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Perspective

Disruptive Technologies in Smart Cities: A Survey on Current Trends and Challenges

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Received: 16 August 2020; Accepted: 9 September 2020; Published: 13 September 2020

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Abstract: This paper aims to explore the most important disruptive technologies in the development of the smart city. Every smart city is a dynamic and complex system that attracts an increasing number of people in search of the benefits of urbanisation. According to the United Nations, 68% of the world population will be living in cities by 2050. This creates challenges related to limited resources and infrastructure (energy, water, transportation system, etc.). To solve these problems, new and emerging technologies are created. Internet of Things, big data, blockchain, artificial intelligence, data analytics, and machine and cognitive learning are just a few examples. They generate changes in key sectors such as health, energy, transportation, education, public safety, etc. Based on a comprehensive literature review, we identified the main disruptive technologies in smart cities. Applications that integrate these technologies help cities to be smarter and offer better living conditions and easier access to products and services for residents. Disruptive technologies are generally considered key drivers in smart city progress. This paper presents these disruptive technologies, their applications in smart cities, the most important challenges and critics.

Keywords: smart city; disruptive technologies; Internet of Things; artificial intelligence; blockchain

1. Introduction

The continuous growth of the population in urban areas has led to new challenges. The availability of resources (physical infrastructure), the quality of knowledge communication, and human and social capital (social infrastructure) are considered some of the most important [1]. Access to education, healthcare, transport, justice, social services, utilities, etc., must be available for a population that has grown from 33.6% in 1960 to 55.7% in 2019 [2] and which—according to the estimation of the World Health Organisation—is expected to increase by 1.63% per year between 2020 and 2025, and by 1.44% per year between 2025 and 2030 [3]. To ensure the sustainability of future megacities, an important role is played by how data are gathered, stored, and accessed. Both city authorities and information and communication technology (ICT) companies are responsible for finding the best methods and technologies. Currently, data management systems that integrate the Internet of Things (IoT), big data, and cloud computing are improving certain operations, such as traffic control, sustainable resource management, quality of life, and infrastructure [4]. The smart cities concept includes a wide variety of applications from different fields. Lim et al. [5] identify four groups of technological factors in smart cities, namely, the "4Cs": Connection between things and people, Collection of data for context awareness, Computation in the cloud, and Communication by wireless means. These factors require a variety of technologies characterised by an accelerated and continuous dynamic. The massive amount of information, the speed of updating, and the increasing number of users are some of the elements that determine the emergence of disruptive innovations, mainly in the ICT area. They are rapidly assimilated by consumers. The disruptive technologies are defined as "innovative solutions that require fewer resources and can grow exponentially, very often, shaking up the economy and structure of the related businesses" [6]. They also bring some challenges. The controlled transition of the labour market due to automation, winning the war on talent between metropolitan areas, social cohesion, inclusiveness, solidarity, secure digital environment, privacy, and resilience are some of the most significant [7]. Ullah et al. [8] identify Big9 disruptive technologies clustered in three domains: data mining—big data and artificial intelligence (AI); networking—cloud, software as a service, IoT and drones; and data collection technologies—3D scanning, weareble tech, virtual and augmented realities. Investment in these technologies has the potential to accelerate the evolution of the smart city [9]. This is conditioned by the coordination between the three pillars of a city: the industry (production), citizen (consumption), and government (circulation) [10].

The technological evolution depends on the economic context—smart economy in smart cities. This concept is used in various contexts regarding smart urban design and development, economic development, strategic planning, advertisement of the cities, and branding [11]. Without a universally accepted definition, all proposals mix the following terms in various variants: 'innovation and creativity', 'technology', 'renewable resources', 'environmental protection', 'social responsibility', 'new jobs and new business', 'labour market flexibility', 'competitiveness', 'entrepreneurship', and 'integration in local and international markets'. All these concepts, integrated into the definition of the smart economy, prove both its complex role in the development of the smart city and the influence of the evolution of all other fields in the development of the smart economy. They are both drivers and consequences. First, the adoption of the disruptive tehnologies requires considerable financial and human investment. This can be achieved by attracting talent, by infusing public and private investment, and by citizens' involvement as consumers and suppliers. Citizens are important sources of information for co-creating Internet-based applications in all sectors of the economy [12] and are creators and beneficiaries of technological evolution and economic progress.

This research further explores the opportunities and challenges of four disruptive technologies: IoT, big data, AI, and blockchain for the development of smart cities. Previous research presents the role of disruptive technologies in specific fields of the cities in general or in the particular case of smart cities, such as real estate [8], transportation and mobility [13–15], health [16], smart homes [17], etc. Other research address only one disruptive technology such as AI [18,19], big data [20], blockchain [21,22], or IoT [23]. This paper offers an overview of all these disruptive technologies together with their contribution to the development of smart cities. It is also exemplified how they are used for each of the six specific components of the smart city (smart economy, smart mobility, smart governance, smart people, smart living, and smart environment). The interdependence between these technologies and the critical aspects that must be had in their implementation and use in real life is highlighted.

This paper has the following structure: Section 2 presents a background of previous research, Section 3 introduces the materials and methods employed to analyse the disruptive technologies in smart cities, then Section 4 displays the results of our search, while Section 5 discusses their relevance. Finally, Section 6 concludes the paper and suggests potential future research.

2. Background

There are various definitions of smart cities, all related in various ways to the evolution of the digital society. However, smart cities are not just about automating routine functions, optimising the use of space, buildings, or traffic management systems. They should provide support for monitoring activity in cities, understanding, and the analysis of economic and social life to increase the efficiency and quality of life and to ensure equity. The smart city also means providing premises that could generate smarter and more accessible ways to interact, especially between citizens and local government or between suppliers of products and services and consumers. According to Batty et al. [24], in smart cities, ICT is "merged with traditional infrastructures, coordinated and integrated using new digital technologies". Everything becomes part of a system of ultra-connected subsystems that allows real-time access to information, products, and services. The level of integration of these subsystems is an indicator of the intelligence of cities and allows for the optimisation of the flow of information between subsystems and citizens.

According to Muvuna et al. [25], smart cities have to be redesigned to become more sustainable, integrated, and collaborative. Many projects address specific issues facing the city administration and citizens. They have been developed to solve specific problems related to parking, air pollution, traffic congestion, waste management, tax management, health information management, etc. Chourabi et al. [26] identified eight groups of critical factors in creating a framework for smart cities' development: management and organization, technology, governance, policy context, people and communities, economy, built infrastructure, and natural environment. They are currently the basis for setting priorities on local government agendas. Neirotti et al. [27] divided concerns about smart cities into two major areas (Figure 1).

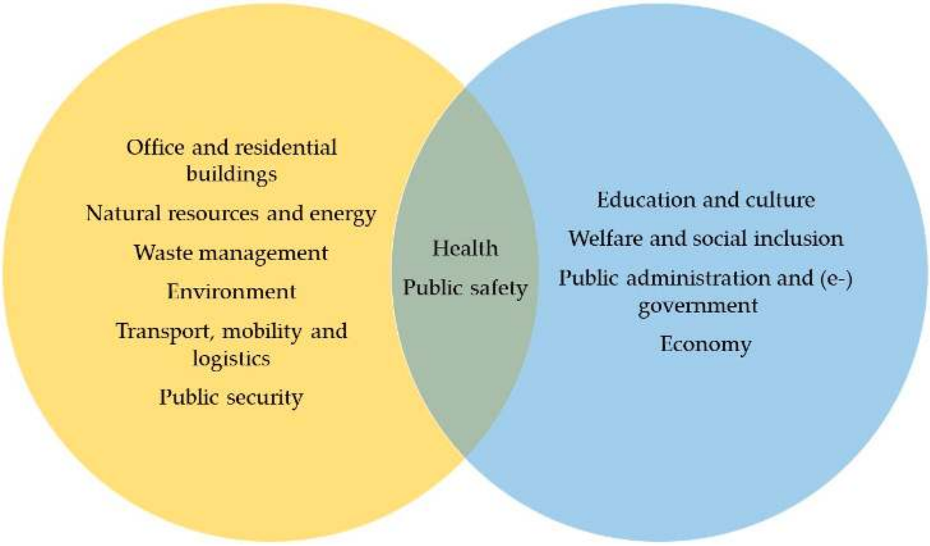

Figure 1. 'Hard' and 'soft' domains of smart cities (author' elaboration after [27]).

Tangible assets or 'hard' domain refer to initiatives on buildings (residential and office), natural resources management, energy management, energy grids, waste management, environment, transport, and logistics, and public security. Intangible assets or 'soft' domain include investment and innovation in education and culture, welfare and social inclusion, public administration and (e-) government, and the economy. Health and public safety are special categories. They are at the interaction between hard and soft domains because it involves both the creation of devices and software, as well as campaigns and practices created to generate social values [27]. All these categories of assets transform the city into a living one that feels and acts due to the connection of billions of sensors, wireless technologies, and software solutions capable of managing a huge volume of various data (big data). This is possible due to the evolution of Big9 disruptive technologies [8]. They underlie the development of applications for entertainment, building management, traffic management, water quality, public safety and services, smart lighting, forest fire detection, wine quality, autonomous vehicles, smart home, and office, etc. The next sections present more information about these technologies and specific areas of use.

According to Batty et al. [24], smart cities are instruments that support the improvement of competitiveness and contribute to a significant increase in the quality of life. Open data, infrastructures, mobile applications, public participation tools, IoT platforms, etc., are designed to ensure that citizens have access to the resources needed. According to Deloitte Consulting Group [7]:

"A city is smart when investments in (i) human and social capital, (ii) traditional infrastructure and (iii) disruptive technologies fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance."

According to a report published by Statista [28], the worldwide spending on the IoT was around USD 646 billion in 2018 and USD 1100 billion in 2023. The most significant increases are estimated in the fields of discrete manufacturing, utilities, transport, and logistics. AI software revenue is also forecast to grow from USD 10.1 billion in 2018 to USD 126.0 billion by 2025 according to a report published by Tractica [29] across 28 industry sectors. Smart projects require specialised staff and create new jobs and opportunities for start-ups. Blockchain has the potential to improve transaction speeds, enhancing security, and reducing costs in the banking sector [30], which would enable real-time accounting [31], and would improve the trustworthiness of financial statements [32]. According to a report published by Statista [33], the spending on blockchain solutions was USD 1.5 billion in 2018 from USD 0.95 in 2017 and is expected to grow to USD 15.9 billion by 2023. They increase the dynamics of transactions and, implicitly, of economic activity as a whole. AI and IoT change the professional and social life of citizens. They have access to a wide volume of information and services and have more free time, as a significant part of their tasks are taken over by these technologies. Regarding the evolution of big data by 2022, the worldwide big data analytics revenue will be USD 274.3 billion according to a report published by International Data Corporation [34]. The evolution of these disruptive technologies will have a favorable economic impact. Figure 2 shows this relationship.

Figure 2. Relationship between disruptive technologies and economic progress.

Huang et al. [35] use the concept of a feeling economy to describe the changes generated by AI. According to them, "AI performs many of the analytical and thinking tasks, and human workers gravitate more toward interpersonal and empathetic tasks". The number of jobs that involve feeling tasks, such as communicating with people inside and outside the organisation, establishing and maintaining interpersonal relationships, and selling to or influencing others, resolving conflicts and negotiating with others, working directly with the public, training teams [35], etc., exceeds those requiring thinking or mechanical tasks. Unlike the feeling economy, the current stage—the thinking economy—requires a significant amount of time allocated for processing, analysis, data interpretation, decision making, work planning and prioritisation, monitoring and controlling resources, updating and using relevant knowledge, and interpreting the meaning of information. The evolution is allowed by the innovations in the field of IoT, big data, and AI technologies that automate the previous tasks.

3. Material and Methods

We have performed a rapid review of available literature on disruptive technologies in smart cities to answer the following research questions:

(1) What are the disruptive technologies that significantly influence the evolution of smart cities?
(2) How can these contribute to the development of smarter cities?

According to Cartaxo et al. [36], rapid review offers "reliable content", fosters "the learning of new concepts", is "problem-oriented" and provides a "flexible knowledge transfer medium". We searched in the following electronic libraries: IEEE Xplore, Web of Science, and Scopus. The combination of phrases was ("disruptive technolog*" AND "smart cit*"). We used the truncation technique for the words that can have various endings to include all their forms into the search. The truncation symbol is an asterisk in this case. The publication date or subject area were not restricted to embrace all relevant publications. The results are presented in Table 1.

Table 1. Databases, key terms used and results.

Database	Query	Number of Papers
IEEE Xplore	"All Metadata":"disruptive technolog*" AND "smart cit*" OR "Abstract":"disruptive technolog*" AND "smart cit*" OR "Document Title":"disruptive technolog*" AND "smart cit*"	21
Web of Science	("disruptive technolog*" AND "smart cit*") Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.	26
Scopus	TITLE-ABS-KEY ("disruptive technolog*" AND "smart cit*") AND (LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "ch"))	42

We filtered publications with the Mendeley Desktop application. The inclusion criteria were being original research or review articles, written in English and covered certain search words. First, duplicates, conference reviews, and announcements of conferences or other events were removed. After this selection, the resulting group comprises 59 papers. Second, we exclude irrelevant papers for research aim. This exclusion reduced the results to 51 articles relevant and reasonable for our research. After the screening process, the full text of studies fulfilling the inclusion criteria was downloaded and the content of these texts was examined to establish the extent to which they are appropriate for this research. From these papers, we identified the most important disruptive technologies that support the evolution of smart cities. The word cloud presented in the next section highlights these technologies, based on the analysis of the title and abstract of the selected articles. To faithfully present their contribution to the development of smarter cities, we completed the research with other references, specific to each disruptive technology. They are described in the next sections together with the fields of application and their positive and negative impact on the city's development. The qualitative evaluation of these publications aimed to form an image on the contribution of the disruptive technologies that significantly contribute to the development of smart cities, as well as the key challenges that arise in their use.

4. Results

The first step in the analysis of the selected articles was to identify the most important disruptive technologies. Based on the fact that Ullah et al.'s. [8] classification corroborated with the results obtained from the analysis of the selected articles, we considered the following four disruptive technologies with major implications for the development of smart cities: IoT, AI, big data, and blockchain. To identify these technologies, we generated the word cloud presented in Figure 3 based on the titles and abstracts of the selected articles. The cloud highlights both the technologies considered disruptive for smart cities and their main areas of application such as 'vehicle, 'transport', 'life', 'vehicle', 'economic', 'mobility', 'sustainable', etc. However, their potential is much greater, as shown by the results presented in the following sections. The cloud was generated from the 100 most used words and the common ones were removed. The cloud shows also the main challenges and concerns in the development and implementation of these technologies: architecture, environment integration, citizen privacy, infrastructure, collaboration, and sustainability.

Next sections present, with examples, each disruptive technology, IoT, AI, big data and blockchain, and their specific applications in smart cities.

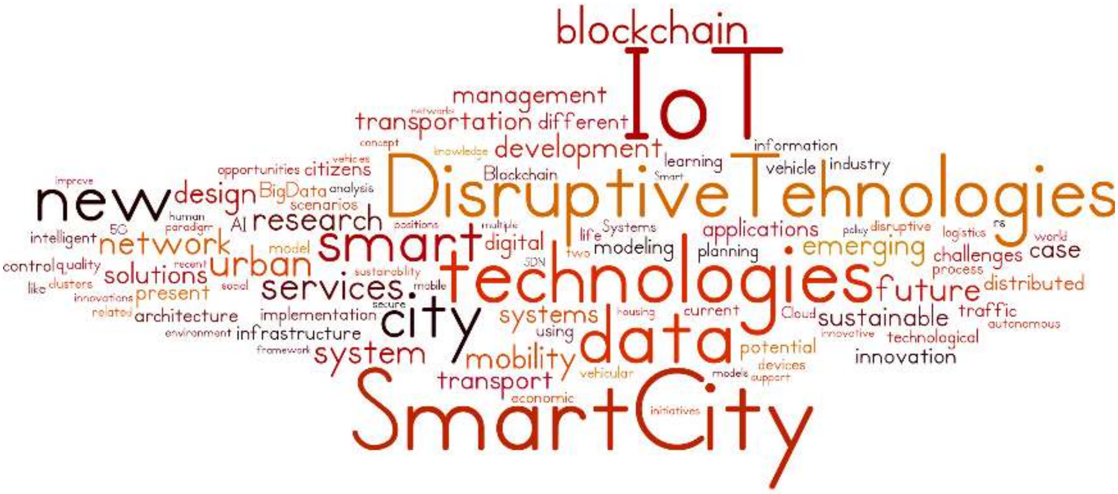

Figure 3. Disruptive technologies in smart cities—a word cloud generated by the Wordle App.

4.1. Internet of Things

Smart city infrastructure is an extension of the digital city and integrates a wide range of technologies developed around IoT. According to Hashem et al. [20], this "provides a platform for sensors and actuator devices to communicate seamlessly within the smart city environment and enables an increasingly convenient information sharing across platforms".

IoT creates new opportunities for the use of electronic devices by interconnecting them. The devices perceive and collect environmental information and transmit this information to other devices. Later it can be accessed by interested users. According to a study published by Statista Research Department [37], the number of connected devices is currently 30.73 billion and is estimated to reach 75.44 billion by 2025. Furthermore, the new technologies 5G will become an enabler for IoT by allowing a wide number of simultaneous connections and ubiquity of network in smart cities characterized by densely populated areas with high mobility [38]. IoT has a wide variety of applications, including retail and logistics, smart homes, smart grid, smart farming, smart finance, and insurance, transportation, smart manufacturing, smart supply chain, healthcare, environmental monitoring [39], etc. For example, Baloyi and Telukdarie [40] analysed the benefits of IoT for Disaster Risk Reduction. Sensors monitor activity in the natural environment (water level, wind speed, volcanic gas fluctuations, etc.) and transmit information to an integrated monitoring and control system that informs the vulnerable population and automatically initiates actions to reduce the possible damage, such as opening dams, activating fire suppression systems, etc. The data are also used for predictions and preventions. Another example is the Collaborative Road Mobility System (CRMS), developed for L'Aquila city, Italy, that allows vehicles and transport infrastructure to interconnect, share information and use it to coordinate their actions [41]. The system also integrates a mobile application for traffic coordination that assists drivers in an eco-friendly manner. Other applications of IoT are intelligent waste collection, smart parking [42], air quality monitoring, health monitoring, including mental health, traffic control [20], etc. Table 2 presents a selection of IoT applications in smart city components.

Table 2. Applications of Internet of Things (IoT) in smart cities.

Smart Economy	Smart Mobility	Smart Governance	Smart People	Smart Living	Smart Environment
Industry monitoring [10]	Traffic management [11,41]	E-government [43]	Education [44]	Entertainment [23]	Air pollution [45]
Infrastructure monitoring		E-procurement [46]	Healthcare [16]		Noise monitoring [23]
Efficient transportation planning [41,47]		Utility management [23]	Entrepreneurial opportunities [48]	Emergency services [49]	Waste management [50]
Food and agriculture [51]	Smart parking [52]	Defense [18]			Building management [53]
Radiation and electromagnetic level [54]	Quality of shipment conditions	Public safety [18,23]		Surveillance [23]	Radiation and electromagnetic level [54]
Smart lighting [55]		Public services [43]			
Efficient energy consumption [4,53]					
Wine quality	Vehicle auto-diagnosis [56]	Cultural facilities [4]	Smart home and office [17,23]		Forest fire detection [40]

The development of hyperconnected, ubiquitous networks of devices involves taking into account all their components and characteristics. Intel [43] identified six dimensions of policy principles for the development and use of IoT technologies: connectivity and interoperability, privacy and security, intelligent analytics and big data, open standards, data, and device discoverability, and public and private partnership. However, IoT generates a large volume of data, many of them partially structured or unstructured. As a result, there is a need for more advanced technologies to store, process, and analyse these data, to extract and synthesise relevant information and to make decisions and initiate actions based on the results. Big data and AI are these technologies.

4.2. Big Data and Artificial Intelligence

The evolution of AI is closely linked to the development of big data technologies in the opinion of researchers [57–59] since they complement each other. AI becomes better as the volume of data acquired increases, and big data is useful only together with software to analyse it. These technologies offer the possibility to collect and make useful the information provided by devices connected by the Internet. Since we agree with this approach, we present them together in this section of the paper. Sensor networks generate a huge volume of data. Big data technologies allow for their management. According to Thakuriah et al. [60], big data "refers to structured and unstructured data generated naturally as a part of transactional, operational, planning and social activities, or the linkage of such data to purposefully designed data". Some authors consider big data a strategic economic resource similar in importance to gold and oil [45].

The sources of big data are directed data generated by traditional forms of surveillance and, in this case, the technology is focused on a person or place by a human operator, automated data generated by devices or systems, and volunteered data generated by users [61]. After data collection or receipt, big data analytics and algorithms are used to process and analyse the data to identify and extract useful information for different users, people, or machines [40]. As a result, big data technologies are indispensable for IoT operation in smart cities. They are not, however, without problems and challenges. According Colding et al. [62], big data analytics have "a huge potential to enhance smart city services; however, the combination of the IoT and big data is still an immature, unexplored research avenue, with new challenges for achieving the goal of the smart city". They facilitate, for example, the involvement of citizens who can become providers of information. According to Neirotti et al. [27], citizens' knowledge is a rich source of up-to-date information and could improve the quality of urban space analysis, compared to traditional forms of spatial planning. This option can be considered an extension of democracy and increases the chances of accepting local development plans.

Big data analytics is possible due to the evolution of AI. In smart cities, their use can provide a variety of economic and social benefits, from traffic decongestion and parking, optimizing energy consumption, healthcare and security, to changing the way citizens live every day, interact and work [18]. The accuracy of the results is conditioned both by the performance of the applications used to interpret the data and by the volume of available data.

The beginning of AI in the early 1950s was followed by periods of growth, stagnation, and decline. Recent studies show a close relationship between big data technologies and AI evolution [57,59]. Figure 4 presents an analysis from Google Trends [63] on the popularity of big data, AI, machine learning, and IoT between 2004 and 2020. Between 2004 to 2008, a decline in AI is observed, followed by a period of moderate evolution until 2011 and another decline between 2011 and 2014. After 2014, AI's popularity rises again. These changes overlap with a significant increase in big data popularity.

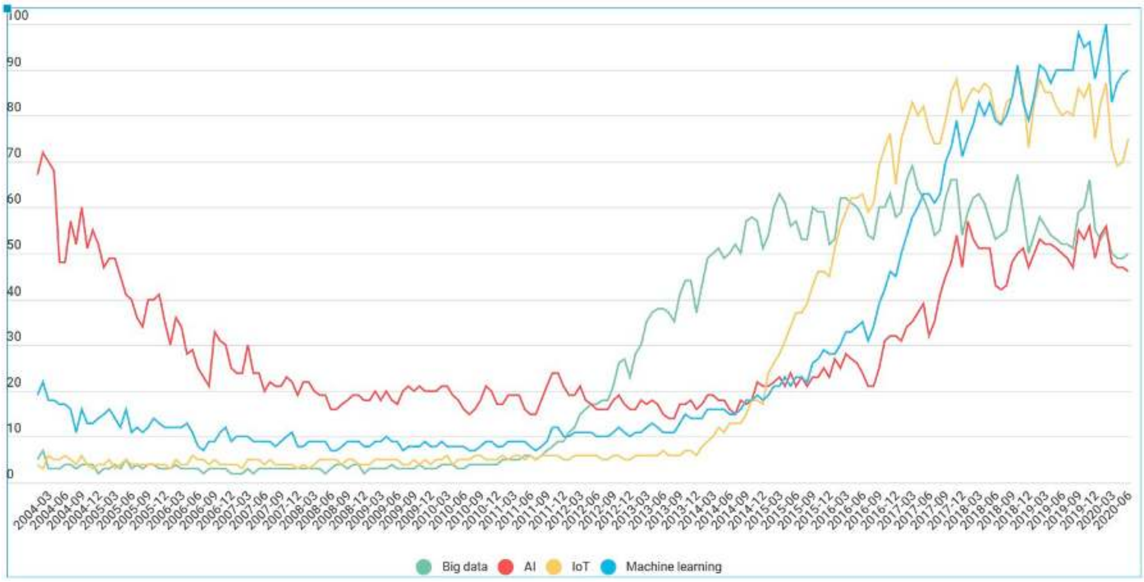

Figure 4. Popularity of the concepts of big data, artificial intelligence (AI), IoT and machine learning based on their searches between 2004 and 2020 [63].

AI has a variety of subfields, such as robotics, NLP (content subtraction, question answering, classification, machine translation, and text generation), expert systems, speech recognition (speech to text and text to speech), vision (image recognition, machine vision), etc. Big data technologies allow or the collection of a very large volume of data from all networks. A wide variety of devices and sensors are integrated into the infrastructure. The data obtained are processed using AI-based software by applying advanced analyses. The results are used, finally, to improve the citizens 'quality of life. They will enable better results to be provided for long-term strategic planning, better public services, and better use of resources [64]. Machine learning, for example, needs a wide volume of data to ensure correct results. Big data can provide access to this data. Together with IoT and AI, big data have the potential to make smart cities more efficient and responsive [65] provided they are integrated into a physical infrastructure which, by itself, both through the production and use process, optimises the consumption of resources and reduces the negative impact on the environment. Some examples of AI and big data-based applications are presented below. In Glasgow, a network of sensors uses AI and big data to connect streetlight and traffic lights to support monitor traffic flows and increase connectivity to reduce travel time, including making decisions to plan the commutes [66]. The Seattle Police Department launched a platform for police officers' activities management to track actions such as use-of-force incidents, the number of arrests, self-initiated trips, response to calls, the number of stops, and civilian complaints [67]. London Metropolitan Police use facial recognition technology to identify suspects [68]. The Las Vegas Health Department uses machine learning to collect and examine tweets to select restaurants where inspections are required to prevent foodborne illness [69]. Big data and IoT help to improve the sustainability of smart cities through visualisation techniques. They provide tools for collecting, processing, and presenting the necessary evidence to make strategic and tactical decisions taking into account the expertise of users and facilitating their understanding [70].

Applications based on AI and big data technologies are used to improve knowledge, teaching and learning tools, as well as quickly updating the curriculum by accessing a wide variety of scientific information according to economic and social requirements; to identify patterns of traffic to anticipate future traffic and control traffic lights [5,71]; community energy management, building energy management, and electric vehicles [5]; waste management (trash collection locations and times scheduled) [72]; healthcare to predict contagious diseases and epidemics and ubiquitous availability of citizen's health data [16]; understanding, monitoring, regulating and planning for better city management [61]; real-time video image processing to identify lawbreakers [73] or video-based real-time intrusion detection system [74] to increase the safety of citizen. AI and machine learning are very important to precisely monitor and estimate the real-time traffic flow data in urban environments [19]. In healthcare, AI and big data analytics help with the evaluation of the general health conditions of patients, hospital disinfection, creation, understanding and classification of clinical documentation, cancer prognosis and prediction, rapid intervention in emergencies, surgeries, assistance for seniors, treatment, perform tasks for administrative purposes, etc. Table 3 presents a selection of big data and AI applications in smart city components.

Table 3. Applications of AI and big data in smart cities.

<table>
<tr><th>Smart Economy</th><th>Smart Mobility</th><th>Smart Governance</th><th>Smart People</th><th>Smart Living</th><th>Smart Environment</th></tr>
<tr><td>Support business decisions [58]</td><td>Traffic management [14,19]</td><td>E-government [9,61]</td><td>Education [75]</td><td>Entertainment [76]</td><td>Water quality [77,78]</td></tr>
<tr><td colspan="2">Smart lighting [5,79]</td><td>Planning [70]</td><td colspan="2">Healthcare [16,80]</td><td>Disaster prevention [70]</td></tr>
<tr><td>Automating the data management process [81]</td><td>Transport congestion [9]</td><td>E-procurement [46]</td><td>Entrepreneurial opportunities [48]</td><td>Crowd monitoring [73,74]</td><td>Air quality prediction [82]</td></tr>
<tr><td>Complex statistical analyses [81]</td><td>Smart parking [83]</td><td>Public safety [73,74]</td><td colspan="2">Social comfort [57]</td><td>Building management [84]</td></tr>
<tr><td colspan="6">Efficient energy [5,84,85]</td></tr>
<tr><td>Perform repetitive tasks [9]</td><td>Vehicle auto-diagnosis [9]</td><td colspan="3">Smart home [86]</td><td>Waste management [50,72]</td></tr>
</table>

According to Guevara et al. [38], big data and IoT due to 5G technologies will gather more useful information for citizens. The automotive industry is an example of an industry with major benefits brought by the evolution of AI and IoT. All big companies such as Audi, BMW, Daimler, Mercedes-Bosch alliance, Delphi, Didi Chuxing, Ford, General Motors, Honda, Huawei, Hyundai, Jaguar Land Rover, Lyft, Microsoft, nuTonomy, PSA, Renault-Nissan alliance, Samsung, Tesla, Toyota, Uber, Volkswagen Group, Volvo, Waymo, ZF and Zoox work on the development of connected and autonomous vehicles [56]. They will have numerous benefits for users from creating more free time to increasing traffic safety and accident prevention and will create safety smart cities.

4.3. Blockchain

Along with big data and AI, blockchain has developed as a technology that contributes to increasing the intelligence of cities. This is described as a distributed, replicated, and secure digital register that allows contracting parties to see a system of records that are immutable [57]. Blockchain has evolved rapidly. Now it has reached version 4.0, which aims to integrate this technology into the industry to meet all the business needs of users, even if they use different platforms. It encompasses all applications of blockchain technology that is not limited to cryptocurrencies, such as electronic voting, healthcare records management, identity management, decentralised notary, etc. [87]. Given the diversity of financial and contractual transactions that occur in the case of urban governance, as well as the large number of parties involved, the use of blockchain technologies can bring considerable improvements. Furthermore, blockchain technology can enhance trust in data since technology is encrypted and secure [57]. Smart contracts can be used by smart city administrations to overcome bureaucratic difficulties and political issues. In this way, they reduce the amount of time required in developing projects. According to Marsal-Llacuna [88], "blockchains' virtual and physical networking symbiosis through smart contracts empowers citizens for a bottom-up delivery of codes, owned and implemented by them and not by a central authority. In 2018, 60% of the market value of blockchain belonged to the financial sector, but it spread rapidly in other industries, such as health and agriculture [33]. For example, Hîrțan et al. [14] designed a reputation system based on blockchain technology for intelligent transport systems. Users contribute with data to the system and receive real traffic information. The system evaluates the behavior of enrolled users before integrating the received data based on data received from every vehicle. It was tested on a traffic simulator that can simulate thousands of cars in real city environments (for Rome, Beijing, and San Francisco, in this case).

A PWC report [89] on the application of blockchain technology in smart cities estimates that, together with IoT, AI and machine learning, will lead to a significant improvement in urban governance. According to the same report, cities will be characterised by prosperity, stronger and interconnected communities, healthier people, positive growth, and increased social mobility at an unprecedented level [89]. Blockchain can be used for the decentralisation of voting platforms for local elections and legislative issues; providing transaction security in decentralised smart grid energy trading and real-time and flexible pricing [22,90]; in intelligent transport systems to create better usage of the legacy infrastructure and resources [15], to provide a secure communication platform for smart cities; to control and configure devices in IoT [91]; security and energy efficiency in smart homes [17], storing the medical data in an immutable and secure manner and flexible access of the patients and doctors to their medical records; in supply chain management for data sharing tracking the detailed product information as a counterfeit product detection system; and providing on-demand, personalised and integrated services [22]. Table 4 presents a selection of blockchain applications in smart city components.

Table 4. Applications of blockchain in smart cities.

Smart Economy	Smart Mobility	Smart Governance	Smart People	Smart Living	Smart Environment
Access control system [87]	Vehicles communication management [92]	E-procurement/ Smart contracts [46,89]	Personal data management [92]		Air quality monitoring [93]
Shipment tracking [92]			Healthcare [22,92]		
Transportation planning [14,47]					
Agriculture [94]	Traffic management [14]	E-voting [89]	Smart home [17,87]		
Transaction history management [92]		Public safety [91]			
		Smart grid energy [22,90]			

Blockchain technologies are just beginning but offer many opportunities for the development of smart cities due to their characteristics, such as decentralisation, audibility, immutability, and transparency. They are complementary to big data and AI technologies that alone cannot guarantee data quality due to threats such as hacking and human mistakes [88]. By integrating them with blockchain, users' trust in data will increase.

5. Discussion

This study conducts a review of disruptive technologies in smart cities. The research investigates the available literature under the following constraints: English language, three database sources (IEEE Xplore, Web of Science, and Scopus), research and literature review papers only, focus on disruptive technologies and smart cities with limited variants on search keywords. The results facilitated the discussion on current status and progress on the topic of the paper.

Smart cities, through their citizen, integrate IoT, AI, big data, and blockchain into real daily life. The following main points and critical issues are disclosed by our research:

- The disruptive technologies have the potential to generate positive changes in the smart city by promoting sustainable economic and social activities.
- IoT, AI, and big data are useful in automating decision making and problem solving and support the development of smarter cities.
- Blockchain increases the trust in data proving a secure communication platform and better usage of the legacy infrastructure and resources.
- The literature on disruptive technologies in smart cities associates these technologies, especially with AI, big data, IoT, and blockchain.
- AI, big data, IoT, and blockchain are interdependent and complementary and provide support for all other emerging technologies used in smart cities (wearable tech, social robotics, virtual and augmented reality, 3D printing, digital twins, etc.).
- Disruptive technologies in the actual context of smart cities mainly concentrate on mobility and transport, environmental sustainability, health, security, business efficiency, energy efficiency, and education.

The results of the review reveal that disruptive technologies have a profound impact on smart cities, both on physical setup and operational level. They must adapt to the diversity of citizens' problems and needs, to the variety of environmental conditions, and possess a degree of transparency. They also must have the technical performances required by well-trained and more selective users. The level of acceptance of technological innovation will be influenced by the level of trust individuals and companies in these technologies. In this context, it is very important for the final users' implication in their development. They may be allowed to customise applications and devices according to their own needs and lifestyles. Thus, they become not only users but also providers of innovation and increase the chances of assimilating it in everyday life. An important feature of the technologies analysed refers to their contribution to the data security and citizens' safety. These issues are increasingly critical and blockchain is coming with important improvements. The European Commission [95] underlined seven key requirements for the successful use of AI, (1) human agency and oversight, (2) technical robustness and safety, (3) privacy and data governance, (4) transparency, (5) diversity, non-discrimination and fairness, (6) societal and environmental wellbeing, and (7) accountability. They are also applicable to the other disruptive technologies presented in this paper considering the strong relationship between them. The success of disruptive technologies deployment to make cities smarter depends on the citizens' knowledge and interest to keep public and personal values in their adoption [81]. As can be seen from the previous section, there is a wide variety of areas that use applications based on IoT, AI, big data, or blockchain. For each disruptive technology, we present a selection of applications to create the premises for identifying other potential uses.

However, the ubiquity of ICT also has some disadvantages. There are opinions against this trend, argued by the negative effects on the environment, the limitation of human contacts, deculturalisation, etc. According to Allam and Newman [96], smart cities are often described as the "magic bullet" to all urbanization issues.

Each of the three disruptive technologies presented above has its critics. For example, in the case of big data, Mattern [97] estimates that it suffers from "data-fication, the presumption that all meaningful flows and activity can be sensed and measured". It is necessary to maintain a balance between technology and the real needs of the city translated by citizens' needs and environmental protection. Big data allows for the more efficient and dynamic collection and management of various aspects of the city, but a series of safe and sustainable tools, policies, and practices to regulate urban life must complement and validate the innovation in this field.

Confidentiality is another important issue to study when considering the issue of collecting and accessing all data in the smart city. According to Hough [98], privacy has four components: solitude, intimacy, anonymity, and reserve. Regulatory organisations must provide the legal framework to protect the population for each component, but it is quite difficult to predict all possible violations [57]. The technologies used to implement, smart office, smart house and smart health allow access to a wide variety of private information [99]. It is very important not to limit or influence citizens' free will. Moreover, educating citizens to be aware of the boundary between public and confidential information is very important. Otherwise, data can be used to invade their privacy or to manipulate them [100]. Another important aspect is the impact on the environment. According to Beck et al. [21], it is necessary to analyse the environmental implications of powering an expanding network to support the computing power required for blockchain operation. For example, mining bitcoins requires very high and growing energy consumption [101]. Other aspects that should be considered are the distribution of wealth, predominant social arrangements, and geopolitical balance [21]. Moreover, millions of interconnected devices involve the consumption of non-renewable resources for their development. The energy consumption is difficult to estimate globally, and e-waste is difficult to recycle. A study to assess the relationship between the production process in this area and the real usefulness of products is very difficult to achieve but is very useful.

6. Conclusions

This study offers a novel contribution to the literature by mapping out the landscape of disruptive technologies and smart cities. According to the United Nations [102], by 2030, the world is projected to have 43 megacities with more than 10 million inhabitants. In this context, more and more cities have to become smart or smarter. This study aimed to reveal how disruptive technologies, IoT, big data, AI, and blockchain, in this case, contribute to the progress of smart cities. The raising of the technological level of cities is not a goal. It is the driver. The goal of financial and human investment in ICT must be the optimization of the city's functions. The smart city must be smart through the long-term well-being of citizens. This depends on the level of digitisation, but the use and usefulness of ICT in everyday life are overestimated. Over time, this can lead to a loss of privacy, a lack of focus on important goals, an irreversible negative impact on the environment, and deficiencies in the capacity to integrate into society. As a result, the existence of technological limitations is very important. However, it is obvious that, beyond these potential dangers, disruptive technologies bring invaluable benefits to smart cities as presented in this paper. The broad finding of our review findings reveals that: (1) the potential of IoT, big data, AI, and blockchain to provide positive changes in smart cities is huge if they are used with responsibility; (2) these technologies are interdependent and complementary, and will evolve together. The specific findings are: (1) IoT, big data, AI, and blockchain are the most significant disruptive technologies for the evolution of smart cities; (2) they are emerging fields of research and practice in the context of smart cities; (3) the central focus of the literature in this field is on their application in mobility and transport, environmental sustainability, health, security, business efficiency, energy efficiency, and education and less on their risks.

This article is not lacking in limitations. One limitation is the strictly theoretical character and another limitation is associated with the features of the rapid review. To address this, we searched the most representative databases for papers to score a reasonable pool of relevant results.

Successful implementation of these technologies involves collaboration between the public and private sectors, between government organisations and citizens, as well as between universities and companies to ensure a natural evolution, informing citizens about the benefits and risks of using ICT, studying the psychological impact, and establishing responsibilities both ICT developers and users. IoT, big data, artificial intelligence, and blockchain are just some of the disruptive technologies that underlie the evolution of the smart city. Gamification, wearable tech, social robotics, virtual and augmented reality, 3D printing, digital twins, etc., are other disruptive technologies developed based on technologies presented in this paper and will be the subject of future research.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

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