologies for Smart Cities' Transportation: Geo-Information, Data Analytics and Machine Learning Approaches. *ISPRS International Journal of Geo-Information*, *11*(2). doi: 10.3390/ijgi11020085

Anthopoulos, L., & Kazantzi, V. (2022). Urban energy efficiency assessment models from an AI and big data perspective: Tools for policy makers. *Sustainable Cities and Society*, *76*. doi: 10.1016/j.scs.2021.103492

Anuradha, M., Jayasankar, T., Prakash, N. B., Sikkandar, M. Y., Hemalakshmi, G. R., Bharatiraja, C., & Britto, A. S. F. (2021). IoT enabled cancer prediction system to enhance the authentication and security using cloud computing. *Microprocessors and Microsystems*, *80*. doi: 10.1016/j.micpro.2020.103301

Aqib, M., Mehmood, R., Alzahrani, A., & Katib, I. (2020). In-memory deep learning computations on gpus for prediction of road traffic incidents using big data fusion. In *EAI/Springer Innovations in Communication and Computing* (pp. 79-114). Springer Science and Business Media Deutschland GmbH. doi: 10.1007/978-3-030-13705-2_4

Atitallah, S. B., Driss, M., Boulila, W., & Ghezala, H. B. (2020). Leveraging Deep Learning and IoT big data analytics to support the smart cities development: Review and future directions. *Computer Science Review*, *38*. doi: 10.1016/j.cosrev.2020.100303

Augustine, P. (2020). The industry use cases for the Digital Twin idea. In P. Raj & P. Evangeline (Eds.), *Advances in Computers* (pp. 79-105). Academic Press Inc. doi: 10.1016/bs.adcom.2019.10.008

Aymen, F., & Mahmoudi, C. (2019). A novel energy optimization approach for electrical vehicles in a smart city. *Energies*, *12*(5). doi: 10.3390/en12050929

Badura, D. (2017). Urban traffic modeling and simulation. *Forum Scientiae Oeconomia*, *5*(4), 85-97. doi: 10.23762/FSO_VOL5NO4_17_7

Bilan, S., Šuleř, P., Skrynnyk, O., Krajňáková, E., & Vasilyeva, T. (2022). Systematic bibliometric review of artificial intelligence technology in organizational management, development, change and culture. *Business: Theory and Practice*, *23*(1), 1-13. doi: 10.3846/btp.2022.13204

Bornmann, L., & Haunschild, R. (2017). Quality and impact considerations in bibliometrics: a reply to Ricker. *Scientometrics*, *111*(3), 1857-1859. doi: 10.1007/s11192-017-2373-3

Boulos, M. N. K., Wilson, J. T., & Clauson, K. A. (2018). Geospatial blockchain: promises, challenges, and scenarios in health and healthcare. *International Journal of Health Geographics*, *17*. doi: 10.1186/s12942-018-0144-x

Braun, T., Fung, B. C. M., Iqbal, F., & Shah, B. (2018). Security and privacy challenges in smart cities. *Sustainable Cities and Society*, *39*, 499-507. doi: 10.1016/j.scs.2018.02.039

Bucchiarone, A., Battisti, S., Marconi, A., Maldacea, R., & Ponce, D. C. (2021). Autonomous Shuttle-as-a-Service (ASaaS): Challenges, Opportunities, and Social Implications. *IEEE Transactions on Intelligent Transportation Systems*, *22*(6), 3790-3799. doi: 10.1109/TITS.2020.3025670

Castelli, M., Sormani, R., Trujillo, L., & Popovič, A. (2017). Predicting per capita violent crimes in urban areas: an artificial intelligence approach. *Journal of Ambient Intelligence and Humanized Computing*, *8*(1), 29-36. doi: 10.1007/s12652-015-0334-3

Chang, C.-Y., Ko, K.-S., Guo, S.-J., Hung, S.-S., & Lin, Y.-T. (2020). CO multi-forecasting model for indoor health and safety management in smart home. *Journal of Internet Technology*, *21*(1), 273-284. doi: 10.3966/160792642020012101023

Chen, J., Ramanathan, L., & Alazab, M. (2021). Holistic big data integrated artificial intelligent modeling to improve privacy and security in data management of smart cities. *Microprocessors and Microsystems*, *81*. doi: 10.1016/j.micpro.2020.103722

Chen, M., Liu, W., Wang, T., Liu, A., & Zeng, Z. (2021). Edge intelligence computing for mobile augmented reality with deep reinforcement learning approach. *Computer Networks*, *195*. doi: 10.1016/j.comnet.2021.108186

Chen, Y., Lu, Y., Bulysheva, L., & Kataev, M. Y. (2022). Applications of Blockchain in Industry 4.0: a Review. *Information Systems Frontiers*. doi: 10.1007/s10796-022-10248-7

Choudhary, P., & Sarthy, P. (2022). Transforming Cities for Sustainability: Role of Standards on Smart City. *2022 2nd International Conference on Power Electronics and IoT Applications in Renewable Energy and Its Control, PARC 2022*. doi: 10.1109/PARC52418.2022.9726674

Chui, K. T., Lytras, M. D., & Visvizi, A. (2018). Energy sustainability in smart cities: Artificial intelligence, smart monitoring, and optimization of energy consumption. *Energies*, *11*(11). doi: 10.3390/en11112869

Communication from The Commission to The European Parliament, The European Council, The Council, The European Economic and Social Committee and The Committee of the regions. The European Green Deal. COM (2019) 640 Final. (2019).

Cubric, M. (2020). Drivers, barriers and social considerations for AI adoption in business and management: A tertiary study. *Technology in Society*, *62*. doi: 10.1016/j.techsoc.2020.101257

Cui, Q., Wang, Y., Chen, K.-C., Ni, W., Lin, I.-C., Tao, X., & Zhang, P. (2019). Big data analytics and network calculus enabling intelligent management of autonomous vehicles in a smart city. *IEEE Internet of Things Journal*, *6*(2), 2021-2034. doi: 10.1109/JIOT.2018.2872442

David, M., Mbabazi, E. S., Nakatumba-Nabende, J., & Marvin, G. (2023). Crime Forecasting using Interpretable Regression Techniques. *7th International Conference on Trends in Electronics and Informatics, ICOEI 2023 - Proceedings*, 1405-1411. doi: 10.1109/ICOEI56765.2023.10126071

De Giovanni, P. (2023). Sustainability of the Metaverse: A Transition to Industry 5.0. *Sustainability*, *15*(7). doi: 10.3390/su15076079

Diro, A. A., & Chilamkurti, N. (2018). Distributed attack detection scheme using deep learning approach for Internet of Things. *Future Generation Computer Systems*, *82*, 761-768. doi: 10.1016/j.future.2017.08.043

Dong, Y., & Yao, Y.-D. (2021). IoT platform for covid-19 prevention and control: A survey. *IEEE Access*, *9*, 49929-49941. doi: 10.1109/ACCESS.2021.3068276

Ejdys, J., & Gulc, A. (2020). Trust in Courier Services and Its Antecedents as a Determinant of Perceived Service Quality and Future Intention to Use Courier Service. *Sustainability*, *12*, 1-18. doi: 10.3390/su12219088

Elghaish, F., Matarneh, S. T., Edwards, D. J., Pour Rahimian, F., El-Gohary, H., & Ejohwomu, O. (2022). Applications of Industry 4.0 digital technologies towards a construction circular economy: gap analysis and conceptual framework. *Construction Innovation*, *22*(3), 647-670. doi: 10.1108/CI-03-2022-0062

Espina-Romero, L., Guerrero-Alcedo, J., Goñi Avila, N., Noroño Sánchez, J. G., Gutiérrez Hurtado, H., & Quiñones Li, A. (2023). Industry 5.0: Tracking Scientific Activity on the Most Influential Industries, Associated Topics, and Future Research Agenda. *Sustainability*, *15*(6). doi: 10.3390/su15065554

Ferdowsi, A., Challita, U., & Saad, W. (2019). Deep Learning for Reliable Mobile Edge Analytics in Intelligent Transportation Systems: An Overview. *IEEE Vehicular Technology Magazine*, *14*(1), 62-70. doi: 10.1109/MVT.2018.2883777

Fernández, C., Manyà, F., Mateu, C., & Sole-Mauri, F. (2014). Modeling energy consumption in automated vacuum waste collection systems. *Environmental Modelling and Software*, *56*, 63-73. doi: 10.1016/j.envsoft.2013.11.013

Frey, C., Hertweck, P., Richter, L., & Warweg, O. (2022). Bauhaus.MobilityLab: A Living Lab for the Development and Evaluation of AI-Assisted Services. *Smart Cities*, *5*(1), 133-145. doi: 10.3390/smartcities5010009

Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital Twin: Enabling Technologies, Challenges and Open Research. *IEEE Access*, *8*, 108952-108971. doi: 10.1109/ACCESS.2020.2998358

Gaber, H., Othman, A. M., & Fahad, A. H. (2020). Future of connected autonomous vehicles in smart cities. In *Solving Urban Infrastructure Problems Using Smart City Technologies: Handbook on Planning, Design, Development, and Regulation* (pp. 599-611). Elsevier. doi: 10.1016/B978-0-12-816816-5.00027-9

Gad, A. G. (2022). Particle Swarm Optimization Algorithm and Its Applications: A Systematic Review. *Archives of Computational Methods in Engineering*, *29*(5), 2531-2561. doi: 10.1007/s11831-021-09694-4

Galindo, F. (2014). Methods for law and ICT: An approach for the development of smart cities. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *8929*, 26-40. doi: 10.1007/978-3-662-45960-7

Gams, M., Gu, I. Y.-H., Härmä, A., Muñoz, A., & Tam, V. (2019). Artificial intelligence and ambient intelligence. *Journal of Ambient Intelligence and Smart Environments*, *11*(1), 71-86. doi: 10.3233/AIS-180508

Garcia-Retuerta, D., Chamoso, P., Hernández, G., Guzmán, A. S. R., Yigitcanlar, T., & Corchado, J. M. (2021). An efficient management platform for developing smart cities: Solution for real-time and future crowd detection. *Electronics*, *10*(7). doi: 10.3390/electronics10070765

Gaska, K., & Generowicz, A. (2020). SMART Computational Solutions for the Optimization of Selected Technology Processes as an Innovation and Progress in Improving Energy Efficiency of Smart Cities—A Case Study. *Energies*, *13*(13). doi: 10.3390/en13133338

Ghadami, N., Gheibi, M., Kian, Z., Faramarz, M. G., Naghedi, R., Eftekhari, M., Fathollahi-Fard, A. M., Dulebenets, M. A., & Tian, G. (2021). Implementation of solar energy in smart cities using an integration of artificial neural network, photovoltaic system and classical Delphi methods. *Sustainable Cities and Society*, *74*. doi: 10.1016/j.scs.2021.103149

Ghazal, T. M., Hasan, M. K., Alshurideh, M. T., Alzoubi, H. M., Ahmad, M., Akbar, S. S., Al Kurdi, B., & Akour, I. A. (2021). IoT for smart cities: Machine learning approaches in smart healthcare—A review. *Future Internet*, *13*(8). doi: 10.3390/fi13080218

Glińska, E., & Siemieniako, D. (2018). Binge drinking in relation to services - Bibliometric analysis of scientific research directions. *Engineering Management in Production and Services*, *10*(1), 45-54. doi: 10.1515/emj-2018-0004

Gohari, A., Ahmad, A. B., Rahim, R. B. A., Supa'at, A. S. M., Razak, S. A., & Gismalla, M. S. M. (2022). Involvement of Surveillance Drones in Smart Cities: A Systematic Review. *IEEE Access*, *10*, 56611-56628. doi: 10.1109/ACCESS.2022.3177904

Golinska-Dawson, P., & Sethanan, K. (2023). Sustainable Urban Freight for Energy-Efficient Smart Cities—Systematic Literature Review. *Energies*, *16*(6). doi: 10.3390/en16062617

Gudanowska, A. E. (2017). A Map of Current Research Trends within Technology Management in the Light of Selected Literature. *Management and Production Engineering Review*, *8*(1), 78-88. doi: 10.1515/mper-2017-0009

Gupta, S., Modgil, S., Lee, C.-K., Cho, M., & Park, Y. (2022). Artificial intelligence enabled robots for stay experience in the hospitality industry in a smart city. *Industrial Management and Data Systems*, *122*(10), 2331-2350. doi: 10.1108/IMDS-10-2021-0621

Halicka, K. (2017). Main Concepts of Technology Analysis in the Light of the Literature on the Subject. *Procedia Engineering, 182*, 291-298. doi: 10.1016/j.proeng.2017.03.196

Hantrais, L., Allin, P., Kritikos, M., Sogomonjan, M., Anand, P. B., Livingstone, S., Williams, M., & Innes, M. (2021). Covid-19 and the digital revolution. *Contemporary Social Science*, *16*(2), 256-270. doi: 10.1080/21582041.2020.1833234

Hariri, R. H., Fredericks, E. M., & Bowers, K. M. (2019). Uncertainty in big data analytics: survey, opportunities, and challenges. *Journal of Big Data*, *6*(1). doi: 10.1186/s40537-019-0206-3

Hu, S., & Jiang, T. (2019). Artificial Intelligence Technology Challenges Patent Laws. *Proceedings - 2019 International Conference on Intelligent Transportation, Big Data and Smart City, ICITBS 2019*, 241-244. doi: 10.1109/ICITBS.2019.00064

Hu, Y.-C., Lin, Y.-H., & Gururaj, H. L. (2021). Partitional clustering-hybridized neuro-fuzzy classification evolved through parallel evolutionary computing and applied to energy decomposition for demand-side management in a smart home. *Processes*, *9*(9). doi: 10.3390/pr9091539

Javed, A. R., Shahzad, F., Rehman, S. U., Bin Zikria, Y., Razzak, I., Jalil, Z., & Xu, G. D. (2022). Future smart cities requirements, emerging technologies, applications, challenges, and future aspects. *Cities*, *129*. doi: 10.1016/j.cities.2022.103794

Jiang, Y., Xiao, W., Wang, R., & Barnawi, A. (2020). Smart Urban Living: Enabling Emotion-Guided Interaction with Next Generation Sensing Fabric. *IEEE Access*, *8*, 28395-28402. doi: 10.1109/ACCESS.2019.2961957

Kaginalkar, A., Kumar, S., Gargava, P., & Niyogi, D. (2021). Review of urban computing in air quality management as smart city service: An integrated IoT, AI, and cloud technology perspective. *Urban Climate*, *39*. doi: 10.1016/j.uclim.2021.100972

Kakderi, C., Oikonomaki, E., & Papadaki, I. (2021). Smart and Resilient Urban Futures for Sustainability in the Post COVID-19 Era: A Review of Policy Responses on Urban Mobility. *Sustainability*, *13*(11). doi: 10.3390/su13116486

Kamel Boulos, M. N., Peng, G., & Vopham, T. (2019). An overview of GeoAI applications in health and healthcare. *International Journal of Health Geographics*, *18*(1). doi: 10.1186/s12942-019-0171-2

Keathley-Herring, H., Van Aken, E., Gonzalez-Aleu, F., Deschamps, F., Letens, G., & Orlandini, P. C. (2016). Assessing the maturity of a research area: bibliometric review and proposed framework. *Scientometrics*, *109*(2), 927-951. doi: 10.1007/s11192-016-2096-x

Khan, N., Haq, I. U., Khan, S. U., Rho, S., Lee, M. Y., & Baik, S. W. (2021). DB-Net: A novel dilated CNN based multi-step forecasting model for power consumption in integrated local energy systems. *International Journal of Electrical Power and Energy Systems*, *133*. doi: 10.1016/j.ijepes.2021.107023

Khatoon, S., Rahman, S. M. M., Alrubaian, M., & Alamri, A. (2019). Privacy-Preserved, Provable Secure, Mutually Authenticated Key Agreement Protocol for Healthcare in a Smart City Environment. *IEEE Access*, *7*, 47962-47971. doi: 10.1109/ACCESS.2019.2909556

Khoa, T. A., Nhu, L. M. B., Son, H. H., Trong, N. M., Phuc, C. H., Phuong, N. T. H., Van Dung, N., Nam, N. H., Chau, D. S. T., & Duc, D. N. M. (2020). Designing Efficient Smart Home Management with IoT Smart Lighting: A Case Study. *Wireless Communications and Mobile Computing*, *2020*. doi: 10.1155/2020/8896637

Kim, K., Kim, J. S., Jeong, S., Park, J.-H., & Kim, H. K. (2021). Cybersecurity for autonomous vehicles: Review of attacks and defense. *Computers and Security*, *103*. doi: 10.1016/j.cose.2020.102150

Kozłowska, J., Benvenga, M. A., & de Alencar Nääs, I. (2023). Investment Risk and Energy Security Assessment of European Union Countries Using Multicriteria Analysis. *Energies*, *16*, 1-28. doi: 10.3390/en16010330

Ktari, J., Frikha, T., Hamdi, M., Elmannai, H., & Hmam, H. (2022). Lightweight AI Framework for Industry 4.0 Case Study: Water Meter Recognition. *Big Data and Cognitive Computing*, *6*(3). doi: 10.3390/bdcc6030072

Kummitha, R. K. R. (2020). Smart technologies for fighting pandemics: The techno-and human-driven approaches in controlling the virus transmission. *Government Information Quarterly*, *37*(3). doi: 10.1016/j.giq.2020.101481

Kuru, K. (2021). Planning the Future of Smart Cities with Swarms of Fully Autonomous Unmanned Aerial Vehicles Using a Novel Framework. *IEEE Access*, *9*, 6571-6595. doi: 10.1109/ACCESS.2020.3049094

Kuźmicz, K., Ryciuk, U., Glińska, E., Kiryluk, H., & Rollnik-Sadowska, E. (2022). Perspectives of mobility development in remote areas attractive to tourists. *Ekonomia i Środowisko*, *80*, 150-188. doi: 10.34659/eis.2022.80.1.440

Laamarti, F., Badawi, H. F., Ding, Y., Arafsha, F., Hafidh, B., & Saddik, A. E. (2020). An ISO/IEEE 11073 Standardized Digital Twin Framework for Health and Well-Being in Smart Cities. *IEEE Access*, *8*, 105950-105961. doi: 10.1109/ACCESS.2020.2999871

Le, L. T., Nguyen, H., Dou, J., & Zhou, J. (2019). A comparative study of PSO-ANN, GA-ANN, ICA-ANN, and ABC-ANN in estimating the heating load of buildings' energy efficiency for smart city planning. *Applied Sciences*, *9*(13). doi: 10.3390/app9132630

Leung, C. K., Braun, P., & Cuzzocrea, A. (2019). AI-Based Sensor Information Fusion for Supporting Deep Supervised Learning. *Sensors*, *19*(6). doi: 10.3390/s19061345

Liu, Y., Huang, A., Luo, Y., Huang, H., Liu, Y., Chen, Y., Feng, L., Chen, T., Yu, H., & Yang, Q. (2020). FedVision: An online visual object detection platform powered by federated learning. In R. Puri & N.

Yorke-Smith (Eds.), *Proceedings of the 32nd Innovative Applications of Artificial Intelligence Conference, IAAI 2020* (pp. 13172-13179). The AAAI Press.

Liu, Y., Ma, X., Shu, L., Yang, Q., Zhang, Y., Huo, Z., & Zhou, Z. (2020). Internet of things for noise mapping in smart cities: State of the art and future directions. *IEEE Network*, *34*(4), 112-118. doi: 10.1109/MNET.011.1900634

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. doi: 10.1109/MNET.2019.1800254

Li, W., Yigitcanlar, T., Liu, A., & Erol, I. (2022). Mapping two decades of smart home research: A systematic scientometric analysis. *Technological Forecasting and Social Change*, *179*. doi: 10.1016/j.techfore.2022.121676

Loh, H. W., Ooi, C. P., Seoni, S., Barua, P. D., Molinari, F., & Acharya, U. R. (2022). Application of explainable artificial intelligence for healthcare: A systematic review of the last decade (2011-2022). *Computer Methods and Programs in Biomedicine*, *226*. doi: 10.1016/j.cmpb.2022.107161

López-Blanco, R., Martín, J. H., Alonso, R. S., & Prieto, J. (2023). Time Series Forecasting for Improving Quality of Life and Ecosystem Services in Smart Cities. In V. Julián, J. Carneiro, R. S. Alonso, P. Chamoso, & P. Novais (Eds.), *Lecture Notes in Networks and Systems: Vol. 603 LNNS* (pp. 74-85). Springer Science and Business Media Deutschland GmbH. doi: 10.1007/978-3-031-22356-3_8

Lourenco, V., Mann, P., Guimaraes, A., Paes, A., & De Oliveira, D. (2018). Towards Safer (Smart) Cities: Discovering Urban Crime Patterns Using Logic-based Relational Machine Learning. *Proceedings of the International Joint Conference on Neural Networks*, *2018-July*. doi: 10.1109/IJCNN.2018.8489374

Lv, Z., Qiao, L., Singh, A. K., & Wang, Q. (2021). AI-empowered IoT Security for Smart Cities. *ACM Transactions on Internet Technology*, *21*(4), 99. doi: 10.1145/3406115

Łasak, P., & Wyciślak, S. (2023). Blockchain and cloud platforms in banking services: A paradox perspective. *Journal of Entrepreneurship, Management, and Innovation*, *19*(4), 12-47. doi: 10.7341/20231941

Ma, M., Stankovic, J. A., & Feng, L. (2018). CityResolver: A Decision Support System for Conflict Resolution in Smart Cities. *Proceedings - 9th ACM/IEEE International Conference on Cyber-Physical Systems, ICCPS 2018*, 55-64. doi: 10.1109/ICCPS.2018.00014

Ma, Y., Ping, K., Wu, C., Chen, L., Shi, H., & Chong, D. (2020). Artificial Intelligence powered Internet of Things and smart public service. *Library Hi Tech*, *38*(1), 165-179. doi: 10.1108/LHT-12-2017-0274

Mendling, J., Decker, G., Hull, R., Reijers, H. A., & Weber, I. (2018). How do Machine Learning, Robotic Process Automation, and Blockchains Affect the Human Factor in Business Process Management? *Communications of the Association for Information Systems*, 297-320. doi: 10.17705/1CAIS.04319

Muhammad, K., Lloret, J., & Baik, S. W. (2019). Intelligent and energy-efficient data prioritization in green smart cities: Current challenges and future directions. *IEEE Communications Magazine*, *57*(2), 60-65. doi: 10.1109/MCOM.2018.1800371

Nam, K., Dutt, C. S., Chathoth, P., Daghfous, A., & Khan, M. S. (2021). The adoption of artificial intelligence and robotics in the hotel industry: prospects and challenges. *Electronic Markets*, *31*(3), 553-574. doi: 10.1007/s12525-020-00442-3

Navarro-Espinoza, A., López-Bonilla, O. R., García-Guerrero, E. E., Tlelo-Cuautle, E., López-Mancilla, D., Hernández-Mejía, C., & Inzunza-González, E. (2022). Traffic Flow Prediction for Smart Traffic Lights Using Machine Learning Algorithms. *Technologies*, *10*(1). doi: 10.3390/technologies10010005

Nguyen, D. C., Ding, M., Pathirana, P. N., Seneviratne, A., Li, J., & Vincent Poor, H. (2021). Federated Learning for Internet of Things: A Comprehensive Survey. *IEEE Communications Surveys and Tutorials*, *23*(3), 1622-1658. doi: 10.1109/COMST.2021.3075439

Nikitas, A., Michalakopoulou, K., Njoya, E. T., & Karampatzakis, D. (2020). Artificial intelligence, transport and the smart city: Definitions and dimensions of a new mobility era. *Sustainability (Switzerland)*, *12*(7), 1-19. doi: 10.3390/su12072789

Niñerola, A., Sánchez-Rebull, M.-V., & Hernández-Lara, A.-B. (2019). Tourism research on sustainability: A bibliometric analysis. *Sustainability (Switzerland)*, *11*(5). doi: 10.3390/su11051377

O'Dwyer, E., Pan, I., Acha, S., & Shah, N. (2019). Smart energy systems for sustainable smart cities: Current developments, trends and future directions. *Applied Energy*, *237*, 581-597. doi: 10.1016/j.apenergy.2019.01.024

Ortega-Fernández, A., Martín-Rojas, R., & García-Morales, V. J. (2020). Artificial intelligence in the urban environment: Smart cities as models for developing innovation and sustainability. *Sustainability (Switzerland)*, *12*(19). doi: 10.3390/SU12197860

Paiva, S., Ahad, M. A., Tripathi, G., Feroz, N., & Casalino, G. (2021). Enabling technologies for urban smart mobility: Recent trends, opportunities and challenges. *Sensors*, *21*(6), 1-45. doi: 10.3390/s21062143

Park, S., Park, S., Choi, M. I., Lee, S., Lee, T., Kim, S., Cho, K., & Park, S. (2020). Reinforcement Learning-Based BEMS Architecture for Energy Usage Optimization. *Sensors*, *20*(17). doi: 10.3390/s20174918

Perc, M., Ozer, M., & Hojnik, J. (2019). Social and juristic challenges of artificial intelligence. *Palgrave Communications*, *5*(1). doi: 10.1057/s41599-019-0278-x

Pramod, M. S., Balodi, A., Pratik, A., Satya Sankalp, G., Varshita, B., & Amrit, R. (2023). Energy-Effcient Reinforcement Learning in Wireless Sensor Networks Using 5G for Smart Cities. In *Applications of 5G and Beyond in Smart Cities* (pp. 63-86). CRC Press. doi: 10.1201/9781003227861-4

Ragab, A., Osama, A., & Ramzy, A. (2023). Simulation of the Environmental Impact of Industries in Smart Cities. *Ain Shams Engineering Journal*, *14*(6). doi: 10.1016/j.asej.2022.102103

Rani, S., Mishra, R. K., Usman, M., Kataria, A., Kumar, P., Bhambri, P., & Mishra, A. K. (2021). Amalgamation of advanced technologies for sustainable development of smart city environment: A review. *IEEE Access*, *9*, 150060-150087. doi: 10.1109/ACCESS.2021.3125527

Reebadiya, D., Rathod, T., Gupta, R., Tanwar, S., & Kumar, N. (2021). Blockchain-based Secure and Intelligent Sensing Scheme for Autonomous Vehicles Activity Tracking Beyond 5G Networks. *Peer-to-Peer Networking and Applications*, *14*(5), 2757-2774. doi: 10.1007/s12083-021-01073-x

Sarker, I. H. (2021). Machine Learning: Algorithms, Real-World Applications and Research Directions. *SN Computer Science*, *2*(3). doi: 10.1007/s42979-021-00592-x

Sarker, I. H., Khan, A. I., Abushark, Y. B., & Alsolami, F. (2022). Internet of Things (IoT) Security Intelligence: A Comprehensive Overview, Machine Learning Solutions and Research Directions. *Mobile Networks and Applications*. doi: 10.1007/s11036-022-01937-3

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. doi: 10.1109/ACCESS.2020.2990123

Shankar, K., Perumal, E., Elhoseny, M., Taher, F., Gupta, B. B., & El-Latif, A. A. A. (2021). Synergic Deep Learning for Smart Health Diagnosis of COVID-19 for Connected Living and Smart Cities. *ACM Transactions on Internet Technology*, *22*(3). doi: 10.1145/3453168

Shi, J., Liu, S., Zhang, L., Yang, B., Shu, L., Yang, Y., Ren, M., Wang, Y., Chen, J., Chen, W., Chai, Y., & Tao, X. (2020). Smart Textile-Integrated Microelectronic Systems for Wearable Applications. *Advanced Materials*, *32*(5). doi: 10.1002/adma.201901958

Shi, X., Luo, J., Luo, J., Li, X., Han, K., Li, D., Cao, X., & Wang, Z. L. (2022). Flexible Wood-Based Triboelectric Self-Powered Smart Home System. *ACS Nano*, *16*(2), 3341-3350. doi: 10.1021/acsnano.1c11587

Siderska, J., Alsqour, M., & Alsaqoor, S. (2023). Employees' attitudes towards implementing robotic process automation technology at service companies. *Human Technology*, *19*(1), 23-40. doi: 10.14254/1795-6889.2023.19-1.3

Siderska, J., & Jadaan, K. S. (2018). Cloud manufacturing: A service-oriented manufacturing paradigm. A review paper. *Engineering Management in Production and Services*, *10*(1), 22-31. doi: 10.1515/emj-2018-0002

Singh, S. K., Rathore, S., & Park, J. H. (2020). BlockIoTIntelligence: A Blockchain-enabled Intelligent IoT Architecture with Artificial Intelligence. *Future Generation Computer Systems*, *110*, 721-743. doi: 10.1016/j.future.2019.09.002

Singh, S., Sharma, P. K., Yoon, B., Shojafar, M., Cho, G. H., & Ra, I.-H. (2020). Convergence of blockchain and artificial intelligence in IoT network for the sustainable smart city. *Sustainable Cities and Society*, *63*. doi: 10.1016/j.scs.2020.102364

Skouby, K. E., & Lynggaard, P. (2014). Smart home and smart city solutions enabled by 5G, IoT, AAI and CoT services. *Proceedings of 2014 International Conference on Contemporary Computing and Informatics, IC3I 2014*, 874-878. doi: 10.1109/IC3I.2014.7019822

Szpilko, D. (2017). *Tourism Supply Chain – Overview of Selected Literature. Procedia Engineering*, *182*, 687-693. doi: 10.1016/j.proeng.2017.03.180

Szpilko, D., & Ejdys, J. (2022). European Green Deal — research directions. A systematic literature review. *Ekonomia i Środowisko - Economics and Environment*, *81*(2), 8-38. doi: 10.34659/eis.2022.81.2.455

Szpilko, D., Budna, K., Drmeyan, H., & Remiszewska, A. (2023). Sustainable and smart mobility — research directions. A systematic literature review. *Ekonomia i Środowisko - Economics and Environment*, *86*(3). doi: 10.34659/eis.2023.86.3.584

Szpilko, D., Szydło, J., & Winkowska, J. (2020). Social Participation of City Inhabitants Versus Their Future Orientation. Evidence From Poland. *WSEAS Transactions on Business and Economics*, *17*, 692-702. doi: 10.37394/23207.2020.17.67

Szum, K. (2021). IoT-based smart cities: A bibliometric analysis and literature review. *Engineering Management in Production and Services*, *13*(2), 115-136. doi: 10.2478/emj-2021-0017

Tian, Y., & Pan, L. (2015). Predicting Short-Term Traffic Flow by Long Short-Term Memory Recurrent Neural Network. *2015 IEEE International Conference on Smart City/SocialCom/SustainCom (SmartCity)*, 153-158. doi: 10.1109/SmartCity.2015.63

Toglaw, S., Aloqaily, M., & Alkheir, A. A. (2018). Connected, autonomous and electric vehicles: The optimum value for a successful business model. *2018 5th International Conference on Internet of Things: Systems, Management and Security, IoTSMS 2018*, 303-308. doi: 10.1109/IoTSMS.2018.8554391

Tomaszewska, E. J., & Florea, A. (2018). Urban smart mobility in the scientific literature - Bibliometric analysis. *Engineering Management in Production and Services*, *10*(2), 41-56. doi: 10.2478/emj-2018-0010

Ullah, Z., Al-Turjman, F., Moatasim, U., Mostarda, L., & Gagliardi, R. (2020). UAVs joint optimization problems and machine learning to improve the 5G and Beyond communication. *Computer Networks*, *182*. doi: 10.1016/j.comnet.2020.107478

Ullah, Z., Al-Turjman, F., Mostarda, L., & Gagliardi, R. (2020). Applications of Artificial Intelligence and Machine learning in smart cities. *Computer Communications*, *154*, 313-323. doi: 10.1016/j.comcom.2020.02.069

United Nation. (2015). Transforming our world: the 2030 Agenda for Sustainable Development. In *United Nation: Vol. A/RES/70/1*.

van Eck, N. J., & Waltman, L. (2018). *VOSviewer Manual. Manual for VOSviewer version 1.6.11 software documentation.*

Vázquez-Canteli, J. R., Ulyanin, S., Kämpf, J., & Nagy, Z. (2019). Fusing TensorFlow with building energy simulation for intelligent energy management in smart cities. *Sustainable Cities and Society*, *45*, 243-257. doi: 10.1016/j.scs.2018.11.021

Wang, K., Zhao, Y. F., Gangadhari, R. K., & Li, Z. X. (2021). Analyzing the Adoption Challenges of the Internet of Things (IoT) and Artificial Intelligence (AI) for Smart Cities in China. *Sustainability*, *13*(19). doi: 10.3390/su131910983

Wences, P., Martinez, A., Estrada, H., & Gonzalez, M. (2017). Decision-making intelligent system for passenger of urban transports. In P. Singh, J. Bravo, & S. F. Ochoa (Eds.), *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) LNCS* (pp. 128-139). Springer Verlag. doi: 10.1007/978-3-319-67585-5_14

Winkowska, J., Szpilko, D., & Pejić, S. (2019). Smart city concept in the light of the literature review. *Engineering Management in Production and Services*, *11*(2), 70-86. doi: 10.2478/emj-2019-0012

Wirtz, B. W., Weyerer, J. C., & Geyer, C. (2019). Artificial Intelligence and the Public Sector—Applications and Challenges. *International Journal of Public Administration*, *42*(7), 596-615. doi: 10.1080/01900692.2018.1498103

Wu, T.-Y., Meng, Q., Chen, Y.-C., Kumari, S., & Chen, C.-M. (2023). Toward a Secure Smart-Home IoT Access Control Scheme Based on Home Registration Approach. *Mathematics*, *11*(9). doi: 10.3390/math11092123

Wu, Y. (2021). Cloud-Edge Orchestration for the Internet of Things: Architecture and AI-Powered Data Processing. *IEEE Internet of Things Journal*, *8*(16), 12792-12805. doi: 10.1109/JIOT.2020.3014845

Wu, Z., & Chu, W. (2021). Sampling Strategy Analysis of Machine Learning Models for Energy Consumption Prediction. *2021 9th IEEE International Conference on Smart Energy Grid Engineering, SEGE 2021*, 77-81. doi: 10.1109/SEGE52446.2021.9534987

Yamakami, T. (2017). An organizational coordination model for IoT: A case study of requirement engineering of city-government in Tokyo in city platform as a service. *International Conference on Information and Communication Technology Convergence: ICT Convergence Technologies Leading the Fourth Industrial Revolution, ICTC 2017*, *2017-December*, 259-263. doi: 10.1109/ICTC.2017.8190982

Yigitcanlar, T., Desouza, K. C., Butler, L., & Roozkhosh, F. (2020). Contributions and risks of artificial intelligence (AI) in building smarter cities: Insights from a systematic review of the literature. *Energies*, *13*(6). doi: 10.3390/en13061473

Yuan, T. T., Da RochaNeto, W., Rothenberg, C. E., Obraczka, K., Barakat, C., & Turletti, T. (2022). Machine learning for next-generation intelligent transportation systems: A survey. *Transactions on Emerging Telecommunications Technologies*, *33*(4). doi: 10.1002/ett.4427

Zheng, Z., Zhou, Y., Sun, Y., Wang, Z., Liu, B., & Li, K. (2022). Applications of federated learning in smart cities: recent advances, taxonomy, and open challenges. *Connection Science*, *34*(1), 1-28. doi: 10.1080/09540091.2021.1936455

Zhi-Xian, Z., & Zhang, F. (2022). Image Real-Time Detection Using LSE-Yolo Neural Network in Artificial Intelligence-Based Internet of Things for Smart Cities and Smart Homes. *Wireless Communications and Mobile Computing*, *2022*. doi: 10.1155/2022/2608798

Zhou, H., Liu, Q., Yan, K., & Du, Y. (2021). Deep Learning Enhanced Solar Energy Forecasting with AI-Driven IoT. *Wireless Communications and Mobile Computing*, *2021*. doi: 10.1155/2021/9249387