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The Impacts of the Fourth Industrial Revolution on Smart and Sustainable Cities

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Abstract: This article aims to analyze the impacts of the Fourth Industrial Revolution on the implementation of smart sustainable cities. For this purpose, a data mining process was conducted to analyze the terms that had a higher incidence in the literature in order to classify them by relevance and identify their interdependencies in the concepts of sustainable cities and smart cities. As a result, we highlight that the Fourth Industrial Revolution will have implications on several factors that are deeply connected to the success of cities in becoming sustainable: job creation, industries, innovation, environmental preservation, community involvement, and accessibility. In this context, policymakers will have opportunities and challenges that must be faced. Big data, the IoT, augmented reality, and simulations can have positive and negative externalities. Positive externalities include new information that could be mined, analyzed, and used for identifying previously unseen problems, the provision of new industrial innovations that can make economies thrive, helping promote inclusion for disabled people, as well as helping society to foresee problems and hence adapt to them in a timely manner.

Keywords: smart cities; sustainable cities; smart sustainable cities; fourth industrial; revolution; sustainable development

1. Introduction

Cities, by concentrating a large portion of human activity, play an important role in the social, environmental, and economic spheres [1]. Cities continue to attract an increasing number of people in search of a job and an improved quality of life [2,3]. However, urbanization, in addition to unsustainable practices, generates negative impacts on the environment [4] not only at the local level, but also through large-scale consequences called 'ecological footprints' that are beyond their immediate vicinity [5,6].

At the same time, new disruptive technologies are causing profound changes that are understood to blend the physical, digital, and biological spheres in the so-called Fourth Industrial Revolution [7]. This industrial revolution differs fundamentally from the previous three because of the fusion of disruptive technologies and the constant interaction of its different spheres [8–10]. In this sense, this revolution suggests the creation of new models of business, as well as new systems for production, consumption, transportation, and leisure. In the perspective of sustainable development, Industry 4.0 can be used to promote more sustainable, inclusive, and socially just cities [11–13].

This new conception is not just about the industry but also about overall transformation using digital integration and intelligent engineering, as many authors have suggested [14–19].

In the literature, studies on the topic [20–23] argue that the use of digital technologies is a complex phenomenon, and that the development of a more sophisticated understanding of this phenomenon will aid in the organization of public policies that assist in the deployment of smart cities. The literature also highlights that smart grids will depend on a digital communications network, which can intelligently and regularly monitor how households and industries in a municipality use base resource assets such as water and energy. In this way, smart cities will be able to take advantage of the communication resources available, using sensors linked to the urban infrastructure to optimize their operations so that the quality of life of their inhabitants is improved.

Bakici et al. (2013) [24] pointed out that information and communication technologies are adapting to the way cities organize and formulate their policies directed toward urban growth. Smart cities are based on the use of technologies in various fields, such as economy, education, security, and urban mobility, among others. All cities have size, culture, population, form, and function characteristics that differentiate them. Based on the same premise, Zygiaris (2013) [25] presented a study of a model that can be used in different realities and adapted to the policies necessary for each city in order to address the characteristics of intelligent innovation ecosystems that will elucidate the understanding of sustainable cities. Therefore, the use of arising innovations, such as digital technology as a catalyst for the transformation of the urban environment, points to an auspicious horizon that promises to deliver more efficiency [26].

In this context, and in the face of the need for deeper knowledge about such a complex system that involves several social, economic, and technological actors, this article presents the following question: how has the literature approached the impacts of the Fourth Industrial Revolution on smart sustainable cities?

This article analyzes the impacts of the Fourth Industrial Revolution's innovations in the social, economic, and environmental spheres and its application in the urban context, such as rapid innovations, employment generation, better use of urban resources, and longer product life cycles, which contribute to the development of smart sustainable cities. Considering that the Fourth Industrial Revolution is new and still underway, this article contributes to a growing discussion in all spheres of society and aims to guide debates in the literature and in policymaking.

The structure of the article is as follows. After a brief introduction, we characterize smart cities, sustainable cities, and smart sustainable cities in the literature. Then, the Fourth Industrial Revolution and its impacts on smart sustainable cities are analyzed. A theoretical discussion follows, identifying gaps in the literature. The methodology is presented, followed by our results and discussion. In our conclusions, we summarize the contributions of this article and the challenges left for future studies.

2. Smart Cities

There is no strict definition of what a 'smart city' is [27] but the term is commonly used to refer to the convergence of technologies and cities [4].

Although smart cities are often mistaken for other similar but more specific terms, such as intelligent cities, information cities, and virtual cities, smart cities aim to encompass all of those and add a main but missing component: people [28,29]. In other words, smart cities are at the interface between the social and technological dimensions [11] aiming to improve the quality of life of city dwellers [20]. For a better understanding and visualization of the structure, motivations, and aim of smart cities, Table 1 presents the main concepts found in the literature.

Given the above-mentioned examples presented in Table 1, it can be concluded that smart city models are based on the use of information and communications technology (ICT) [30] to manage and regulate city flows [31], increase efficiency, safety and convenience [32] use fundamental concepts that are instrumented, interconnected and intelligent [21], and aim to achieve city development with greater competence in the triple bottom line: social, economic, and environmental [5,33]. There are several components that build a smart city, which can vary in different levels from one model to another according to the focus of each one [34].

These components constitute several domains of the city, where the meaning of the label 'smart' has different connotations in each domain (Osman, 2019). Mostly, smart city proposals consist of four main attributes: sustainability, quality of life, urbanization, and smartness, under which some sub-attributes are related [35].

Giffinger and Pichler-Milanovic (2007) [36] argued that although the term smart city is understood as a certain capacity of a city and does not focus on unique aspects, an additional definition requires the identification of certain characteristics for assessment when analyzing the success factors of smart city initiatives. Chourabi et al. (2012) [37] organized the critical factors into eight categories to create a framework that could be used to characterize how to envision a smart city and its design initiatives: management and organization, technology, governance, policy, people and communities, the economy, built infrastructure, and the natural environment.

Table 1. Smart cities' main concepts.

Authors	Year of Publication	Concept
[22]	2004	A smart city is a city that uses technology to guarantee citizens access to services and allow them to keep in touch with their surroundings in a simple and cheap way.
[20]	2010	Smart cities aim to optimize the infrastructure and logistical operations of cities from the communications and sensor capacities, thereby improving the quality of life for everyone.
[38]	2010	"What makes a "smart city" smart is the combined use of software systems, server infrastructure, network infrastructure, and client devices—which Forrester calls Smart Computing technologies—to better connect seven critical city infrastructure components and services: city administration, education, healthcare, public safety, real estate, transportation, and utilities." p. 1
[21]	2010	A city "connecting the physical infrastructure, the information-technology infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city" p. 2
[24]	2012	"Smart Cities base their strategy on the use of information and communication technologies in several fields such as economy, environment, mobility and governance to transform the city infrastructure and services". p.135
[39]	2012	"A smart city is understood as a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as "green" referring to urban infrastructure for environment protection and reduction of CO_2 emission, "interconnected" related to revolution of broadband economy, "intelligent" declaring the capacity to produce added value information from the processing of city's real-time data from sensors and activators, whereas the terms "innovating", "knowledge" cities interchangeably refer to the city's ability to raise innovation based on knowledgeable and creative human capital". p. 218
[40]	2014	Smart cities aim to optimize the infrastructure and logistical operations of cities from the communications and sensor capacities, thereby improving the quality of life for everyone.

Mohanty et al. (2016) [34] presented in their article nine components: smart infrastructure, smart buildings, smart transportation, smart energy, smart health care, smart technology, smart governance, smart education, and smart citizens. Despite the various components that integrate smart cities, Lim et al. (2018) [41] summarized that the popularity of these models in the scientific literature and international politics can be attributed to the fact that they are known for improvements in six major dimensions, which were initially defined by Giffinger and Gudrun (2010) [36]: economy, mobility, environment, people, living standards, and the governance of cities.

A smart environment involves the use of technological tools to improve critical aspects of city living, such as waste disposal, food growth, pollution control, smart electric grids, housing quality, and facility management [13]. In this dimension, city leaders should explore opportunities to innovate technologies to enhance the natural environment [42]. The smart people factor involves several aspects, such as affinity to lifelong learning, social and ethnic plurality, flexibility, open-mindedness, and participation in public life. Other elements such as creativity, human capital, and cooperation are also cited as factors with the potential to solve problems related to urban agglomerations, among others [28,43].

The notion of smart living implies delivering a better quality of life for these citizens through the provision of new and improved services such as cultural facilities, health conditions, individual safety, housing quality, and education facilities in order to promote social cohesion and security, as well as to highlight tourist attractions [44,45]. In the matter of transport, authors Mohanty et al. (2016) [34] and Silva et al. (2018) [35] argued that traditional transports, such as road transportation, train transportation, airline transport, and water transport, have existed for a long time, but with the limitation of operating independently, making global usage difficult. Mobility consists of public transportation, daily commutes using private vehicles, and leisure travel, among other types. Thus, intelligent transport systems (ITSs), with their focus on deploying IoT networks for transportation involving varied functionalities and applications, may provide wide accessibility and efficiency to citizens of smart cities, regardless of any physical, sensorial, or cognitive limitations [46].

3. Sustainable Cities

The twenty-first century is considered by some authors as the century of the cities, since the urban world population surpassed the rural population for the first time in 2008 [47]. Urbanization is an ongoing process; there were 371 cities with more than 1 million residents in 2000, 548 cities in 2018, and 706 are projected by 2030 around the world, 43 of which will be megacities, meaning they will have at least 10 million inhabitants [3]. Urbanization is a reality of the twenty-first century, not a choice. Therefore, it is not possible to choose whether urbanization will happen, but how it will happen [48].

Table 2 presents the main concepts of sustainable cities that were collected from the literature. Urban areas cause profound environmental changes locally [48]. One factor that impacts the environmental aspect of the cities is waste production, since the increase in consumption caused by urbanization and population growth results in more waste [49]. In that sense, cities concentrate residue production [6], contaminated water, and soils [50], as well as the spread of diseases and the worsening of natural disasters such as floods [51].

Another aspect that is fundamental to achieving sustainability in cities is governance, which can be understood as a series of legal and administrative measures to provide services. Cities are providers of basic services [47], but there is still a lack of basic services worldwide; there are 2.5 billion people in the world without access to basic sanitation, 780 million people without access to safe water, and 270 million people without access to electricity. Since 1990, the number of people living in slums has increased in absolute numbers [51].

In the economic field, the Lisbon Ranking, created to measure smart sustainable cities (SSCs) in Europe [52], concluded that richer cities (using GDP per capita as a measure) performed better in the rankings.

Sustainable cities also need to pay attention to the issue of transportation. Although there is no consensus in the literature on how to measure and evaluate sustainable transport, current traffic and trends are not sustainable in the long run [53].

The main problem is oil dependence; 96% of transport in the European Union depends on oil or oil products, but it is a scarce resource. In a few years, even if this dependence does not end, oil will become gradually more expensive as it becomes necessary to seek other options [54], such as encouraging bicycles or public transport. The availability of varied and accessible public transportation is a trademark of sustainable cities [55].

Table 2. Sustainable cities' main concepts.

Authors	Year of Publication	Concept
[56]	2011	A sustainable city is one composed by a relation of several subsystems seeking to promote welfare for its population.
[57]	2015	A sustainable city could be seen as a city that is able to meet the basic needs of their inhabitants, such as infrastructure, civic services, health and medical assistance, housing, education, transport, jobs, and good governance, with benefits to all sectors of society.
[55]	2016	Sustainable cities are those which meet specific requirements and characteristics structured within efficient and sustainable policies.
[58]	2016	A sustainable city must not only integrate methods to mitigate their effect on the environment, but also become a space which promotes a better quality of life for its citizens.
[24]	2016	"Smart Cities base their strategy on the use of information and communication technologies in several fields such as economy, environment, mobility and governance to transform the city infrastructure and services". p. 135
[59]	2018	Sustainable cities can be understood as a set of approaches for practically applying the knowledge of urban sustainability and related technologies to the planning and design of existing and new cities or districts.

While smart cities are projected, expectations grow that their policies will reduce impacts from this fast urbanization and drive sustainable development [38,60,61]. However, there is no agreement in the literature that the concept of smart cities as a whole does emphasize the concerns of sustainability [62]. Solutions in these models have been criticized often for being too technocentric, driven by technology company agendas while lacking proper attention to city needs and environmental issues [63]. These concerns have opened the way for a new term.

The idea of smart sustainable cities (SSCs) has emerged in the literature by matching urban sustainability and smartness [63]. These models use information and communication technologies (ICTs) as their basis to improve the quality of life and deliver efficient services in urban environments, keeping in sight the need to ensure they meet the needs of present and future generations concerning economic, social, environmental, and cultural aspects [64].

Hara et al. (2016) [65] argued that there is a need to create key performance indicators to evaluate an SSC based on sustainable development and its triple bottom line: social, economic, and environmental factors. Ahvenniemi et al. (2017) [66] stated that one of the main goals for SSCs is to improve sustainability with help from available technologies, as ICTs are increasingly used to implement sustainability in urban centers. Ibrahim et al. (2017) [67] found several roadmaps for urban centers to become SSCs in the literature; however, none of them cover all the spheres that are necessary, such as evaluating current challenges for a city or a city's readiness for change. A coherent and systematic model is needed to capture the transversal readiness of a city in its infrastructure in order to understand the essential aspects in transforming cities.

Bibri (2018) [59] argued that SSCs are built in a socially constructed understanding and socially anchored practices regarding ICT use in urban sustainability, so they are shaped by and can shape sociocultural structures and policymaking. The success of SSCs derives from transformational powers, relations of knowledge, the workforce, the capacity of ICT legitimization, and a new wave of computational innovation regarding urban sustainability. The authors claim that ICTs must be directed toward an environmental aspect of sustainability, solving complex environmental issues and creating a holistic approach to urban development.

Developing an SSC requires an efficient and effective transformation process, considering aspects such as the city's context and needs, local interests, the population's quality of life, and smart sustainable solutions that need to be delivered at all levels in cities [57]. SSCs present a new way of considering and optimizing available and new resources, a purpose that can be achieved through the support of various information and communication technologies [68]. In this context, Industry 4.0 emerges as a powerful force that is expected to change urban development and future cities [69].

4. Fourth Industrial Revolution

The increasing demand for capital and the consumption of goods in the globalized world requires opportunities for the realization of advanced manufacturing [70], which makes it possible to guarantee a production system that is both viable and sustainable [71] to meet the needs of the population. For several hundred years, the industrialization process has been shaped to make manufacturing processes increasingly complex, automatic, and autonomous [72].

In the nineteenth century, the First Industrial Revolution transformed manufacturing processes with steam-powered mechanical equipment. In the early part of the twentieth century, the use of electric power to drive production lines made mass production possible, qualifying the Second Industrial Revolution. Finally, in the 1970s, the Third Industrial Revolution was characterized by the automation of production from the application of electronics and information technology (IT) [73,74].

The concept of Industry 4.0 was formulated in 2011 by the President of the World Economic Forum in Davos, Klaus Schwab [75] as a proposal for developing the German economy [72] based on high-tech strategies [76], combining the Internet of things (IoT), cyber-physical systems (CPS) and Internet of services to cooperate with each other and with humans within a system. Therefore, the difference of this fourth wave of technological advances is the very close interaction between the physical, digital, and biological worlds [77]. In Table 3, the nine technology trends that are the building blocks of Industry 4.0 are presented and conceptualized based on the literature.

Table 3. The nine pillars of technological advancement.

Technology Category	Main Ideas	Authors
Big Data and Data Analytics	Composed of characteristics called "V"s, such as volume, velocity, variety, and veracity, big data is a term that refers to the large growing data sets that are collected using digital communication devices from satellites to smart phone applications, which are stored in computer databases and 'mined' by computer advanced algorithms.	[78,79]
Autonomous Robots	The progress of technology enables researchers to create advanced machines that can perform increasing numbers of tasks autonomously without human control or supervision. in this sense, intelligent autonomous systems operating in physical environments—the so-called autonomous robots which have long been used in manufacturing—are becoming more autonomous, flexible, and cooperative.	[39,80,81]
Simulation	In the Industry 4.0 context, simulations will be used more extensively in plant operations to mirror the physical world in a virtual model, which can include machines, products, and humans, reducing the time of configuration of the machine, shortening downtime, reducing production failures, and increasing the quality and speed of decision-making.	[77,82]
System Integration: Horizontal and Vertical System Integration	The technological breakthroughs behind the Industry 4.0 revolution require corporations to adapt their production mode with the aim of creating operational synergy and providing competitive advantages within the value chain production system.	[76]

Table 3. *Cont.*

Technology Category	Main Ideas	Authors
The Industrial Internet of Things	The main concept of the Internet of things (IoT) is to connect smart objects within cyber-physical systems, where objects will interact with each other and can be supervised remotely by users. With this in mind, a definition of the industrial Internet of things (IoT) may be the use of certain IoT technologies in an industrial setting or manufacturing for the promotion of goals distinctive to industry.	[83,84]
Cybersecurity and Cyber-Physical Systems (CPS)	Cyber-physical systems (CPS) arise through devices for interaction between computing objects, people, and the physical environment, and they include systems such as smart grids. Enabled with the IoT, CPS help in the process of collecting, storing, and managing data.	[85,86]
The Cloud	The integration between the IoT and the cloud with respect to the Industry 4.0 revolution can help in the unfolding of data management problems in a way that guarantees better accessibility and viability of the services. Cloud computing enables hosted services to be delivered more efficiently through a software development platform to process the large amount of data generated by the IoT.	[69,87,88]
Additive Manufacturing	Additive layer fabrication is used to construct or assemble parts so that the product prototype can be available quickly and changed according to the customer's needs. With the advances of the Fourth Industrial Revolution and increasing technological adaptation, the capacity of additive manufacturing has grown from the optimization of configurations.	[89]
Augmented Reality	Through Industry 4.0, augmented reality has become one of the most exciting technologies to invest in due to the emerging concept of intelligent manufacturing, and it can be used as a support for maintenance operations.	[89]

This new conception is not just about industry but about overall transformation using digital integration and intelligent engineering [17]. Industry 4.0 is rooted in advanced manufacturing, also called the smart manufacturing concept, in which work-in-progress products, components, and production machines will collect and share data in real time, increasing the automation of manufacturing and the integration in which planning, control, and decisions are decentralized, taking the entire product's life cycle and supply chain activities to a new level [14–16,18,19].

This fourth wave of technological advancement is powered by nine foundational technology advances. Many of them are already used in manufacturing, but in this new system, optimized cells will come together as a fully integrated, automated, and optimized production flow, leading to greater efficiencies and changing traditional production relationships [81].

The Fourth Industrial Revolution is underway and is expected to significantly affect the way individuals live and change society in various aspects [90]. The possibility of billions of people connected by mobile devices, with powerful processing and large storage capacities as well as access to knowledge, is unlimited and will be enhanced by the advancement of technology in fields such as artificial intelligence, robotics, the Internet of things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing [91].

In this context of changes, the relevance and necessity of considering the possible social implications or negative externalities generated by these changes also need to be addressed. One of them is the issue of job maintenance and, consequently, income generation, a matter of central concern to developing economies, such as in Brazil. It is reasonable to expect that the replacement of some current jobs by a new wave of automation or robotization will be significant, to the same extent that artificial intelligence could replace analysis functions and the production of basic knowledge, as Schwab (2017) [10] states:

All the changes that affect our economic, social and political systems are fundamental and difficult to undo [...]. It is part of our responsibility to ensure that we establish a set of common values that guide political choices, as well as to carry out the alternatives that will make the fourth industrial revolution an opportunity for everyone (SCHWAB, 2016 [10], pp. 21–22).

The European Schools Science Symposium (ESSS, 2017) [92] proposed to develop nine pillars to enable the consolidation of the Industry 4.0 concept in different industrial segments. One of them deals with cybersecurity, which is one of the technologies that will serve as a pillar for the development of Industry 4.0. Information security is also a key factor, especially in the business context. The high level of connectivity that the industry demands in the control of its processes makes it essential that the systems are secure. By protecting information, the harmful consequences of possible threats and failures that a probable invasion might generate are considerably minimized (ESSS, 2017) [92]. A possible data breach in automated industrial systems can be quite problematic, and the costs of handling it may be high. This state of affairs suggests that organizations need to be prepared to prevent or mitigate the risks of possible violations to their information and control systems. Ensuring the protection of systems is therefore an issue that is gaining increasing relevance in this scenario.

Thinking about Industry 4.0 also means thinking about a multiplicity within the space that is inserted; that is, thinking about the Industry 4.0 revolution is to contextualize it, also talking into account the interactions between the technical and political as well as ethical aspects. Decisions will need to made based on political and moral grounds, as well as economic ones [93].

Figure 1 illustrates this context, highlighting elements of our socioeconomic environment and the pressures posed by the Fourth Industrial Revolution on the definitions of sustainable cities, smart cities, and smart sustainable cities. It also highlights how the literature approaches these points.

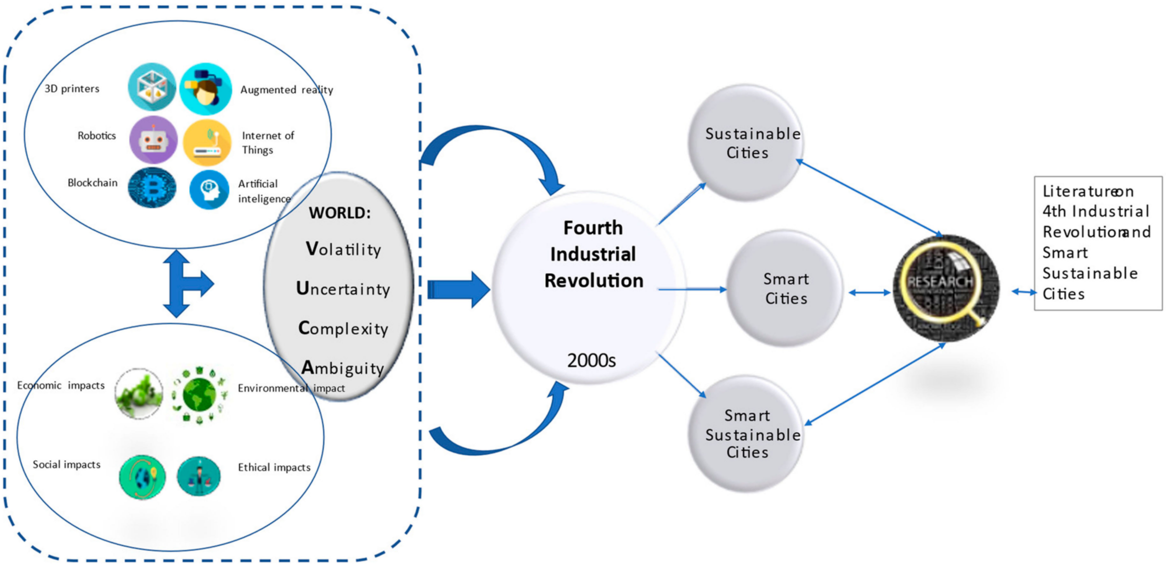

Figure 1. Generic model of the impacts of the Fourth Industrial Revolution on the definitions of sustainable cities, smart cities, and smart sustainable cities.

5. Methodology

The analysis of the impacts of the Fourth Industrial Revolution in the implementation of smart sustainable cities was conducted through a literature review with the following keywords: sustainable cities, smart cities, smart sustainable cities, Fourth Industrial Revolution, and sustainable development. The research was conducted in the databases of

Science Direct, Web of Science, and Scopus, chosen for their relevance. After the research, the 20 most-cited articles and the 20 most relevant articles of each search in all the databases were selected for the analysis of titles and abstracts. After that, 27 articles were selected for complete analysis and composition of the research portfolio. The results of each phase of the research are available in Table 4.

Table 4. Keywords on smart sustainable cities.

Keywords	Science Direct	Web of Science	Scopus
Sustainable Cities	5.369	1.060	2.395
Smart Cities	5.446	4.978	15.691
Smart Sustainable Cities	73	38	87
Fourth Industrial Revolution	822	610	917
Total Number of Articles Selected after Reading Titles and Abstracts	35	43	27
Articles Selected for Analysis	*9*	*7*	*11*
Total		**27**	

After selecting articles as shown in Table 1, data mining was conducted for the articles that presented the main concept of smart cities and sustainable cities, corresponding to the second phase of the research. Those articles were organized and submitted to the collocations extraction process [94] in order to identify the terms that presented the highest frequency and their relations in order to show how international scientists have addressed issues about sustainable cities and smart cities.

As Figure 2 shows, the procedure of entity named recognition (ENR) was applied using the ISNER®® software on the selected 27 articles. Ceci et al. (2012) [94] explained that the ENR procedure has as its main goal the identification and categorization of entities (e.g., words, organizations, or places), expressions of time (e.g., times and dates), and some types of numerical expressions (e.g., percentages and values in money) that can be found in the text.

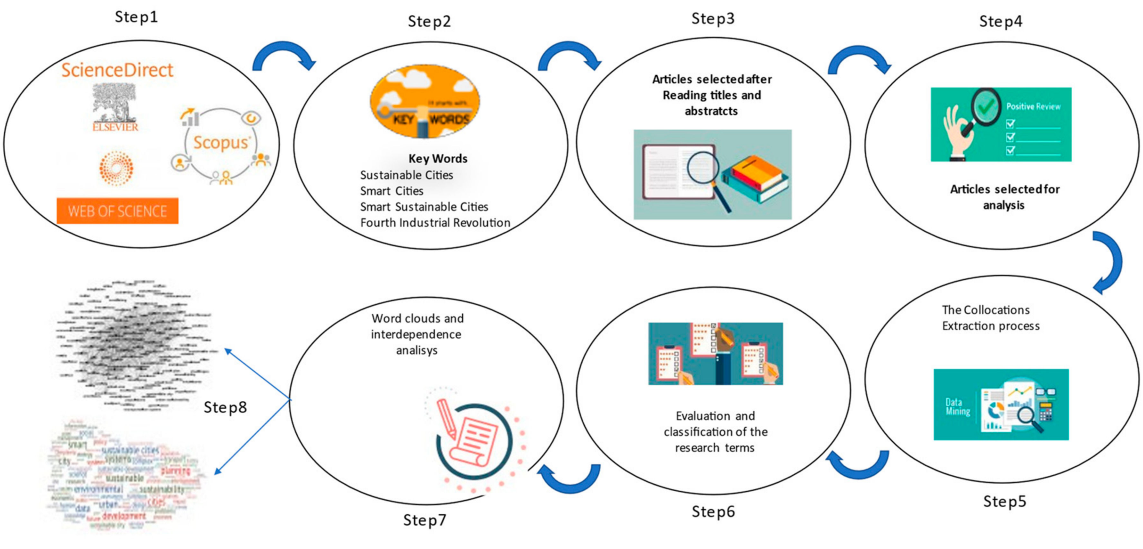

Figure 2. Methodological steps.

The task of identifying entities entails the establishment of limits (boundaries) considering where they begin and end, a process that is especially important in entities composed of more than one word. The following step was to evaluate and interpret the values, a process which the authors undertook manually since automatic approaches are subject to failures [94].

To analyze the entities, three steps were followed: reconnaissance, validation, and classification. For reconnaissance, the authors focused on finding single and composed entities that would be representative of the subject of this article, using the frequency of the terms in the text. For validation, the authors analyzed the terms that they had previously recognized in order to verify if they were representative of the matter at hand. Those entities that were not considered to be relevant to the research were considered non-valid.

Figure 2 presents the methodological steps graphically.

6. Results and Discussion

Based on Figure 2, it was possible to analyze which terms had the highest incidence in the seven articles analyzed. It can be seen that several terms involving the importance of technology for the consolidation of smart cities had a similar frequency, such as smart, services, information, research, systems, data, Internet, urban, network, model, digital, and digital divide. The terms such as those on Figure 3, with the highest incidence represent what the authors of the analyzed articles presented in their studies as the main factors about smart cities. Partridge (2004) [22] argued that the use of digital technologies is a complex phenomenon, and that the development of a more sophisticated understanding of this phenomenon will aid in the organization of public policies that aid in the deployment of intelligent cities.

Figure 3. Smart cities word cloud. Source: Elaborated by the authors, 2019.

Cities are becoming smarter as governments, businesses, and communities gain more reliance on technologies as a means of assisting the challenges faced by rapid population growth. Washburn (2010) [23] pointed out that what makes urban centers smart is the combined use of software systems, server infrastructure, and client devices that can better connect municipal infrastructure services such as education, health, public safety, real state, transportation, and public services. This is because the concept of smart cities is pushing governments, whether state, local, or regional, to evaluate emerging technologies and engage with key stakeholders both inside and outside of organizations.

The cities that can be considered smarter are those that explore the operational data to optimize the operation of the city services, where the fundamental concepts pass to be intelligent, interconnected, and instrumented. This approach can adapt the municipal services to the behavior of the inhabitants, which allows for better optimization and use of the infrastructure of all available resources to promote a better quality of life for the citizens [54].

As smart cities are known as urban environments where the ITC system supports them, Piro et al. (2014) [40] argued that the use of JTIs can provide the urban community with advanced and innovative services and points to the importance of developing a platform for the ITC service. Thus, this model should have the ability to span all available wireless technologies and be the start of a new business, as well as demonstrate the real purpose and importance of creating intelligent environments. After analyzing the importance of the terms and their frequency, Figure 4 was developed, which presents a graph of interdependence for the terms. As can be seen in Figure 4, all terms have a direct connection to each other, but those that present a greater interdependence are support, cities, net, network, quality, technologies, communications, communication, information, digital, data, energy, life, environment, smart, connect, city, and design.

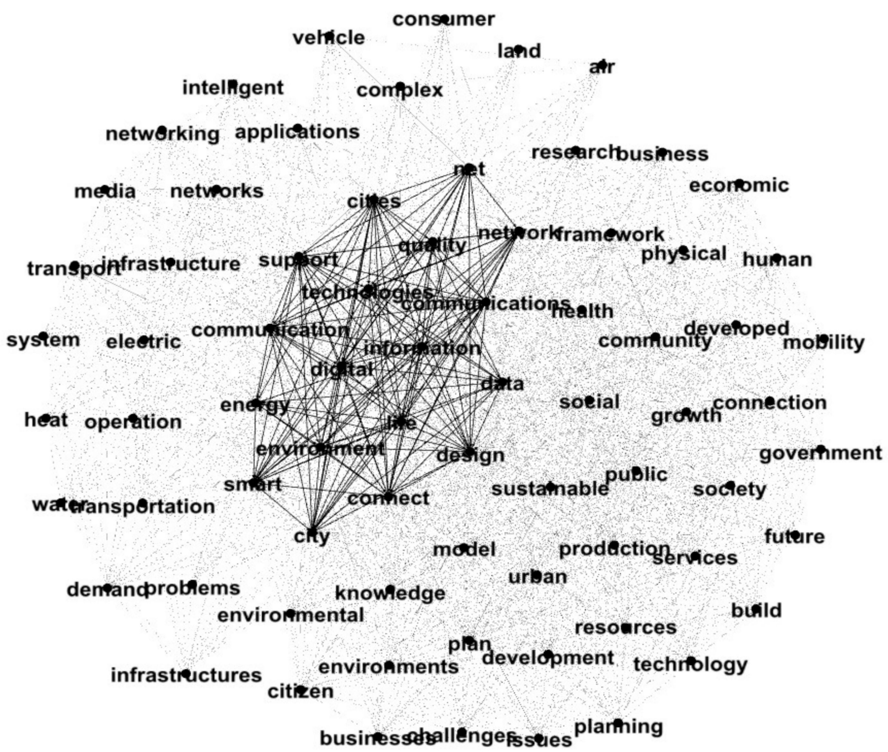

Figure 4. Graph of interdependence for smart city terms. Source: Elaborated by the authors, 2019.

A theoretical justification for the strongest relationship between the terms can be found in several articles, such as when Brock et al. (2019) [95] presented in their study that sufficient support is necessary for the implantation of intelligent cities so that the use of the IoT and ICT is possible and that the quality of life of the population is assured. For Sharma and Park (2018) [96], the construction of intelligent cities is due to the autonomous and distributed infrastructure that includes intelligent systems of information processing, control of the heterogeneous network infrastructure, and detection of the source of information. In this way, the network must be used to meet the demands and overcome the limitations by designing a distributed architecture in a safe, efficient, and effective way in the implantation of sustainable cities.

Figure 5 corresponds to a word cloud, which has the function of presenting the terms with higher and lower incidence in the five articles analyzed for the construction of Table 3, which presents the main concepts found in the literature about sustainable cities. The word cloud is a weighted list model that serves to analyze data of language or text formats, which presents the size of the words according to their repetition in the text [97].

Figure 5. Sustainable cities word cloud. Source: Elaborated by the authors, 2019.

As seen in Figure 5, there are several terms in the word cloud that present a similar frequency, such as systems, planning, environmental, sustainable, urban, development, cities, smart, policy, data, economic, human, energy, and environment. Based on these results, it is possible to analyze how the authors present the main terms regarding the building of a sustainable city. Bond and Morrison-Saunders (2011) [56] presented sustainable development as the main goal in the field of expansion of sustainability evaluation, arguing that sustainability evaluation practices are based on particular frameworks of political controversies, while one of its main goals is to help deliberation on these controversies, creating a movement toward a new sustainability thinking and encompassing all these different ideas.

Ibrahim et al. (2015) [57] added that there are several studies on the complexity of sustainable city implementation around the world, including a need for creating indicators and tools to measure sustainability levels in urban centers, considering that indicators are measures that provide summaries of information. Andrade Guerra et al. (2015) [55] stated that urban centers are important drivers in promoting strategies to implement sustainable development. The authors analyzed the differences in urban mobility in two cities, Newcastle upon Tyne (United Kingdom) and Florianópolis (Brazil), comparing factors such as social and economic indicators, gross domestic product (GDP) per capita, inflation, employment, and population growth by historical numbers in these cities. This comparison was made to create models, ideas, and actions on sustainable transport.

Martos et al. (2016) [58] argued that current population growth levels in urban areas, especially in developing countries, contribute to the fact that cities correspond to 80% of greenhouse gas emissions, further enhancing the need to implement sustainable cities. Decisions regarding sustainable city management and planning must be made while evaluating the consequences. Bibri (2018) [59] stated that underlying theories are the basis for sustainable city practices. Academic research in this field acts on the belief that advances in this underlying knowledge demand the creation of questions that can only be answered in a multifaceted fashion using ICT. As was observed, all authors mentioned the importance of implementing sustainable cities for promoting sustainable development.

Based on this, Figure 6 presents a chart of the interdependence of terms that were analyzed in the literature and used for creating the word cloud. After analyzing the main terms about sustainable cities and smart cities and the relationship between the terms, it was necessary to analyze how each pillar of globalization in Industry 4.0 affected the implementation of sustainable cities in order to respond to the goal proposed by the research.

Figure 6 shows how these relationships can occur. Table 5 shows the interdependencies of the pillars.

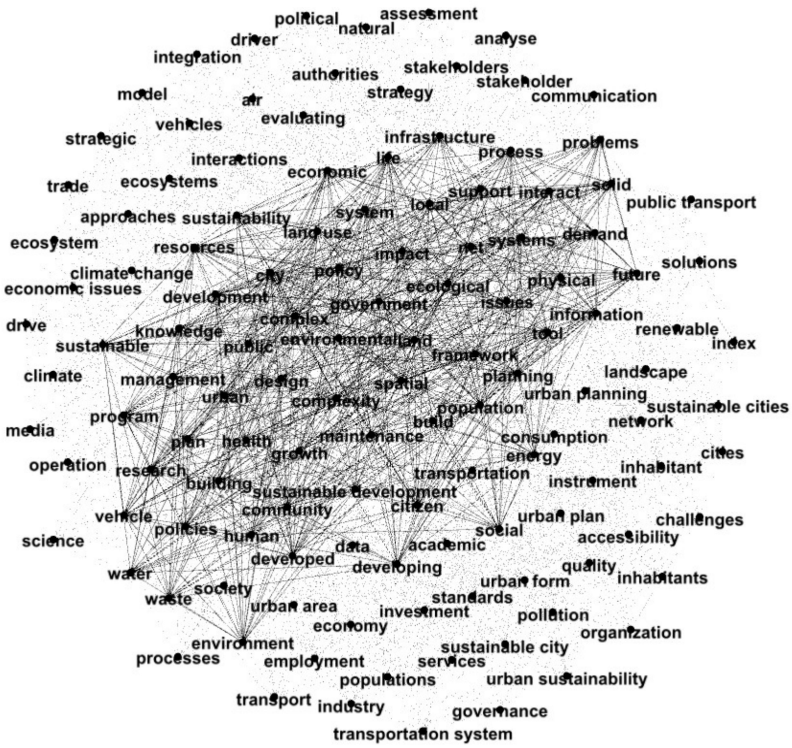

Figure 6. Chart of interdependence for sustainable cities.

The use of big data analytics can be applied in smart service systems such as smart customization and prevention (for crime prevention, midnight bus service routing, and scheduling), smart operations management, intelligent trash pickup, prognostics and health management or intelligent traffic control, smart coaching (for player management, fitness tracking, and baby condition monitoring), as well as smart adaptation and risk management (for intelligent navigation, fleet management, and demand consulting) [98–100].

Facility, security, access to infrastructure, and quality services can be achieved through real-time analyses of city data [101]. Once smart city governance necessitates plurilateral collaboration among the various societal actors, and big data analytics can also play a key role; therefore, organizations or agencies with common interests can easily be identified, leading toward collaborations among them. Moreover, big data analytics can help governments establish and implement satisfactory policies, because they are already familiar with the needs of the people [102,103].

Table 5. Interdependence between pillars of the Fourth Industrial Revolution and SSC implementation.

Technology Category	Main Ideas	Authors
Big Data and Data Analytics	Big data and data analytics (BDA) are applied in many different domains within smart cities. Big data analytics tools help analyze real data to enhance productivity and reduce the uncertainty in decision-making processes. It can be applied in the most diverse dimensions of cities and companies, such as manufacturing, pharmaceutical and health areas, transportation, governance, and energy.	[98,100,102,104]
Autonomous Robots	Provision of public and personal services for citizens and the use of new tools, used by professionals for operating in urban settings.	[105,106]

Table 5. *Cont.*

Technology Category	Main Ideas	Authors
Simulation	Simulations are a powerful tool because, potentially, they provide the designers of the experiments full control over all the variables of the settings. Simulations are made in several aspects, and examples can be cited in the field of safety as a means to support decision-making during real emergencies.	[80,107]
System Integration: Horizontal and Vertical System Integration	Through better operational synergy and competitive advantages, the technological advances resulting from the Industry 4.0 revolution allow the needs of an SSC to be better managed.	[83,84]
The Industrial Internet of Things	The Internet of things (IoT) can be considered one of the main components in ICTs for SSCs as an approach to urban development, due to its great potential to promote sustainability in urban centers. The IoT is directly associated with big data and can be used in several sectors of city management, such as optimizing energetic efficiency and mitigating environmental problems, aside from working in areas such as waste management practices. The use of the IoT and big data can play an important role in catalyzing and improving sustainable development.	[59]
Cybersecurity and Cyber Physical Systems (CPS)	Cybernetic physical systems (CPS) allow integration between computing objects and the environment, and they can be used in the implementation of SSC as facilitators of social well-being and to improve the quality of life of the population through better integration between systems.	[97,108]
The Cloud	The cloud works as an efficient and economic tool to allow to the processing, management, and storage of data, contributing to SSCs having information on city management stored in a safe environment, allowing for better management of available resources.	[109–111]
Additive Manufacturing	Additive manufacturing can contribute to the deployment of a smart and sustainable city, as it is possible to allow new consumption needs where products need to have lower environmental impacts.	[112–114]
Augmented Reality	The use of augmented reality in the context of SSC implementation can happen in several ways to improve the quality of life in communities, providing better inclusion for disabled people and creative solutions such as wearable technologies to help the population's consumption needs.	[13,115–120]

As shown, civil applications of robots in the urban environment consist of the provision of public and personal services for citizens and the use of new tools used by professionals for operating in city settings [121]. To reduce the negative impact of excessive traffic in large urban areas, for example, many innovative concepts for the intelligent transportation of people and freight have recently been developed, such as autonomous delivery robots launched from trucks [105]. Automated transportation systems, door-to-door rubbish collection, street cleaning, object transportation, human guidance, assistance, autonomous wheelchairs, and shop trolleys are already being used in the services sphere and consolidate the trends in robotics research [106].

The major challenge for the use of autonomous robots in the urban context is mostly related to aspects that consider the level of autonomy, especially for the safety issue [122,123]. The autonomy issue affects the extent to which people are willing to use a robot or work with it, as well as the blame and credit attributed to a robot and its human interaction partners, respectively. In this context, it must be designed, studied, and developed with attention and planning [39].

System integration can be seen as one of the greatest motivators of the Fourth Industrial Revolution, since it updates the stages of production and promotes optimization of the industrial process [84]. Alcácer and Cruz-Machado (2019) [124] stated that while the horizontal system present in intercompany integration uses the data storage and management created in the Fourth Industrial Revolution to increase a product's life cycle, promote the exchange of data, and consequently contribute in economic and sustainable spheres, the modernization of the vertical system offers more rapid and secure communication between different sectors in the same company, causing an increase in product quality.

The integration between manufacturing systems supports the growth of the products' quality, duration, and quantity [84] contributing to a more frequent emergence of technological innovations that aims for industrial development in a less environmentally harmful way, adapting companies to the needs of smart sustainable cities, the achievement of economic goals, and the consumers' requirements once it associates production, technology, and environmental awareness [124].

When dealing with the Internet for a smart and sustainable city, the Internet of things (IoT) emerges as one of the main components. It is directly linked to big data, and it can be used in various city management sectors, such as in controlling transparency portals and ensuring that people have better access to public service goods such as schools and security. In addition, it helps decision-makers better understand the needs of their population [59].

As an efficient and economical tool for processing, managing, and storing data in the deployment of an SSC, the use of the cloud allows all data collected from the city to be safely allocated in terms of energy, water, and food consumption, the number of vehicles per highway, and the time spent on commuting to work so that better management of all resources can be achieved, thereby promoting a better quality of life for the population [109].

The idea behind additive manufacturing is to drastically reduce waste production and resource use in manufacturing in order to achieve sustainability [113]. Several factors affect how each product will affect the environment, including the product design and manufacturing processes. With that in mind, tools can be developed in order to identify the cleanest production routes, leaving the smallest possible carbon footprint behind [114]. The influence of additive manufacturing goes beyond the production process; it encompasses the whole life cycle. Additive manufacturing has a high impact on the economic and environmental spheres of sustainable development, while correct end-of-life handling will have a social impact [125]. Additive manufacturing can also be applied in the construction sector, both in projecting buildings with sustainable materials and in projecting new models of buildings that are low in consumption [112].

Augmented reality (AR) has several implications for SSCs. For instance, it can be used to help people with motor disabilities, especially wheelchair users, to touch things beyond arm's length. In a study made by Rashid et al. (2017) [119], the results were promising when people with different levels of disability were evaluated in terms of digital interaction with physical items, contributing to a better inclusion of all citizens in an SSC. Another possible use of AR is to predict scenarios, such as natural disasters. Haynes et al. (2018) [117] proposed a mobile AR application to create flood simulations, aiming to better assess flood risk management. This technology can also be applied in other planning and designing projects.

7. Conclusions

Finding solutions to improve life in cities is not only desirable and important; it is vital. Most of the world's population lives in urban areas, and the world is very likely to continue its trends of urbanization and population growth in the coming decades, while urban areas represent only 3–5% of the Earth's territory [48]. Urban centers need to find models for providing a better quality of life and for meeting the needs of this large concentration of people in a sustainable way. The twenty-first century represents an era of other issues that must be addressed in cooperation, such as food security, climate change, and gender inequality, while at the same time, it sees the rise of new technologies and innovations with large-scale implications, represented by the Fourth Industrial Revolution.

The Fourth Industrial Revolution will have implications for several factors that are deeply connected to the success of cities in becoming sustainable: job creation, industries, innovation, environmental preservation, community involvement, and accessibility. While this amount of profound changes makes it revolutionary, the Fourth Industrial Revolution is very different from the previous three since it is foreseen and planned, which gives us a chance to shape and design it for the needs of our time. Today's challenges for mankind are arguably more complex than they have ever been, but so are our tools.

In the Fourth Industrial Revolution and its pillars, policymakers have some opportunities and challenges that must be faced. Big data, for instance, could provide new information that could be mined, analyzed, and used for identifying previously unseen problems. The IoT can provide new industrial innovations that can make economies thrive. Augmented reality can help to promote inclusion for disabled people, and simulations can help society foresee problems and adapt to them. Smart city policies also incentivize innovation, which increases a city's stock of knowledge, one of the main recognized drivers of economic growth.

Those new technologies also bring fresh problems that must be addressed. It is understood that, while automation will improve industry performance, it may come at the cost of jobs. Cybersecurity issues will also emerge, as people are increasingly connected to their devices and share more information about themselves. There is also a potential ethical issue in allowing machines or systems into important decision-making processes.

In the context of this new revolution, technological innovations and advances invade society, making it more accelerated. Such a circumstance is made possible by technologies directly impacting society, and the dimension or reach of the impacts promoted by the Fourth Industrial Revolution make it unique from the others that preceded it. There is a need to understand more and more the consequences of its impacts on society, the labor market, and on the economy. Regardless of the perspective that this phenomenon is analyzed from, and for change to occur in an inclusive way, we need investment in professional preparation and cyber architectural resizing in industries with systemic innovation. Therefore, let us assume collective responsibility for a future in which innovation and technology have the human being at their core, as well as the public interest from a more sustainable context. We cannot allow a logic that only feeds back into a production and consumption machine, which in itself is exclusive and cannot be consolidated in this crossing. Otherwise, we will have a society of soldiers and productive machines, and consequently, we will subtract from our society and our civilization the supplement of the soul and the supplement of transcendence. Without this reflection and concern, we will not see the cruel reality in which we will live, much less our disfigurement as part of this gear. Therefore, we will not be able to glimpse ways of overcoming them; we will only be replicants of the status quo. Yes, we need innovations. Yes, we need new technologies, but we cannot let our humanity slip away. Society calls for a supplement of the soul and a supplement of human greatness, and the moment is demanding this care.

Future research may explore how the Fourth Industrial Revolution can help solve other problems and boost the achievement of other SDGs. Each pillar in the Fourth Industrial Revolution analyzed here can be expanded to fit into SSC categories.

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