big data and cognitive computing

Article

A Scientific Perspective on Using Artificial Intelligence in Sustainable Urban Development

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Abstract: Digital transformation (or digitalization) is the process of continuous further development of digital technologies (such as smart devices, cloud services, and Big Data) that have a lasting impact on our economy and society. In this manner, digitalization is a huge driver for permanent change, even in the field of Sustainable Urban Development. In the wake of digitalization, expectations are changing, placing pressure at the societal level on the design and development of smart environments for everything that means Sustainable Urban Development. In this sense, the solution is the integration of Artificial Intelligence into Sustainable Urban Development, because technology can simplify people's lives. The aim of this paper is to ascertain which Sustainable Urban Development dimensions are taken into account when integrating Artificial Intelligence and what results can be achieved. These questions formed the basic framework for this research article. In order to make the current state of Artificial Intelligence in Sustainable Urban Development as a snapshot visible, a systematic review of the current literature between 2012 and 2022 was conducted. The data were collected and analyzed using PRISMA. Based on the studies identified, we found a significant growth in studies, starting in 2018, and that Artificial Intelligence applications refer to the Sustainable Urban Development dimensions of environmental protection, economic development, social justice and equity, culture, and governance. The used Artificial Intelligence techniques in Sustainable Urban Development cover a broad field of Artificial Intelligence, such as Artificial Intelligence in general, Machine Learning, Deep Learning, Artificial Neuronal Networks, Operations Research, Predictive Analytics, and Data Mining. However, with the integration of Artificial Intelligence in Sustainable Urban Development, challenges are marked out. These include responsible municipal policies, awareness of data quality, privacy and data security, the formation of partnerships among stakeholders (e.g., local citizens, civil society, industry, and various levels of government), and transparency and traceability in the implementation and rollout of Artificial Intelligence. A first step was taken towards providing an overview of the possible applications of Artificial Intelligence in Sustainable Urban Development. It was clearly shown that Artificial Intelligence is also gaining ground in this sector.

Keywords: digital transformation; economic development; environmental protection; governance; smart cities

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1. Introduction

According to the World Bank [1], we are living in times of increasing urbanization, with 56% of the world's population, 4.4 billion inhabitants, now living in urban areas. More than 80% of the world's gross domestic product (GDP) is currently generated in cities. By 2045, the number of people living in cities will increase by 1.5 times to 6 billion, which means that 2 billion more city dwellers will be added. Almost 7 out of 10 people will live in cities. In addition to the number of people, the average size of cities has also increased [2]. Therefore, in order to meet the resulting challenges, including housing shortages, traffic status, or waste disposal, cities must develop social and economic structures without damaging the environment and create a balance between human inhabitants and natural resources to achieve urbanization [3]. In this context, the concept of "smart city" is taken up as a possible solution approach and socio-technical concept. Smart cities use modern information and communication technologies (ICTs) to shape Urban Development in a sustainable manner. This leads to cities becoming increasingly digital [4], which in turn leads to growth in the generation of data [5]. In order to gain value from the generated data, computer processing and analysis of the data [6] is of particular importance, in addition to data management [7]. Artificial Intelligence (AI) can be an effective way to bring about efficient and cost-effective solutions in Urban Development.

The creation of AI has preoccupied people since the beginning of electronic data processing. As early as 1950, Alan Turing [8] asked the question of whether or not computers could think. In the decades that followed, the science of AI experienced ups and downs. In the 1990s, advances in AI research began to accelerate as the number of scientists increased in the late 1990s, and scientists focused on applying AI to real-world problems. However, this does not mean just building an exceptionally intelligent machine that can solve any real-world problem in a very short time (a machine with general intelligence) [9]. It also means constructing a machine that is capable of performing complex tasks such as performing mechanical tasks that require difficult maneuvering or understanding human language or solving sophisticated computer-based problems that may involve large amounts of data in a very short time and providing feedback on the answers in a human-like manner, among others [10]. In this understanding of AI, Crawford [11] considers that AI is a registry of power. AI has enormous potential not only in industrial processes, but also in Sustainable Urban Development (SUD). For this reason, since the introduction of AI in the twentieth century, societal interest has also grown.

In this article, we want to exemplify the current state-of-the-art in SUD in combination with AI and provide a brief overview, also to identify if there is a need for additional research in this field. Furthermore, we aimed at identifying the scientific relationship between this topic and other research fields. The purpose of this Systematic Literature Review (SLR) is to provide a foundation of knowledge on this specific topic.

The article structure is as follows: in Section 1 we provide an introduction to the topic with an overview about AI and SUD. Section 2 outlines the materials and research methods used, from the term of SLR over formulated research questions (RQs) to the search flow. The results answering the RQ are presented in Section 3. Section 4 discusses the results.

1.1. Artificial Intelligence: A Brief Overview

According to John McCarthy [12], the goal of AI is to develop machines that behave as though they were intelligent. This understanding of AI was formed early in AI development as it was an approach to make a robot think as a human would. AI used to be a study of understanding how a human brain thinks and learns, especially for solving problems and making decisions, although the AI aim was to improve computer functions that were related to human experience. Further questions are essential for the understanding of AI, such as "How does the brain work?" or "How can intelligence be measured?". Ertel [13] showed that AI draws upon many scientific achievements, with few of them well-known to the broad civilization.

AI is a technology that is intended to enable machines to perform human activities. The aim of AI is to emulate human memory, learning behavior, and development [14]. In this manner, AI refers to problem-solving instructions that are adapted to human behavior and have been transferred into a program structure [15]. To do this, computer programs must be able to store and extend collective knowledge and recognize underlying knowledge through patterns, categories, and behavior [16].

AI needs to be differentiated from other concepts [17]. AI involves providing the computer instructions on how to make a decision rather than determining the rules from the data. Examples of AI include business rules and process automation, which are not considered to be Machine Learning (ML). ML, a subset of AI, is a general term for a comprehensive set of algorithms that allow a computer to recognize patterns in past data and use those patterns to predict future outcomes. Another differentiation of ML is Deep Learning (DL). This is a subset of ML that uses large Artificial Neural Networks (ANNs) to identify patterns in data. Figure 1 puts all these concepts in context with each other.

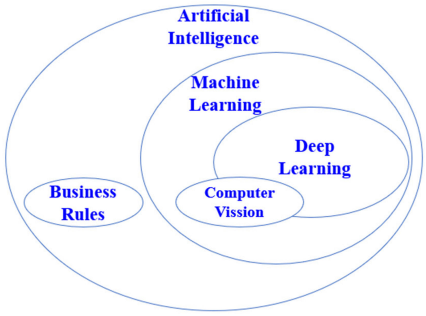

Figure 1. Disciplines of AI (processing by authors adapted by [17]).

In accord with Russel and Norvig [18], we distinguish two AI manifestations: strong AI aims to model human problem-solving creativity, self-awareness, and emotions; weak AI focuses on solving concrete application problems by simulating intelligence through methods of computer science and mathematics.

The application of AI ranges from speech recognition systems to virtual assistants, chatbots, and expert systems. Software products available on the market support the implementation of these use cases. Currently, we find more use cases for weak AI [19].

1.2. Sustainable Urban Development: A Short Introduction

Today, there is no universally accepted definition of what is meant by sustainability in natural systems (sustainable development (SD)). Its roots lie in the 17th and 18th centuries, with an initial forestry orientation [20]. The term was coined in 1713 by Hanns Carl von Carlowitz, the head of the Royal Mining Office in the Kingdom of Saxony [21]. At that time, wood was considered the most important raw material, and it was necessary to counteract the predicted shortage [22]. The scientific discourse began at the end of the 20th century, marked by the study "Limits to the Grow" by the Club of Rome in 1972 [21,23–25]. In the mentioned study, the term "sustainability" was greatly expanded: scientists linked economic, ecological, and social aspects of sustainability and called for a new global economic policy. The Club of Rome plead for a permanent, worldwide state of equilibrium that can only be achieved through "worldwide measures". In the meantime, more than 300 definitions of SD are known [26]. In this context, the SD definition of the World Commission on Environment and Development (WCED), also known as the Our Common Future or Brundtland Report, from 1987, is considered the most frequently cited definition [27]): "Humanity has the ability to make development sustainable—to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" [28] (p. 15). Based on this definition, Germany adopted its national sustainability strategy in 2002 [29], which since 2016 has been oriented towards the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda (United Nations Program) for SD, from the fight against hunger and poverty to affordable and clean energy, climate protection, and the goal of livable, sustainable cities.

When we talk about sustainable cities (or SUD, urban sustainability), several interpretations fall into this division. In Wheeler's [30] opinion, urban planning not only pushes the expansion of road networks but also the electrical supply, the connection to bus and rail networks, as well as the provision of basic needs, such as a minimum level of consumption, sanitation, education, and health. In our paper we use Wheeler's definition of SUD for operational: "Sustainable urban development seeks to create cities and towns that improve the long-term health of the planet's human and ecological systems." [30] (p. 55). According to the Brundtland Commission, the reason for use is the critic, specifically for being anthropocentric and for raising the difficult-to-define concepts of needs [30].

With progress in digitalization and steady growth of cities, efficiency in planning and implementation is becoming more important every year. Land use must be realized as efficiently as possible and not only because of rising costs [23]. SUD is a type of responsibility that is committed by someone who has the significant role as an urban planner. This special role in each city should have deep understanding of the economy [31].

In addition to the increasing population on earth, cities and villages are also becoming more densely populated and inhabited. For this reason, urbanization is inevitable. The growth of urban areas is dominated by megacities. As mentioned by the United Nations estimate, it is proven in the United States that by 2050, more than 70% of the population will be accommodated in cities [32].

According to Slaper and Hall [33], SUD is generally designed to take into account environmental impacts and to provide a social, economic and resilient habitat for the current population without compromising the ability of future generations to experience the same. Saha and Paterson [34], Portney [35], Jepson [36], and Conroy [37] have identified four pillars (or dimensions) of SUD (Figure 2).

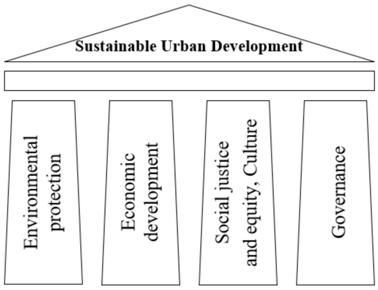

Figure 2. Pillars of SUD (source: processing by authors).

The first dimension is called environmental protection and it maintains environmental quality and carrying capacity. The second is economic development and it maintains economic goals such as growth, prosperity, stability, and fair trade. The third is social justice, equity, and culture, and it supports social purposes such as living standards, well-being, participation, and cultural diversity. The last dimension is governance, which operates and maintains urban service from the public point of view.

These SUD dimensions can be operationalized in individual activities (Table 1).

Table 1. Urban development activities.

Dimensions	Activity Groups	Sub-Activities (Examples, Not Conclusive)
Environmental protection	Energy Efficiency	Alternative energy, energy conservation effort, green building programs, renewable energy, solar access protection, urban forestry programs, wind energy development
	Pollution Prevention and Reduction	Household waste recycling, industrial recycling, curbside recycling, water quality protection
	Open Space and Natural Resource Protection	Green maps, green print plans, open space zoning
	Transportation Planning	Bicycle access plan, carpool lanes, operation of inner-city public transit (buses and/or trains), pedestrian-oriented development
	Tracking Progress on Protecting the Environment	Ecological footprint analysis, urban ecosystem analysis
Economic development	Smart Growth	Eco-industrial park development, brownfield redevelopment/reclamation, infill development
	Local Employment/Industries	Empowerment/enterprise zones, local business incubator programs, import substitution
Social justice and equity, culture		Affordable housing, community gardening, daycare services for service sector and low-income employees, women/minority-oriented business community, youth opportunity and anti-gang programs
Governance		Dispute resolution, public participation (public hearings, neighborhood groups), regional coordination, involvement of the business community

Source(s): [34–37].

2. Materials and Methods

In this section, we discuss the methodology of research applied in our approach for reaching the scientific goal and the search algorithm with the full details of the matter. The principal motivation of this section is to assure the replicability of the results of interrogation for our SLR.

2.1. Methodology

In our approach, we agree with Fink [38] that SLR is "a systematic, explicit and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners" (p. 3), as we can see in Figure 3:

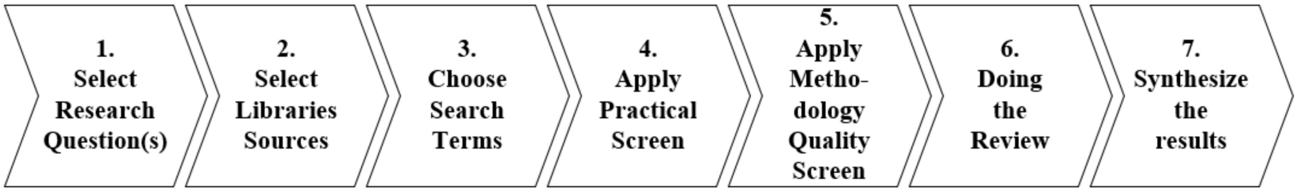

Figure 3. Steps of SLR (source: processing by authors adapted by [38].

The SLR process starts with (1) formulating one or more RQ's, followed by choosing the bibliographic databases, (2) that contain all the relevant content to answer the RQs. To retrieve these libraries, we must choose search terms, (3) that conceptualize the framework for the research questions. To screen out relevant documents from the libraries, criteria for inclusion in and exclusion from the review (4), and methodological criteria for evaluating science quality (5) are defined. This is followed by conducting the review using standardized formalities (6) and synthesizing the results in descriptive form (7).

Within the SLR process, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model was used to exclude irrelevant datasets in a meaningful and traceable manner [39]. PRISMA is a minimal set of elements for documenting in systematic reviews and meta-analyses that is supported by evidence. PRISMA is primarily concerned with reporting reviews that assess the effects of interventions, but it may also serve as a foundation for reporting systematic reviews with goals other than assessing treatments (e.g., evaluating etiology, prevalence, diagnosis, or prognosis) (https://prisma-statement.org, accessed on 1 August 2022). The approach to data collection is based on the methodology of searching journals for common publications in the subject at hand. For this reason, a basic strategy had to be developed in order to obtain the necessary datasets in the later step. The procedure of this survey was carried out as described in Figure 4.

According to our research objective, we formulated a set of research questions (RQs) by reference to the associated purpose:

- RQ1: What studies are there in the world regions/countries? With this question we pursue the goal of identifying the regions or countries where AI will be used in SUD;
- RQ2: What AI techniques are used in Urban Development? The aim of this question is to highlight different AI techniques that are applied in SD;
- RQ3: Which Urban Development dimensions are addressed? The aim of this question is to highlight the dimensions that are applied in SUD;
- RQ4: What are the outcomes of AI use in Urban Development? The reason for formulating this question is to discover the main effects related to the use of AI in Urban Development.

The RQs are designed to ensure that the collection of data is based on content analysis.

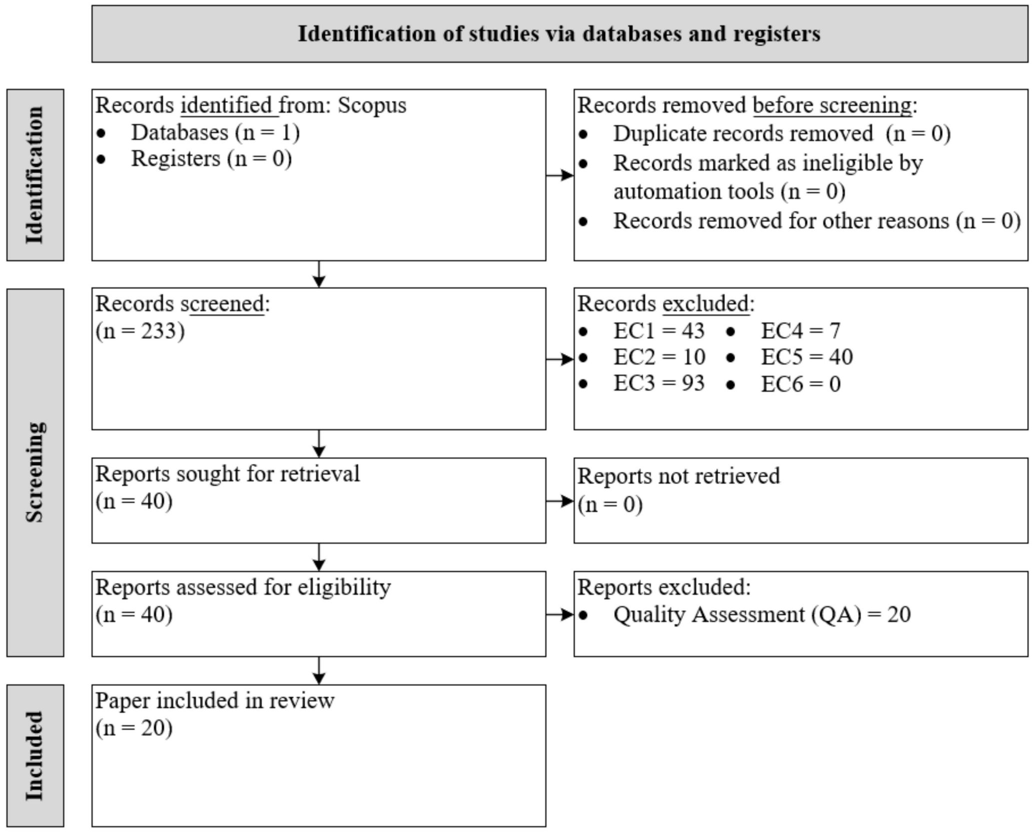

Figure 4. PRISMA Search Flow (updated after Page et al. [39]).

2.2. Search Flow

The database Scopus (http://www.scopus.com, accessed on 19 September 2022) was searched to retrieve the relevant articles with the datasets related to AI in the SUD sector. The search within the title, abstract, and keywords was conducted in late September 2022. A well-structured search strategy was developed for retrieving the best articles according to the topic:

("Artificial Intelligence" OR "AI")

AND ("Urban Development" OR "Sustainable Urban Development")

The search term "Sustainable Urban Development" was included, because it is often used synonymously to the term "Urban Development". The search string was built with the Boolean logic and therefore the word bindings "AND" and "OR" must be used. After applying the above search string, 233 papers remained.

In refining the library results, eligibility criteria were used. More precisely, these criteria serve as a tool for screening out studies that are not relevant to the research. Through these criteria, only those studies that serve the research questions were collected. The types are inclusion criteria (conditions that a study is focused on) and exclusion criteria (conditions used to exclude a study). For our study, the common rules were applied:

1. EC1 (Limitation to Date Range): The articles needed to be published between 2012 and 2022 to ensure timeliness and applicability. A time frame of 10 years was selected to form a research framework for the survey. For this reason, the survey started in the year 2012 and ended in 2022. Before 2012, AI was not yet in widespread use;
2. EC2 (Limitation to Language): The articles should be written in English (articles in other languages are excluded). In order for the conducted study to reach a wider audience, the language barrier of other languages, such as German, were removed from the results. With English as the international language, the results can be read by a larger group of readers;

3. EC3 (Limitation to Source Type): The source needed to be based on a qualitative or quantitative methodological approach, in a scholarly journal. Research methods are either qualitative or quantitative in nature. For this reason, the analyzed papers also had to use either a qualitative or quantitative research method;
4. EC4 (Limitation to Document type): Only articles relevant (other document types, such as conference papers or book chapters are excluded). Since the data collection had to consist mainly of scientific research papers, document types such as books or conference papers had to be excluded from the survey;
5. EC5 (Limitation to Access Type): Articles should be freely accessible (open access), allowing and simplifying the ease of replicating the survey of the studies. Restricted articles require access accounts and may complicate or prevent analysis when replicating the study results (all articles without "Open Access" are excluded);
6. EC6 (Limitation to Scientific Interest): SLR and bibliometric analysis (BA) are excluded from our content analyses. The reason for not including bibliometric analysis is that bibliometric analysis is a popular method for exploring large volumes of scientific data. The reason why bibliometric analysis should not be included is that it is a popular method of exploring large amounts of scientific data.

After identifying 40 documents that met the search strings and the eligibility criteria, the content was screened specifically by titles and abstracts to apply the quality criteria. Quality assessment (QA) portrayed an important role in ensuring that the studies included in a review were consistent with the defined purpose. The scientific and/or empirical quality of selected studies had to be rigorously assessed to remove potential bias and optimize the power of the results. The following checklist of reasons (Rs) was used as part of the quality assessment:

1. R1: Were the authors, abstract, or keywords explicitly provided?
2. R2: Were the aims or objectives of the study clear?
3. R3: Was the research method of the study explained?
4. R4: Was the presenting of the study findings clear?
5. R5: Were the technique of AI clearly addressed?
6. R6: Was the environment of SUD clearly described?
7. R7: Was the subject of the research really research?

A total of 20 documents were not included in the selection of extracted studies as they did not correlate thematically with the topic of the research work. For this reason, the mentioned documents were removed and finally 20 documents could be extracted and included in the analysis. In Figure 4 we represent the full process of Search flow, with the application of all limitations applied on the results of initial interrogation.

3. Results

Before presenting the answers to our research questions, based on the results obtained after the application of research methodology, we show the study characteristics and an overview of the interest over the years in the chosen topic and the distribution of publications in different journals.

3.1. Study Characteristics

With the purpose of reading and categorizing the included papers (n = 20), another table (Table 2) was created, with the help of which the most important attributes of the papers could be noted for later evaluations and comparisons. The table shows the reference number with the title of the paper, purpose and/or objectives, the research methodology, and the study results.

Table 2. Characteristics of included studies.

Ref/Title	Purpose and/or Objectives	Research Method	Study Result(s)
Caprotti, 2022 [40]: Platform urbanism and the Chinese smart city: the co-production and territorialisation of Hangzhou City Brain	The authors analyzed an urban platform (Alibaba's City Brain) to show how smart city development was evolving in urban China, based on two strands of literature: platform urbanism and experimental city.	Case study; Semi-structured interviews; Observations	(1) Digital urban platforms exhibited varying degrees of territorialization at several scales. (2) Territorialization went hand in hand with experimentation. (3) Locality was part of the founding driver for a product that was eventually meant to be widely sold to other urban jurisdictions. (4) Chinese smart and platform cities could be seen as the result of a more dynamic, relational process involving multiple state, corporate, and hybrid actors in the co-production of projects that may be represented as stable. (6) Findings could be generalized outside China.
Panteleeva and Borozdina, 2022 [41]: Sustainable Urban Development Strategic Initiatives	The authors proposed strategic initiatives for the management of urban facilities, especially residential and municipal urban service objects in Russia. They developed a model for assessing the sustainable development of urban facilities based on Artificial Intelligence-based end-to-end technologies.	Descriptive study based on secondary sources including news, journals	A strategic roadmap for the sustainable development of housing and communal service facilities, considered from the aspect of ensuring (forming) a comfortable living environment for citizens.
Arfanuzzaman, 2021 [42]: Harnessing Artificial Intelligence and Big Data for SDGs and prosperous urban future in South Asia	The study aimed to review and assess existing Artificial Intelligence and Big Data technologies deployed in different parts of the world and their potential for tracking and monitoring the progress of city-based Sustainable Development Goals (SDGs) in South Asia.	Descriptive study based on secondary sources including news, journals	(1) AI and Big Data have great potential to mobilize integrated and scalable solutions in Urban Development. (2) A robust data infrastructure and South Asia's technological readiness are key enablers for AI and Big Data solutions to pressing urban problems.
Myeong and Shahzad, 2021 [43]: Integrating Data-Based Strategies and Advanced Technologies with Efficient Air Pollution Management in Smart Cities	The study presented a technology-enabled air quality solution for smart cities to answer the question of how data-driven approaches of Artificial Intelligence, the Internet of Things, methods of innovative leadership, and citizen participation can be incorporated into effective public sector pollution management in smart cities.	Literature review; Survey	(1) Complex proceedings are leading to successful and sustainable smart cities through coordination of their resources and the activities of individuals and organizations on innovation management and leadership platforms. (2) Interest in urbanization grows as technologically driven production processes and distribution of services come to the fore. (3) Harnessing social and spatial complexities of smart growth in smart cities, especially through data-driven air pollution sensing, leads to social and economic gains.

Table 2. *Cont.*

Ref/Title	Purpose and/or Objectives	Research Method	Study Result(s)
Englund et al., 2021 [44]: AI Perspectives in Smart Cities and Communities to Enable Road Vehicle Automation and Smart Traffic Control	The authors described the prospects for Artificial Intelligence in smart cities and communities (SCC) and provided an overview of Artificial Intelligence-based technologies used in transportation to enable road vehicle automation and intelligent traffic control with the goal of energy efficiency and traffic safety.	Descriptive study using secondary sources such as journal articles, news articles, research initiatives, projects, and financial programs publications	(1) The planning and control of traffic systems is of central importance for the flow of traffic in larger cities, which can be supported with traffic simulations. (2) Computer vision and sensor technology are prerequisites for the automation of road vehicles, where safety is paramount. (3) AI applications in the traffic environment are data-intensive; this concerns the scope and frequency as well as the need to bring together a variety of data of different types and from different sources. (4) There are large uncertainties in the requirements for a transport system based on historical data, as such systems that are highly dynamic, and their data are constantly changing. (5) Data protection, low explainability of AI models, and data biases form risks for the development of smart cities.
Zhihui and Guangtian, 2021 [45]: Intelligent Data Mining of Computer-Aided Extension Residential Building Design Based on Algorithm Library	The authors used mathematical computer algorithms of Data Mining as well as extension theory to study and analyze the design as well as extension of residential buildings (architectural design). The approach included knowledge representation, system design and system flow, and interface expression based on the mathematical database.	Literature review; Design science	In addition to classical construction planning (using software for architectural design resulting in computer-aided drawings), AI solutions for Data Mining support in fit-out planning by extracting potentially useful knowledge for conflict resolution from dynamic, extensive and complex data.
Pinter et al., 2020 [46]: Artificial Intelligence for Modeling Real Estate Price Using Call Detail Records and Hybrid Machine Learning Approach	The authors investigated the potential of call detail records (CDR) for property price prediction using Machine Learning AI (multilayer perceptron (MLP)) trained with the particle swarm optimization (PSO) evolutionary algorithm based on Data of Vodafone facilities located in Budapest, Hungary.	Literature review; Quantitative Analysis	(1) Artificial intelligence can successfully estimate the price of real estate with high accuracy. (2) High level of mobilities of people due to their work and activity flows lead from areas with lower real estate prices to regions with higher real estate prices.
Ortega-Fernández et al., 2020 [47]: Artificial Intelligence in the Urban Environment: Smart Cities as Models for Developing Innovation and Sustainability	The aim of the study was to identify dimensions, factors, and indicators that make up a smart city based on existing smart cities in Spain. The minimum factors required for the transformation of a conventional city into a smart city were analyzed.	Empirical causal research design	In order to improve the measures implemented in public administration, mobility, the environment, the economy, and quality of life, this study visualizes and provides guidelines for improvement through the application and implementation of the algorithmic proposals inherent in the current conception of the use of Machine Learning, AI (1), or automatic learning at the city level.

Table 2. *Cont.*

Ref/Title	Purpose and/or Objectives	Research Method	Study Result(s)
D'Amico et al., 2020 [48]: Understanding Sensor Cities: Insights from Technology Giant Company Driven Smart Urbanism Practices	The purpose of this paper was to explore and integrate different sensor cities taken as case studies consistent with the research demand and to discuss technological solutions (e.g., sensors, devices, Internet of Things, Artificial Intelligence, platforms, digital infrastructures, computer models, ICTs), emphasizing the economic, social, and environmental benefits of their practical application.	Literature review; Case Studies	(1) Disruptive urban AI technologies promote highly efficient and computational urban processes and their efficiency, and improve the understanding of planning, monitoring and analyzing the performance of sensor cities by raising awareness among stakeholders (including citizens, businesses, local authorities). (2) Critical aspects to be considered are data quality and integrity, cybersecurity, digital data and information ethics, and regulation.
Yigitcanlar et al., 2020 [49]: Can Building "Artificially Intelligent Cities" Safeguard Humanity from Natural Disasters, Pandemics, and Other Catastrophes? An Urban Scholar's Perspective	This paper generated insights and identified prospective research questions by charting the evolution of Artificial Intelligence and the potential impacts of the systematic adoption of Artificial Intelligence in cities and societies. The generated insights informed urban policymakers, managers, and planners on how to ensure the correct uptake of Artificial Intelligence in our cities, and the identified critical questions offered scholars directions for prospective research and development.	Empirical research design	(1) Despite significant progress, the use of AI technologies alone is not sufficient. Additional innovations in administrative mechanisms are needed, as well as modernization of the political apparatuses of most local governments. (2) Crises, such as the COVID-19 pandemic, create pressure to act. Cities and local governments can respond proactively and agilely to changing environmental conditions, if they are willing. (3) Before making decisions of consequence, e.g., to make an educational offer available online, cities and local governments should assess whether their digital infrastructure capabilities and capacities are sufficient.
Nikitas et al., 2020 [50]: Artificial Intelligence, Transport and the Smart City: Definitions and Dimensions of a New Mobility Era	In this article, the authors provided a description of the key transportation components that will be central to the AI-centric smart city of the (near?) future. At its core, the paper focused on linking Artificial Intelligence, transportation, and the smart city using connected and autonomous vehicles (CAVs), unmanned and personal aerial vehicles (UAVs and PAVs), and mobility-as-a-service (MaaS).	Literature Review	(1) AI technologies can revolutionize mobility towards an autonomous, connected, shared, and digitized transport offer in an unprecedented way. (2) However, it requires a responsible, sustainable, and user-centered architectural framework that "understands" and "satisfies" the human user, markets and society as a whole. (3) It must also lead to improved environmental protection, resource efficiency, increased productivity, social inclusion, integration, health and well-being. (4) Furthermore, trust is the key to success, which is built through awareness-raising campaigns, information, and systematic testing, among other things.

Table 2. *Cont.*

Ref/Title	Purpose and/or Objectives	Research Method	Study Result(s)
Sztubecka et al., 2020 [51]: An Innovative Decision Support System to Improve the Energy Efficiency of Buildings in Urban Areas	This document described an innovative decision support methodology for local energy consumption planning that focuses on modeling energy-saving potential and assessing alternative scenarios based on many strategic goals and preferences of local decisionmakers.	Descriptive study using multi-criteria analysis	The study provides an innovative decision support system based on multi-criteria analysis and GIS (DGIS), with an emphasis on estimating energy-saving potential in metropolitan areas and analyzing different scenarios based on several factors and decisionmakers' preferences. The findings revealed which of the 53 quarters with a distinct dominating building category was most conducive to boosting energy efficiency, and where energy efficiency might be increased by investing in renewable energy sources, taking the decisionmaker into account. Local decisionmakers may utilize the proposed DGIS system to better adapt cities to climate change and safeguard the environment.
Zhao et al., 2019 [52]: Mapping the Knowledge Domain of Smart-City Research: A Bibliometric and Scientometric Analysis	With the aim of better understanding the contexts of smart-city research, including the distribution of topics, knowledge bases, and the research frontiers in the field, this paper was based on the Science Citation Index Expanded (SCIE) and Social Sciences Citation Index (SSCI) in the Web of Science (WoS) Core Collection, and the method used is that of comprehensive scientometric analysis and knowledge mapping in terms of diversity, time slicing, and dynamics, using VOSviewer and CiteSpace to study the literature in the field.	A bibliometric and Scientometric Analysis	(1) While regional cooperation in research is relatively strong, international cooperative efforts need to be strengthened. (2) Researchers are paying more attention in particular to the issue of social ecology, human resources and environmental sustainability. (3) Research on smart cities and supply chains (including supply networks, supply chain management) is currently at an exploratory stage.
Wagner and de Vries, 2019 [53]: Comparative Review of Methods Supporting Decision-Making in Urban Development and Land Management	The paper offered new perspectives towards innovative methods in urban planning and land management and highlights where, when, and which type of tool can be considered useful and valid. The existing gaps, i.e., phases or areas in spatial planning or land management where the methods have not been applied, were also discussed.	Descriptive study using secondary sources such as journal articles, news articles, research initiatives, projects	(1) AI is helpful in solving various urban planning and land management problems. (2) AI should become more accessible and understandable to ordinary citizens. (3) Cellular automata needs further research and development to become more accurate and repeatable. (4) Operational research increasingly requires user-friendly software to overcome its "black-box nature".
Park et al., 2019 [54]: AI-Based Physical and Virtual Platform with 5-Layered Architecture for Sustainable Smart Energy City Development	This paper presented an Artificial Intelligence-based physical and virtual platform using a 5-layer architecture to develop a sustainable smart energy city (SSEC). The architecture employed both a top-down and bottom-up approach and the links between each energy element in the SSEC can readily be analyzed.	Descriptive study using secondary sources such as journal articles, news articles, research initiatives, projects	To construct an sustainable smart energy city (SSEC), this study proposed an AI-based physical and virtual platform with a 5-layer architecture. The design is top-down and bottom-up, has a cyclic structure, and the linkages between each energy are easily examined. It was shown that implementing the platform associated with this architecture will allow for the rapid development and implementation of new services for SSECs.

Table 2. *Cont.*

Ref/Title	Purpose and/or Objectives	Research Method	Study Result(s)
Abarca-Alvarez et al., 2018 [55]: Demographic and Dwelling models by Artificial Intelligence: urban renewal opportunities in Spanish coast	The purpose of this study was to shed light on the Spanish Mediterranean coast's existing residential models and the relationship with the local demographic reality of users. Its aim was to be part of a Decision Support System which focuses on urban regeneration and functional recovery.	Heuristic methodologies	(1) AI can be used to identify complex and relevant demographic phenomena, in this case housing profiles across urban and territorial settings, in a more powerful, robust, and complete way. (2) The territorial location of different housing profiles influences the opportunities and risks of urban regeneration.
Shimizu et al., 2021 [56]: How Do People View Various Kinds of Smart City Services? Focus on the Acquisition of Personal Information	The purpose of this study was to investigate what expectations and anxieties people have about smart city services (SCSs) (here: social credit, Artificial Intelligence (AI) cameras, health information, garbage collection, and automatic vehicles) that differed greatly in the content and amount of captured personal information.	Online survey conducted with Japanese participants using open-ended formulated questions	(1) The expectations of the participants differ among the smart city services. (2) There was a tendency to show low acceptance toward SCSs that collect a large amount of personal data, especially AI cameras and garbage collection.
Fang et al., 2022 [57]: Incorporating Planning Intelligence into Deep Learning: A Planning Support Tool for Street Network Design	The objective of this study was to demonstrate how Deep Learning can support solutions in the design of ad hoc planning proposals for road networks.	Descriptive study using secondary sources such as journal articles, news articles, research initiatives, projects	(1) Deep Learning applications can be used to automate street network generation that can be context-aware, learning-based, and user-guided. (2) The incorporation of planning knowledge leads to more realistic prediction of street configurations.
Mortaheb and Jankowski, 2022 [58]: Smart city re-imagined: City planning and GeoAI in the age of Big Data	The paper proposed a human-centered framework for the smart city that leverages the synergies between City Planning and the scientific domains of Big Data, Geographic Information Science and Systems, and Data Science Geospatial Artificial Intelligence (GeoAI).	Descriptive study using secondary sources such as journal articles, news articles	(1) The planning discipline should play a more important role in the planning, design, and management of future smart cities that are partially or fully powered by networked computing and digitally embedded tools and technologies. (2) Planning must be a discipline that integrates urban design and urban planning. This requires setting a clear vision and well-defined policy goals. (3) GeoAI offers tremendous opportunities for partnerships between practitioners and academics from all disciplines.
Yang et al., 2022 [59]: Measures and Suggestions for Smart Community Development Based on Urban Renewal	Starting from urban regeneration, this paper proposes relevant countermeasures for upgrading and transforming smart facilities and smart applications in the development of smart communities in combination with new technologies such as cloud computing, Big Data, Internet of Things, 5G, and AI as a reference for planning and design.	Descriptive study using secondary sources such as journal articles, news articles and simulation experiment	(1) For the construction of intelligent communities, the basic service facilities of intelligent communities must be improved and public security services must be expanded and developed. (2) It also needs to build comprehensive Artificial Intelligence services and optimize Artificial Intelligence in smart communities. (3) The participation of Artificial Intelligence can simplify the cumbersome procedures in construction projects of smart communities. (4) The government can improve the development of community application scenarios and innovative construction.

Source: processing by authors.

3.2. Overview

For the first overview, we summarized the relevant papers ($n = 20$) by their year of publication and the journals where the papers are published.

The interest in the chosen topic is consistent over the years, as we can see in Table 3:

Table 3. Number of papers by year of publication.

Year	Quantity	Reference(s)
2018	1	[55]
2019	3	[52–54]
2020	6	[46–51]
2021	5	[42–45,56]
2022	5	[40,41,57–59]

Note: In the tables, the authors only use the reference in square brackets for reasons of space. Source: processing by authors.

The number of research articles published from 2010 to 2022 increased significantly after 2018. For example, in 2018 only one article on the topic of Artificial Intelligence in urban development was published [53], while in 2020, six research articles with similar research topics were published. In 2021, a small decrease was recorded, but compared with 2018 and 2019, the published articles are significantly more. The year 2022 cannot be fully considered in this count because 2022 has not yet been completed (search was carried out in September 2022).

The articles were published in different journals, related to environmental, cultural, economic, and social sustainability and sustainable development of human beings (Table 4). Besides the name of the journal with the assigned quantity and references, the International Standard Serial Number (ISSN) and the Impact Factor (IF) were printed. The ISSN is an internationally recognized identification number for serial publications [60]. The IF is a measure of the frequency with which the average article in a journal is cited in a given year. The calculation is based on a two-year period and involves dividing the number of times articles were cited by the number of articles that are citable. It is used to measure the importance or rank of a journal by calculating the frequency of citation of its articles [61].

Table 4. Number of papers by scholar journals.

Journal	Quantity	Reference(s)	ISSN *	IF *
GeoJournal	1	[40]	1572-9893	1.978
Sustainability	6	[41,43,47,50,52,54]	2071-1050	3.889
Environmental and Sustainability Indicators	1	[42]	2665-9727	4.050
Smart Cities	1	[44]	2624-6511	N/A
Hindawi Complexity	1	[45]	1099-0526	2.121
Entropy	1	[46]	1099-4300	2.738
Sensors	2	[48,49]	1424-8220	3.847
International Journal of Sustainable Development and Planning	1	[55]	0198-9715	1.703
Remote Sensing	1	[51]	2072-4292	5.349
Land	1	[53]	2073-445X	3.905
Journal of Urban Technology	3	[56–58]	2226-5856	5.465
Wireless Communications and Mobile Computing	1	[59]	1530-8677	2.336

* The International Standard Serial Number (ISSN) is chosen from the Source Homepages, the Impact Factor (IF) from Academic Accelerator [62]. Source: processing by authors.

Basically, it can be stated that the impact factor of the analyzed journals is on average and that there are no major deviations. Only one journal (Smart Cities) does not have an impact factor, which raises the question of how suitable this journal is for a critical analysis.

3.3. RQ 1: What Studies Are There in the (Different) World Regions/Countries?

The papers found and shown in Table 5 provide us an overview of the world regions or countries in which AI in the SUD sector is currently used for further statements. If countries or regions are named precisely, this either refers to the data collected for testing AI solutions or it is about contextualizing existing AI solutions and their transferability to other countries or regions. It can be seen that most of the surveyed articles are without an assignment. The remaining articles could be assigned to the countries such as China, Poland, Spain, as well as Hungary, Pakistan, and South Asia, Sweden, and Russia. Asia and China are followed by Spain with two publications each at the top of the evaluation, but it must be mentioned that these results can only be attributed to the collection of data from the Scopus database. The significance of whether more is published about SUD in combination with AI in China and Asia can only be forced and confirmed by looking at other databases. However, for the objective consideration of the topic, the informative value of the Scopus database was sufficient.

Table 5. Countries of publication of the research articles.

Area (Country/Region)	Reference(s)
China	[40,45]
Russia	[41]
South Asia	[42,59]
Pakistan	[43]
Sweden	[44]
Hungary	[46]
Spain	[47,55]
Poland	[51]
Japan	[56]
No Assignment	[48–50,52] [53,54,57,58]

Source: processing by authors.

3.4. RQ2: What Artificial Intelligence Techniques Are Used in Sustainable Urban Development?

Table 6 provides an overview of the AI techniques used in the studies. According to the table, AI in a general definition term (without a specific method) is the most frequently addressed technique in the SUD. However, not only did AI emerge as a prevalent methodology in the techniques used in the surveyed studies, but common techniques that are sometimes associated with AI in combination were also mentioned in the various studies. These techniques include Big Data, which ranked second among papers in the results, Internet of Things (IoT), ML, and ANN. Furthermore, it was possible to identify techniques that are necessary for the use of AI, such as DL or Data Mining (DM). Furthermore, Predictive Analytics (PRs), Cellular Automata (CR), and OR were used in the studies in the area of SUD. Based on this table, a clear answer can be obtained at least for the question of the most commonly used techniques. Given the versatility of AI, it is not surprising that AI is most frequently used in general applications.

Table 6. Studies in AI techniques.

AI Techniques	Reference(s)
AI (in general)	[40–43,47,49–51,53,54,56,58,59]
Big Data	[42,51]
Machine Learning	[46]
Artificial Neuronal Networks	[46,55]
Internet of Things	[43,44,48,52]
Operational Research	[52]
Data Mining	[45]
Predictive Analytics	[48]
Cellular Automata	[53]
Deep Learning	[57]

Source: processing by authors.

3.5. RQ3: Which Sustainable Urban Development Dimensions Are Addressed?

SUD refers to four distinct pillars (see Figure 1 and Table 1 above): environmental, economic, social, and governance. From the public point of view, this requires that humanity must contribute to economic growth, social progress, and promote environmental sustainability, which must be operated and maintained. Table 7 orders the SUD dimensions that were addressed in the studies.

Table 7. SUD dimensions addressed in the studies.

SUD Dimensions	Reference(s)
Environmental protection	[40–51,55–58]
Economic development	[40,42,43,48–54,56–58]
Social justice and equity, culture	[42,43,47,48,51,52,55,56,58]
Governance	[40,47–49,52,53,59]

Source: processing by authors.

The searched studies address all the SUD dimensions because the success of SUD can only be achieved through an integrated approach. Physical urban renewal measures must be combined with measures to promote education, economic development, social inclusion, and environmental protection. Strong partnerships are also needed between local citizens, civil society, business, and the various levels of government.

The focus, as you would expect, is on environmental protection and economic development. These are the main drivers for bringing SUD in general and smart cities in detail into reality. From the environmental point of view, we are all living on one planet, and we breathe the same air. Otherwise, the world is more complex, in which mutual dependence is constantly increasing. In the midfield of research interest, we find the social justice and equity, and culture dimension (see Table 1). Moreover, the collected studies touch on the topic of governance, because governance as a process of interactions through the laws, norms, power, or language of an organized society becomes a label of quality awarded to international organizations.

3.6. RQ4: What Are the Outcomes of Artificial Intelligence Use in Sustainable Urban Development?

According to all studies, AI has great potential to address major problems related to SUD, including environmental degradation, land-use change, urban growth, urban planning, energy efficiency, pollution, extreme weather events, agriculture, food insecurity, and public transportation [41,44]. Examples of interesting advances in this area through the use of Artificial Intelligence are real-time monitoring of traffic flow and crime predictions, automation of decision-making processes and problems in urban planning, classification of residential areas, but also support services in public administration (e.g., chatbots).

However, it is also noted that some AI solutions have a moderate potential for solving problems such as humanitarian crises [45], urban heat impact, inadequate early warning systems, limited disaster preparedness, and deforestation.

Further, it is specifically noted that AI-based SUD solutions can cause a number of potential privacy harms. These include, for example, lack of anonymization of collected data with re-identification or geo-surveillance enabled as a result. At this point, there needs to be a regulator in the form of government and privacy legislation (e.g., the General Data Protection Regulation (GDPR) of the European Union).

The studies further emphasize that AI should become more accessible and understandable [49] for ordinary citizens. In concrete terms, this means improving human-machine interaction through user-friendly software. In the application of AI, inequality and digital inequality must not be reinforced.

Additionally, trust and confidence in the transformative capability of AI in the context of SUD is quite important [45]. People need to believe that change can be truly beneficial for many of us, that they can become active and engaged participants in the new urban ecosystem, and that they can make sense of the opportunities that AI offers and which can be put to good use. AI must not be used to increase the wealth of the top 1% of income earners (i.e., the world's 10 richest people and monopolistic multinational corporations), or power of partisan and unethical politicians.

Successful application of AI requires a good understanding of the relationships between AI and data [54] on the one hand, and the characteristics and variables of the urban system on the other hand. Therefore, the studies proclaim that a robust data structure, integrated from different sources, as well as the technological readiness to use AI are decisive factors and thus prerequisites for the success of such solutions in the SUD sector.

4. Discussion

The reason for the research was to determine an initial overview of the use of AI in SUD from 2012 to 2022. In order to make a reliable statement on this topic, the basic theories of AI and SUD had to be noted and explained first. Basically, our study was intended to provide an overview regarding the objective of the research assumed and the research questions assigned to this objective.

4.1. New Challenges for the SUD

The studies in the field confirm that AI has also arrived in the SUD. This development is driven by technologies such as Big Data and the IoT. Such solutions collect, process, analyze, and integrate large amounts of data to improve the functioning of our cities in everyday life. They offer a range of opportunities for urban purposes, including economics, the environment, mobility, culture, and governance.

But the increasing expansion of AI in SUD also brings new challenges:

1. Smart SUD expects a responsible local policy that meets the needs of all stakeholders (including citizens, authorities, organizations, and companies). This refers in particular to the handling of data. This requires identification, consistency, and comprehensibility of data among all stakeholders;
2. When integrating and using the data collected by AI, great importance must be attached to data quality, data protection, and data security. This is because the data collected is primarily personal data, collected by technological solutions that analyze human behavior. These solutions are not without controversy, also from the point of view of regulatory requirements. A holistic approach, such as data governance, can be a solution at this point;
3. Concrete solutions are often provided by the private sector. Since SUD is primarily a governmental task, solid partnerships between the public and private sectors must be formed;
4. Since the acceptance of the population plays a major role in the implementation of new technologies, especially in the urban sector, the implementation and introduction must be transparent and comprehensible. In addition, there must be comprehensible and continuous communication.

As can be seen from the points above, the introduction of new technologies is a major challenge. It does not matter whether the challenges lie in the implementation of the technology [43,44] or in the acceptance of the population. Basically, the technology used must create added value for the citizens as well as for the political decisionmakers in the respective cities. In order to strategically eliminate this problem, precise planning is required to identify not only the opportunities and risks, but also the strengths and weaknesses of AI in the SUD sector. This study merely provides an overview of the possibilities of AI and SUD. It shows studies that have already dealt with these aspects and want to influence and improve urban planning by means of AI. With the help of this overview, further research can be performed.

Our study provided an initial overview of the topic, and we should consider the following topic areas for future research: The identification of further fields of application with individual and international examples as well as concrete plan examples for a problem in the respective SUD that can be addressed using examples and existing studies. Furthermore, the influence of cultural and social differences in the concrete application of AI in SUD should be investigated and how a central knowledge base could look and be built up. Organizational challenges related to establishing and maintaining long-standing contacts and relationships in partner countries, particularly to build and share publicly available urban data pools, should also be a focus of future research initiatives.

4.2. Principal Limitations

With respect to the SLR conducted, some limitations should be noted. First, we only retrieve one database (Scopus), even though Scopus offers the world's largest collection [63,64] of abstracts, source references, and indexes in the fields of natural and engineering sciences, life sciences, psychology, but also humanities and social sciences. Furthermore, there is an urgent need to include cultural and historical conditions. That means, research should also be conducted on how AI meets the needs and preferences of different cultures, taking into account their historical development. As a further limitation in the consideration of the collected papers, the only research papers extracted were the ones that were accessible in the journals with open access. Furthermore, books, excerpts from books, and conference papers were excluded. Thus, only journals that met the scientific specifications and thus the exclusion criteria were surveyed. In addition, in the area of the language of the research papers, only English papers were used.

5. Conclusions

From the analysis of the results of studies, the authors conclude that AI in the environment of SUD has great potential to mobilize integrative, scalable, and sustainable applications. It is possible to achieve economic and environmentally relevant success through the use of AI techniques.

To achieve these goals, an appropriate governance strategy is needed. It is also evident in the surveyed studies that in most of the use cases of Artificial Intelligence in the urban development concept, a second specific methodology is always in use. This means that Big Data, for example, is frequently used in research approaches. However, not only Big Data is found in the studies, but also other methodologies such as IoT (see Table 6). In conclusion, with the help of reviewing the studies that have dealt with AI and SUD, an increase in the papers published in journals have been observed since 2018. The peak of studies dealing with this topic was recorded in 2020.

All articles were published in journals related to sustainability and sustainable development. Six studies, Panteleeva and Borozdina [41], Myeong and Shahzad [43], Ortega-Fernández et al. [47], Nikitas et al. [50], Zhao et al. [52], and Park et al. [54] were published in the *Sustainability Journal*, a journal with an IF in the midfield (see Table 6).

In grouping the AI techniques, two viewpoints were categorized. First, it could be surveyed that the most mentioned technique is AI in general. Thereby, no more precise definition is provided in the papers. The second most common technique in AI is IoT.

At the level of SUD (see Table 7), the papers mainly addressed the protection of the environment (e.g., Caprotti [40], Panteleeva and Borozdina [41], Abarca-Alvarez et al. [55], or Mortaheb and Jankowski [58]). Therefore, this confirms that environmental protection also plays an equally important role at the level of urban development as the advancement of AI. Above all, environmental protection is a fundamental building block for the future generation and thus secures the population. The basic information for further investigation in the field of AI in SUD is thus collected and can be analyzed and studied more deeply by means of further studies and research. For more precise statements about individual developments of certain techniques in SUD, further research must be pursued.

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