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Smart sustainable cities: characterization and impacts for sustainable development goals

Alana Corsi[1] Regina Negri Pagani[2] Tibério Bruno Rocha e Cruz[3] Fabiane Florencio de Souza[4] João Luiz Kovaleski[5]

[1] Master's in industrial Engineering, Federal Technological University of Paraná - UTFPR. Ponta Grossa, Paraná – Brazil. alanacorsi@alunos.utfpr.edu.br
[2] PhD in industrial Engineering, Federal Technological University of Paraná - UTFPR. Ponta Grossa, Paraná – Brazil. reginapagani@utfpr.edu.br
[3] Bachelor's Degree in industrial Engineering, Federal Technological University of Paraná - UTFPR. Ponta Grossa, Paraná – Brazil. tiberiocruz@alunos.utfpr.edu.br
[4] Master's in industrial Engineering, Federal Technological University of Paraná - UTFPR. Ponta Grossa, Paraná – Brazil. fabianesouza@alunos.utfpr.edu.br
[5] PhD in Industrial instrumentation, Université Joseph Fourier. Grenoble - França. kovaleski@utfpr.edu.br

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Abstract

Objective: The present work aims to explore the concept of Smart Sustainable Cities, create the correlation between the terms Smart Cities and Sustainable Development, map technologies and projects implemented in this model of urban agglomeration, and identify the benefits generated for sustainable development, through the SDGs.
Methodology: A content analysis was carried out using the Methodi Ordinatio, a systematic literature review multicriteria methodology.
Relevance: Smart Sustainable Cities arise with the aim of promoting technological development, but also facing the problems generated by cities. However, the concepts and structures of these cities are not clear, as well as which technologies are implemented and their impacts on sustainable development.
Results: Smart Sustainable Cities generate benefits for the three sustainable axes, in greater proportion for the Social axis, followed by the Environmental axis, and with less impact for the Economic axis.
Contributions: This paper contributes to the academy by increasing the theoretical material, and to decision-makers, by highlighting the structures that make up the Smart Sustainable Cities as well as their results for sustainable development.

Keywords: Smart Cities. Smart Sustainable Cities. Sustainable Development. Sustainable Development Goals.

Smart Sustainable Cities: Caracterização e seus impactos para os Objetivos do Desenvolvimento Sustentável

Resumo

Objetivo: O presente trabalho visa explorar o conceito de Smart Sustainable Cities, criar a correlação entre os termos Smart Cities e Desenvolvimento Sustentável, mapear tecnologias e projetos implementados neste modelo de aglomeração urbana, e identificar os benefícios gerados para o desenvolvimento sustentável, por meio dos ODS.
Metodologia: A análise de conteúdo foi realizada utilizando a Methodi Ordinatio, uma metodologia multicritério de revisão sistemática da literatura.
Relevância: As Cidades Inteligentes Sustentáveis surgem com o objetivo de promover o desenvolvimento tecnológico, mas também enfrentar os problemas gerados pelas cidades. No entanto, os conceitos e estruturas dessas cidades não são claros, bem como quais tecnologias são implementadas e seus impactos no desenvolvimento sustentável.

Resultados: As Cidades Inteligentes Sustentáveis geram benefícios para os três eixos sustentáveis, em maior proporção para o eixo Social, seguido do eixo Ambiental, e com menor impacto para o eixo Econômico.
Contribuições: Este artigo contribui para a academia, aumentando o aporte teórico, e para os tomadores de decisão, ao destacar as estruturas que compões as Cidades Inteligentes Sustentáveis bem como seus resultados para o desenvolvimento sustentável.

Palavras-chave: Smart Cities, Smart Sustainable Cities, Desenvolvimento Sustentável, Objetivos do Desenvolvimento Sustentável.

Ciudades Inteligentes y Sostenibles: Caracterización y sus impactos para los Objetivos de Desarrollo Sostenible

Resumen
Objetivo: El presente trabajo tiene como objetivo explorar el concepto de Ciudades Inteligentes Sostenibles, crear la correlación entre los términos Ciudades Inteligentes y Desarrollo Sostenible, mapear tecnologías y proyectos implementados en este modelo de aglomeración urbana, e identificar los beneficios generados para el desarrollo sostenible, a través de los ODS.
Metodología: El análisis de contenido se realizó utilizando Methodi Ordinatio, una metodología de revisión sistemática de la literatura multicritério.
Relevancia: Las Smart Cities Sostenibles surgen con el objetivo de impulsar el desarrollo tecnológico, pero también afrontar la problemática que generan las ciudades. Sin embargo, los conceptos y estructuras de estas ciudades no están claros, así como qué tecnologías se implementan y sus impactos en las ciudades.
Resultados: Las Ciudades Inteligentes Sostenibles generan beneficios para los tres ejes sostenibles, en mayor proporción al eje Social, seguido del eje Medioambiental, y con menor impacto en el eje Económico.
Contribuciones: Este artículo contribuye a la academia, aumentando el aporte teórico, y a los tomadores de decisiones, destacando las estructuras que componen las Ciudades Inteligentes Sostenibles.
Palabras clave: Ciudades inteligentes, Ciudades inteligentes y sostenibles, Desenvolvimiento sustentable, Metas de desarrollo sostenible.

1 Introduction

The growth of industrialization in cities, accompanied by the deceleration of subsistence family farming activities in the countryside areas, caused a great expansion of urban agglomerations, with a considerable population increase in urban areas (Bayulken & Huisingh, 2015). Since 2007, more than a half of the world's population has been living in urban areas (Madlener & Sunak, 2011), and it is estimated that more than 65% of the population will be living in urban agglomerations by 2050 (UN, 2018), consuming up to 75% of resources global (Madlener & Sunak, 2011). As a result, there has been an increase in social demands for better levels of municipal infrastructure and services (Li et al., 2019), highlighting the need for strategies to combat the problems generated by the accelerated urbanization and consumption patterns (Madlener & Sunak, 2011), which should be in consonance with the sustainable development principles.

In 2015 the United Nations proposed the Sustainable Development Goals (SDG), an agenda with 17 objectives, which should be achieved by 2030, covering the most diverse areas, encouraging the use and transfer of sustainable technologies. Since cities and urban areas are at the centre of economic, social, and environmental processes (UN, 2014), being

responsible for promoting the growth of countries (Wong, 2015), a specific SDG for cities emerges, 11 SDG, aiming specifically to promote sustainability and resilience of cities (UN, 2015). Consequently, differentiated models of cities emerge, such as the so-called Smart Cities.

These models appeared with a focus on Information and Communication Technologies (ICT) infrastructure (Caragliu et al., 2011, Pagani et al., 2019), which monitors and integrates all its critical infrastructures, being able to optimize its resources planning its preventive actions, and monitoring security aspects (Hall, 2000). Although ICTs are used to benefit the lives of citizens, other studies (Rizzon et al., 2017, Corsi, 2020) argue that the simple implementation of these technologies does not guarantee the smartness of cities in terms of more efficient provision of services and infrastructure in satisfying human needs.

The literature review highlights the problem of technocentric definitions of Smart Cities and the lack of alignment with the sustainable agenda. Smart Cities need to align their goals with sustainable goals so that they are not just another model of cities that contribute to the current social problems and insufficient infrastructure, giving birth to the so-called Smart Sustainable Cities, city model based on two concepts: Smart Cities and Sustainable Cities. The term was developed to express the cities that support the massive use of advanced ICTs, considering the impacts for sustainable development and improving quality of life for citizens (Bibri & Krogstie, 2017, Yigitcanlar et al., 2019).

Although the term exists, assumptions from the systematic literature review revealed some gaps: not all Smart Cities concepts include sustainable development as an objective or expected result, resulting in a model of city unrelated to the problems generated by urbanization (Corsi, 2020), there is a lack of works that relate the results of Smart Cities with the SDGs, an action in force to promote Sustainable Development, and when this relationship occurs, there is an uneven distribution of results for the TBL, both in Sustainable Cities and Smart Cities.

From this, a few questions arise:

RQ1. What are the requirements for a city to be considered Smart?

RQ2. What are the most used technologies in Smart Cities and their impacts of technological development promoted by Smart Cities on Sustainable Development?

RQ3. What are the most effective projects/strategies implemented in Smart Cities and which axes of TBL is mostly evidenced?

In order to answer these research questions, the present work aims to characterize the Smart Sustainable Cities, mapping the technologies and projects applied in these cities and the impacts generated for the Sustainable Development Goals (SDGs). To achieve this purpose, a Systematic Literature Review was carried out, using Method Ordinatio

methodology, addressing the themes Smart Cities, Sustainable Development and Technologies.

2 Theoretical background

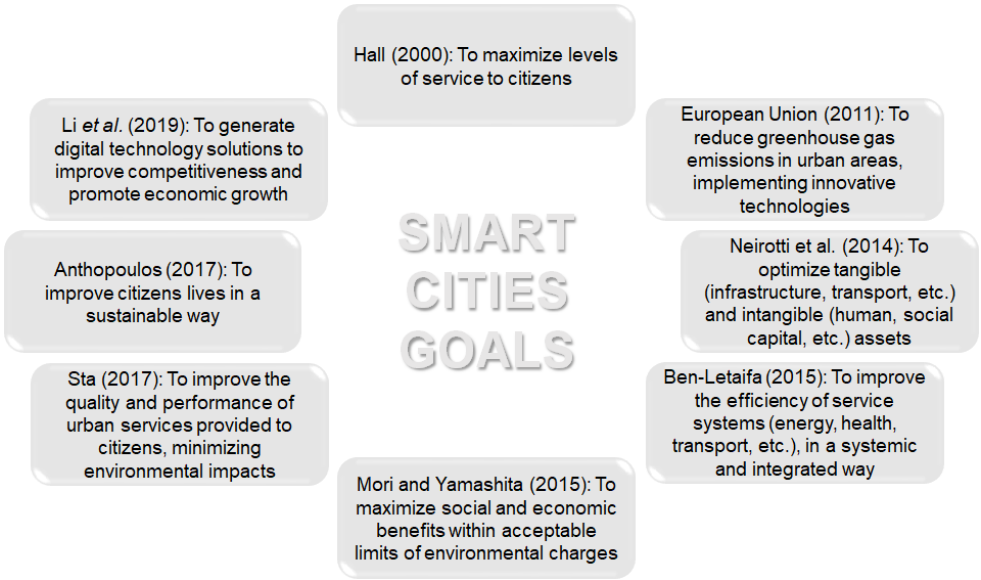
2.1 Characterization of Smart Cities

Smart Cities emerged with a focus on ICT, which monitors and integrates all its critical infrastructures, seeking to optimize its resources (Caragliu et al., 2011, Hall, 2000, Ullah et al., 2021), implementing smart, resource efficient, integrated, lean and economic technologies (Ahvenniemi et al., 2017), while improving competitiveness and fostering economic growth (Li et al., 2019). These technologies are also considered as a solution for better management of cities, maximizing the quality-of-life parameters of the urban population. Therefore, Information and Communication Technologies (ICT), together with the concepts of Internet of things (IoT), consist in a configuration of cities that will be fundamental for urban transformation (Sta, 2017).

Authors highlight different goals for Smart Cities, as detailed in Figure 1.

Figure 1

Smart Cities Goals



Source: Authors.

It can be observed that a common goal is to promote well-being and quality of life for citizens, corroborating the study of Ahvenniemi et al. (2017) and Javed et al. (2021). Although some authors (Anthopoulos, 2017, Sta, 2017) relate Smart Cities to sustainable goals, as identified in the definitions and objectives of Smart Cities, most of them relate Smart Cities to technological components. However, smartness goes beyond the application of technologies

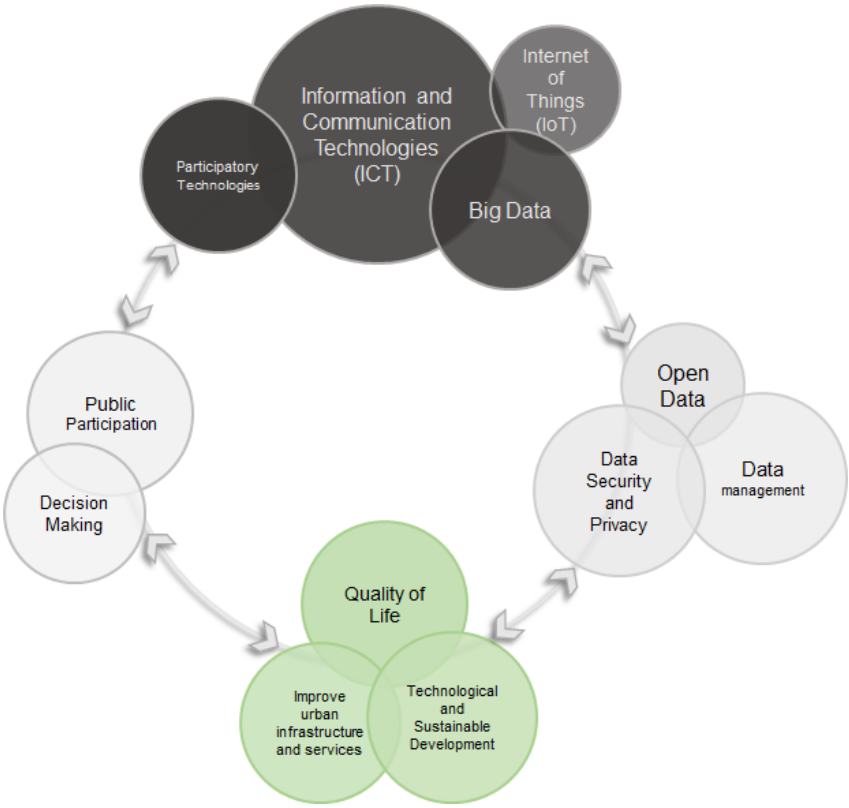
and technological solutions Anttiroiko et al., 2014, Yigitcanlar, 2015). Technologies must be a means to promote urban development, which, in turn, must meet the needs of citizens (Beck & Conti, 2021).

Some authors consider that a city can be considered Smart when it attends to some requirements, like investing in human and social capital, infrastructure, promoting sustainable development and implementing participatory actions and citizen engagement (Caragliu et al., 2011). On the other hand, Rizzon et al. (2017) consider that cities are smart if they implement modern technologies, as ICTs and IoT, in the process of planning and developing urban transformation, however, the application of technologies alone is not enough to become smart. According to Beck et al. (2020), the use of technologies such as ICTs in the territory, together with social values, constitutes the core of the intelligence of cities, with the interaction and active collaboration of citizens in decision-making.

In order to identify the main objectives and requirements, the definitions of the authors, extracted from the articles portfolio on APPENDIX, were analyzed, and the results of the central themes are synthesized in Figure 2.

Figure 2

Central themes of Smart Cities



Source: Authors

As shown in Figure 2, the main themes addressed are: at the top of the figure, the main technologies that define these cities, ICT and Big Data are the most frequent, on the left-hand side is the decision-making process and the importance of citizen participation in decision-making, on the right-hand side is the concern and importance of data and its management, and, finally, at the bottom of the figure, the expected results in this model of cities, being sustainable benefits, and better services and urban infrastructure.

Although there is a consensus that the elements of technologies are fundamental components to Smart Cites, on the other hand, it is evident the concern of other authors with this prioritization of the technological dimension, arguing that other aspects should be as important as technological ones (Macke et al., 2018, Yigitcanlar et al., 2019, Martin et al., 2019).

Some authors (Bibri, 2019, Alkhatib et al., 2019) address impacts for the three axes of sustainability, arguing that the application of innovative technologies to improve urban services results in improved quality of life for citizens, also improving economic development, making society more equal with more liveable and sustainable surrounding environments.

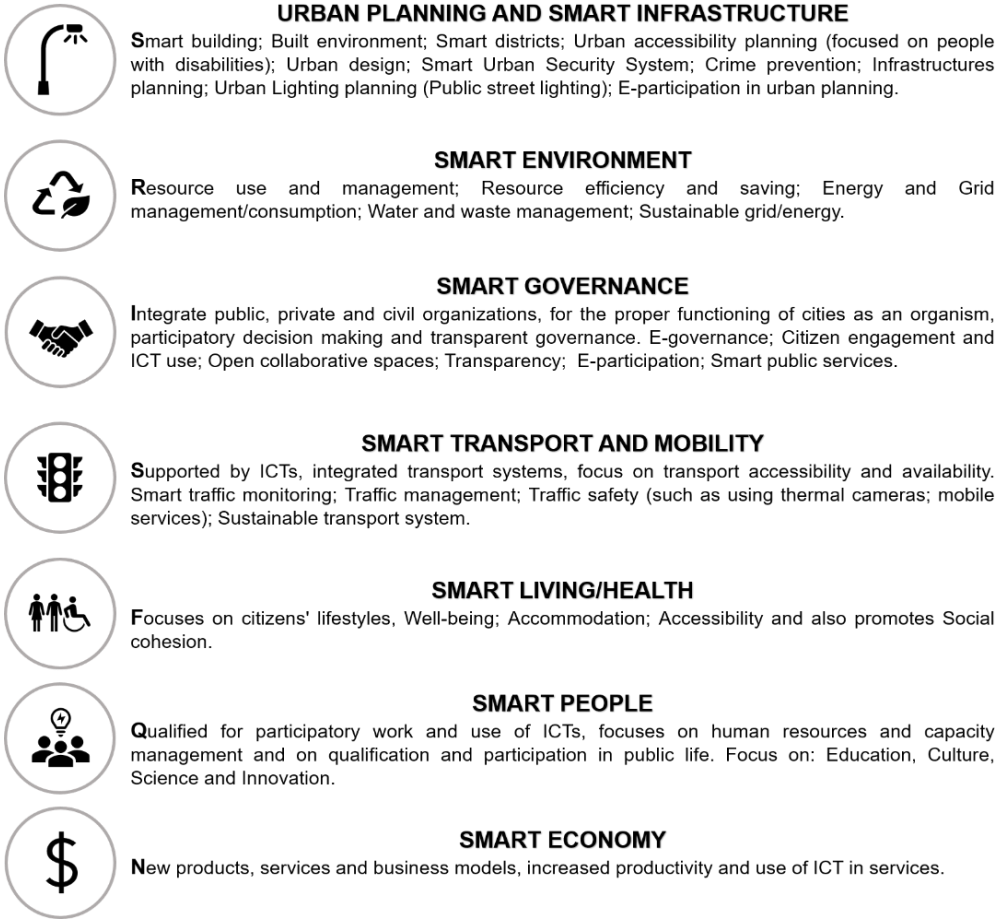
Although a small portion of authors include TBL in the objectives of Smart Cities, it is observed that there is an unequal appreciation between the three axes, corroborating what has been demonstrated in other study (Corsi et al., 2020). This study demonstrated that there is an overvaluation of the environmental and economic axes to the detriment of the social axis, contradicting what was initially proposed by Elkington (1997).

The central actors for the development of these cities are the citizens, as integral and fundamental elements to interact with the technologies, inserting data in real time, and the decision-makers, governments, and policy makers, as agents of implementation of the data made available by the citizens, making decisions and formulating strategies to improve urban services and infrastructure.

In addition to the requirements and central actors, Smart Cities are formed by specific structure or domains, extracted from the articles portfolio on APPENDIX and synthesized in Figure 3.

Figure 3

Smart Cities domains and subdomains



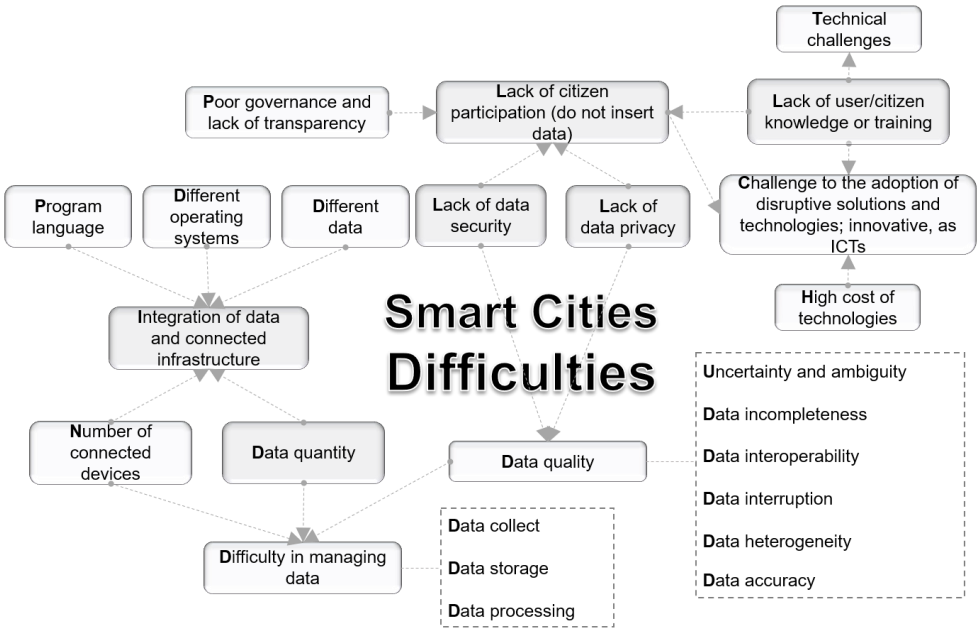
Source: Authors.

According to Sánchez-Corcuera et al. (2019), the domains presented by different authors present similar categories. However, the definition of their subdomains restricts them, making these domains, previously similar, different. We consider that a Smart City will be intelligent if its technological facilities can be understood by the users, that is, its citizens, so that the technologies can be effectively transferred and implemented, overcoming one of the main barriers of technology transfer (Corsi et al., 2021). Thus, technologies must be inserted in the context of cities to supply a need or a problem detected by the citizen, so that this technology works in favour of the citizen, and not the other way around.

There are some difficulties and barriers for the development of Smart Cities as discussed by Razmjoo et al. (2021) and mapped in the portfolio article and summarized in Figure 4.

Figure 4

Smart Cities main difficulties



Source: Authors.

It can be observed that the main difficulties for the development of Smart Cities are related to the characteristics of the data. The most frequent difficulty was the lack of data privacy and security (Allam & Dhunny, 2019), causing disincentive to citizen participation to insert data and interact with participatory technologies (Martin et al., 2019). Smart services are based on participatory decision making, thus, citizen participation becomes essential. According to Praharaj et al. (2018), one of the barriers to effective citizen participation is security and privacy issues for data sharing, being among the biggest challenges of Smart Cities (Paskaleva et al., 2017, Ahmad et al., 2022). According to Beck and Conti (2021), decision-making by governance must be supported by the involvement of city stakeholders, including academia, industry, government, citizens and the environment, as engagement and collaboration lead to intelligence.

A second most addressed difficulty is the integration of the countless connected devices, generating data in real time. Some difficulties can be numbered as causes, such as programs connected with different languages, different operating systems that emit different types of data (Costin & Eastman, 2019), number of connected devices and increasing number of data generated (Sta, 2017). The amount of data made available in real time becomes a major difficulty in Smart environments, since it hinders its collection, storage, and processing, thus impacting its management (Bibri, 2018a), and consequently, in decision making. Additionally, the characteristics or quality of the data are often addressed as difficulties in the development of Smart Cities. The characteristics of the data, as well as their quality, become

fundamental factors for the development of Smart Cities and their smart services, since the essence of these cities is to connect all devices, therefore, without the ability to connect efficiently and without interruptions, cities cannot be fully developed (Costin & Eastman, 2019).

Finally, after the extensive characterization of Smart Cities, it was possible to observe that, although Smart Cities encompass the concepts of Sustainable Development, some authors discuss the lack of results and benefits for the sustainability tripod (TBL). According to Bibri and Krogstie (2017), there is lack of integration between the objectives of promoting technological development and the objective of promoting economic, environmental and social sustainability in cities.

The concept of Smart Sustainable Cities is based on two other concepts of cities, Smart Cities and Sustainable Cities. Therefore, the following Section is reserved to address the concepts of Sustainable Cities, allowing to identify its particularities.

2.2 Sustainable cities

The Smart Sustainable Cities concept is built based on Sustainable Cities and Smart Cities. Sustainable Cities maximize social and economic benefits within the acceptable limits of environmental charges, presenting socioeconomic benefits for citizens, respecting the limits to be met to ensure an adequate environment for all (Mori & Yamashita, 2015), involving the pursuit of maximum sustainable benefits, and balancing ecological inputs and urban socio-environmental, economic, and social benefits (Yang et al., 2017).

The Sustainable Cities concepts encompass the definitions of Sustainable Development. Since the term Sustainable Development was defined in the Brundtland Report, in 1987, it has been replicated in environmental debates, and by several authors, becoming a reference to guide on existing problems and in planning solutions (Bonnett, 2006). The most recent action to promote Sustainable Development is the Sustainable Development Goals (SDG), with an Agenda composed of 17 objectives to be reached by 2030 (UN, 2015). Through SDG 11, it is evident that there is a concern with urbanization and with the problems generated by cities, demonstrating the need to study strategies and create solutions to urban models, as well as there is a need for these urban models to have objectives aligned with sustainable goals in force, not being a "solution" unrelated to current problems.

Fu and Zhang (2017) differentiate the concepts of Sustainable Cities and Smart Cities, relating the first to the TBL (Mori & Yamashita, 2015), and Smart Cities focusing on technologies. Although there is the term Smart Sustainable Cities, the term is little explored (da Silva Neto & Nalini, 2017) and the literature shows little, if any, correlation between Smart Cities and SDGs, as in Pagani et al. (2019) and Blasi et al. (2022), for instance. After

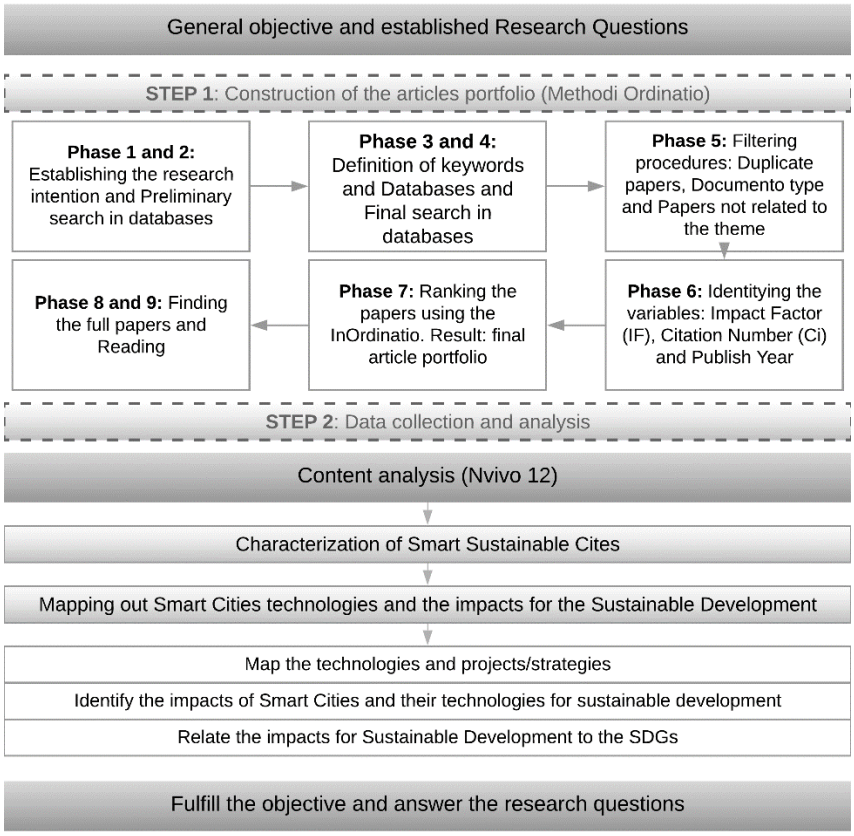
understanding the topics covered in this research, the procedures and methods adopted for its performance were described, as shown in the following section.

3 Materials and methods

The methodological procedures were developed in two steps. The first step was the construction of the portfolio of articles, which consists of a systematic review of literature (SRL), following the protocols of Methodi Ordinatio, proposed by Pagani et al. (2015, 2017). The second step deals with data collection and analysis. The two steps are illustrated in Figure 5 and described in the following sections.

Figure 5

Methodological procedures



Source: Authors.

3.1 Building the portfolio of articles

The methodology Methodi Ordinatio was used to build the portfolio of scientific articles. The methodology is based on the Cochrane Collaboration Model, a model focused on the health area. Therefore, Methodi Ordinatio differentiates itself by not restricting by research area. Furthermore, Methodi Ordinatio has the differential of being a multi-criteria tool, which

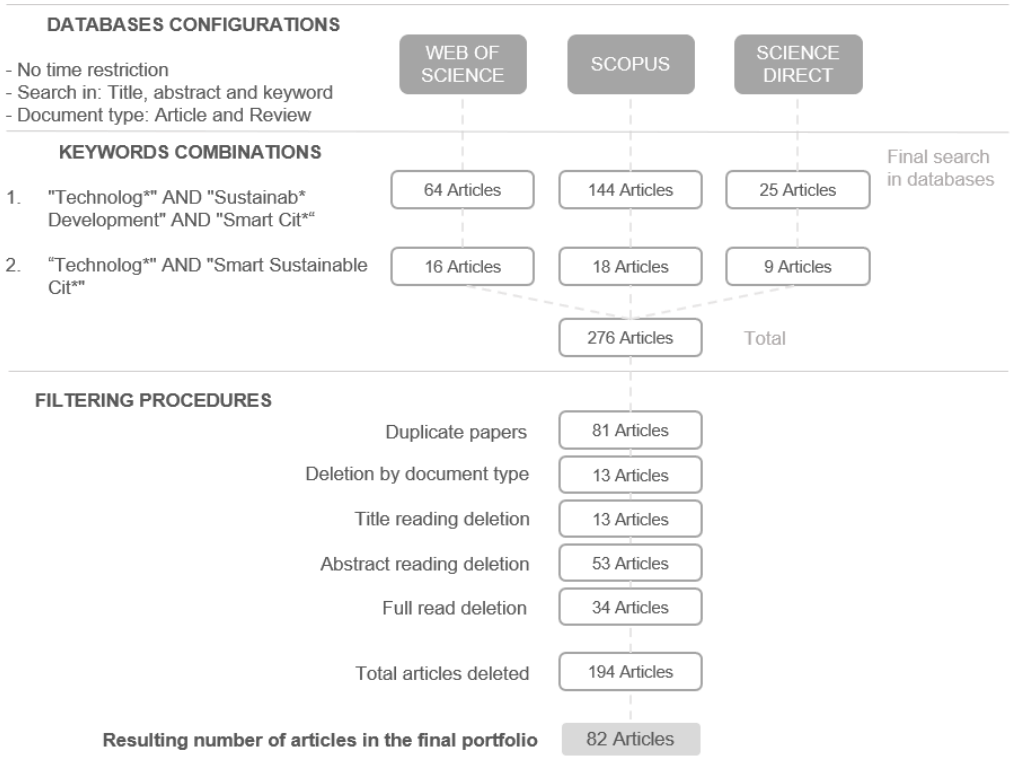
allows prioritizing a portfolio of articles, allowing prioritizing more scientifically relevant studies (Pagani et al., 2015, 2017). As described in other works (Corsi et al., 2020), Methodi Ordinatio consists of nine phases, as described in Figure 5.

Phases 1 to 4 - Establishing the intention of the research, exploring bibliographic databases and Final search in databases: The keywords used in the preliminary searches were "Technology", "Sustainable development" and "Smart city." From the exploratory searches, the final search was performed in the databases with the higher returns, being Science Direct, Scopus and Web of Science. The final search on the database resulted in a total gross of 276 articles, and the keywords combination and the results are illustrated on Figure 6.

Phase 5 – Filtering procedures: The filtering process applied aims to eliminate duplicate articles, conference articles, books, book chapters, and articles whose themes are outside the scope of this research, reading the title, abstract, and, if necessary, the full article. The results of the final search in the databases, and the filtering procedures were summarized in Figure 6.

Figure 6

Final search in databases and filtering procedures



Source: Authors.

Phase 6 - Identifying the metrics of the articles: With the final portfolio defined, the ordering procedure begins using the Impact Factor (IF), Number of citation (Ci), and Year of publication (PublishYear). For the IF, the main metric was the Journal Citation Reports (JCR), from Clarivate, and as alternative metrics, the SCImago Journal Rank (SJR) and Source Normalized Impact per Paper (SNIP) were used. To collect the number of citations, the Google Scholar was used.

Phase 7 – Application of the InOrdinatio Equation, using Equation (1), resulting in the final portfolio of ordered articles, according to Table 1 (APPENDIX).

$$InOrdinatio = (IF/1000) + \alpha*[10-(ResearchYear-PublishYear)] + (Ci) \quad (1)$$

The elements of the equation are: α (alpha value, ranging from 1 to 10, to be defined by the researcher according to the importance of the newness of the theme, for this study, the value of α was defined as 10, since the theme is the object of the study in very recent papers), Research Year (year in which the research was developed).

Phases 8 and 9 – After obtaining the final portfolio of ordered articles, the articles were collected and archived so that systematic readings and analyses could be carried out. With the portfolio ready to read, content analysis was developed. These procedures are detailed in section 3.2.

3.2 Data collection and anális

The content analysis of the portfolio was carried out. Firstly, a characterization was made about Smart Sustainable Cities, through the knowledge obtained in the theoretical background section and in the content analysis of the portfolio, allowing us to answer RQ1. Then, the technologies implemented in the context of Smart Sustainable Cities were mapped so that, subsequently, the impacts that this model of cities could be identified as well as the effects of technological implementation have on Sustainable Development, assessed through the impacts for the SDGs, allowing us to respond to RQ2. Finally, from the technologies, the projects/strategies were mapped, allowing us to respond to RQ3.

For content analysis, the software NVivo 12 was used, being a qualitative analysis tool, which allows better management, organization, and data analysis. For data collection, manual coding tool was used. This configuration generates greater reliability in the data, since it passes through the researcher's sieve, generating, therefore, more reliable analyses. For this, key terms were searched throughout the articles in NVivo12, allowing the full reading of the entire context related to the terms.

The next section presents the results and discussions in the light of the literature.

4 Results and discussions

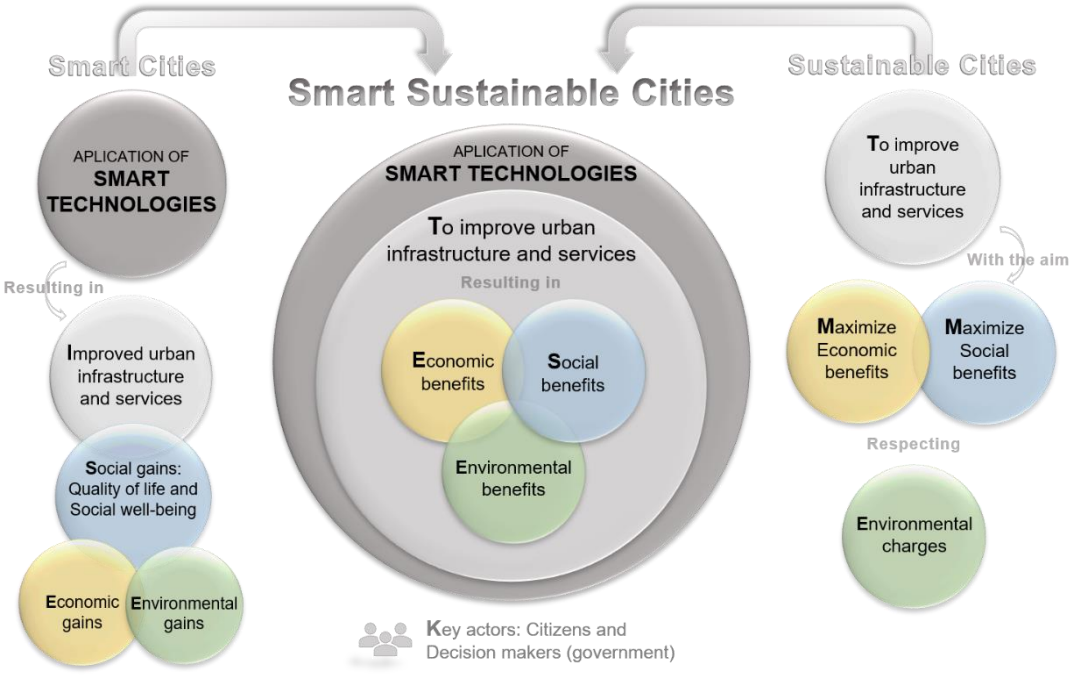
After building the portfolio of scientific articles, the data collection and analysis procedures began. In the section (4.1) a characterization of Smart Sustainable Cities was done. In (4.2) the content analysis was done, mapping the technologies and projects applied in this model of cities, and finally, (4.3) we identified the impacts of these cities, and technologies to the triple bottom line.

4.1 Characterization of smart sustainable cites

From the description of the concepts and objectives of the Smart Cities and Sustainable Cities, we developed a scheme, in Figure 7, to portray what the literature reveals regarding this two concepts, Smart Cities and Sustainable Cities, and the result from the connections of these two models, generating the core concerns of the Smart Sustainable Cities, and allowing to respond to RQ1.

Figure 7

Smart sustainable cities



Source: Authors.

On the left-hand side of the scheme, it is possible to observe the row with the main components of Smart cities. It is noticeable that the focus of Smart Cities is on the technology, mainly on Information and Communication Technologies (ICT) (Li et al., 2019), being one of the most addressed requirements among different authors, corroborating Caragliu et al.

(2011). The implementation of these technologies aims to promote more efficient urban services and infrastructure, while also improving citizens' quality of life (Sánchez-Corcuera et al., 2019). As concluded by Ahvenniemi et al. (2017) and Pagani et al. (2019), not all the authors correlate Smart Cities to the Sustainable Development or TBL, defining cities with a technocentric view, as criticized by Rizzon et al. (2017). Nevertheless, when they present such correlation, we can observe an overestimation of the social axis, and the economic and environmental axis are left aside, or with a much less importance, corroborating Corsi et al. (2020).

On the right-hand side row, we can observe the core elements of Sustainable Cities. This model of city presents sustainable actions to promote more efficient and sustainable urban services and infrastructures, as evidenced in SDG 11 (UN, 2015), and in this context, smart technologies can be implemented as facilitators to achieve these goals (Sta, 2017), resulting in benefits for the TBL. It encompasses, with a greater focus, the elements for the TBL, evidencing their objective of promoting Sustainable Development (Yang et al., 2017). However, as discussed, there is an unequal distribution of benefits for TBL, contradicting what was proposed by Elkington (1997).

In the center of Figure 7 the concept of Smart Sustainable Cities was built. This third model, a more complete one, encompassing both sustainable and technological development objectives, to promote more efficient urban services and infrastructures, quality of life to citizens, economic and environmental benefits, resulting in more sustainable cities and services. They are environments to which ICTs are widely implemented to collect, analyze and synthesize data in urban domains, resulting in the development of smarter functions and services and information that will be useful for more strategic decision-making associated with sustainability (Bibri & Krogstie, 2017), thus incorporating the impacts for the TBL. This model of cities does not neglect the current problems of cities, as highlighted by (Corsi, 2020), and the concept emerges when technologies are implemented for sustainable purposes in cities (Yigitcanlar et al., 2019).

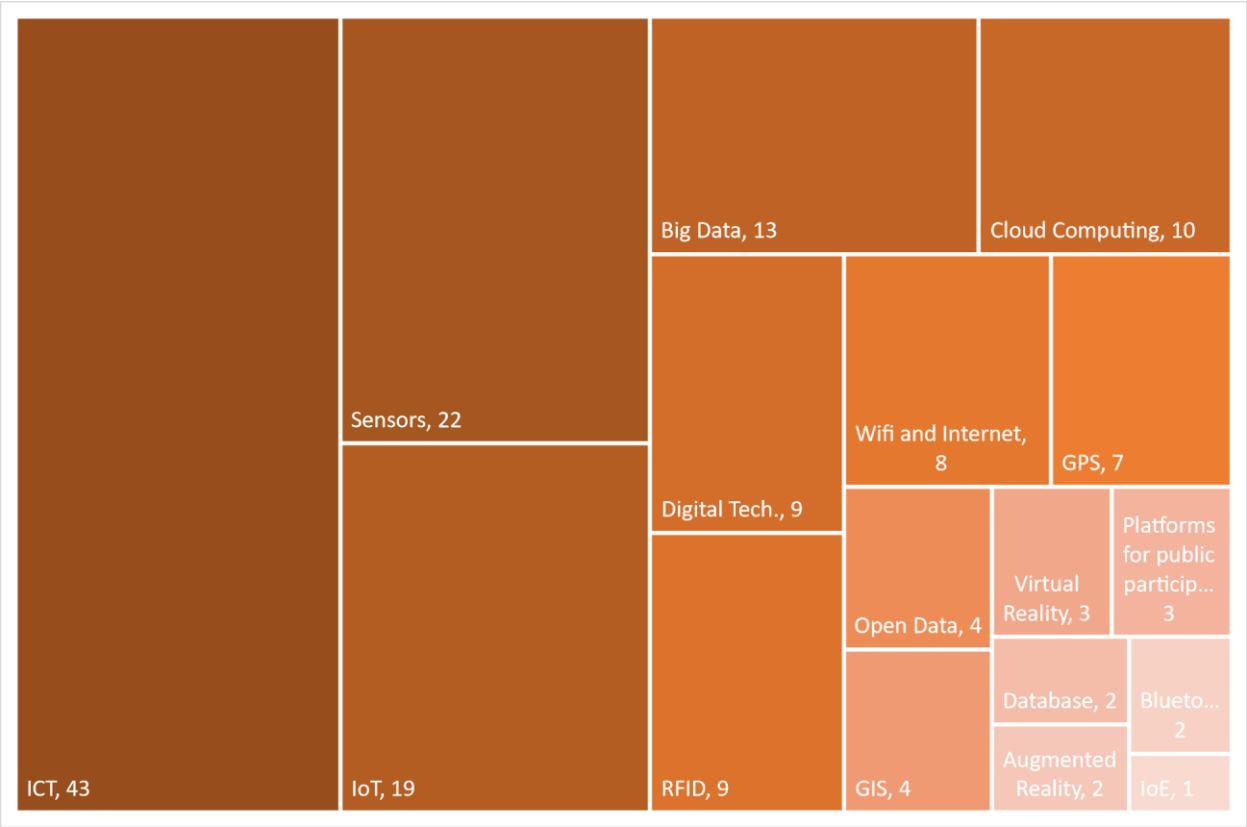
Thus, it can be concluded that Smart Sustainable Cities focus on technological implementation, such as ICTs and IoT, to improve the quality of life and well-being of citizens, and to offer better levels of services and urban infrastructure, also aiming to promote economic development and efficiency in resource consumption. The central actors for the development of these cities are the citizens, as integral and fundamental elements to interact with the technologies, inserting data in real time, and the decision makers, governments and policy makers, as agents of implementation of the data made available by the citizens, making decisions and formulating strategies to improve urban services and infrastructure.

4.2 Smart sustainable cities' most frequently addressed technologies

The technologies mentioned in the article portfolio were mapped and synthesized according to Figure 8, helping to answer RQ2.

Figure 8

Smart sustainable cities technologies



Source: Authors.

It is observed that the most frequently mentioned technologies are Information and Communication Technologies (ICT), corroborating several definitions of Smart Cities (Ullah et al., 2021). According to Martin et al. (2019), ICTs allow participatory decision-making processes, being one of the pillars of Smart Cities resulting in improvement such as the well-being of citizens, creation of "smart" and accessible environments, reaching a more inclusive and egalitarian society (Picatoste et al., 2018). As an expected result in the context of Smart Cities, ICTs are also addressed in the SDGs with the aim of generating knowledge, empowering women, and accelerating human progress, mentioned in SDGs 4, 5, 9 and 17 (UN, 2015). ICTs are implemented aiming to monitor, understand, investigate, and assist in the planning of these cities helping them achieve their specific goals (Bibri & Krogstie, 2017a).

The second most common technology are sensors. According to Bibri and Krogstie (2017c), the sensors are differentiated by the type of energy they detect as a signal, such as location sensors (GPS), optical (infrared, UV), light (photocell), image (stereo camera,

infrared), sound (microphone), temperature (thermometers), heat (bolometer), movement (speedometer), orientation (gyroscope), physical movement (accelerometer), traceability (RFID, NFC), and others. The most frequent sensor was Radio Frequency Identification (RFID), a technology that performs the identification of characteristics by radio frequency (Alavi et al., 2018).

RFID was applied with the purpose of tracking citizens, in order to promote greater security, resulting also in the concern on the part of government and users, in guaranteeing the privacy and security of individuals (Pérez-Delhoyo et al., 2017), which according to Allam and Dhunny (2019) is one of the main challenges of Smart Cities, also being a challenge to public participation (Paskaleva, 2011). In addition, it was also implemented in order to detect parked cars for mobility management projects (Beccali et al., 2017) and in planning collections and waste recovery operations, with the application of technology in dumps to detect the presence of certain types of waste (Shah et al., 2018). According to Pérez-Delhoyo et al. (2017), RFID has the advantages of not needing human cooperation and not involving energy costs like GPS.

Another sensor frequently addressed was the Global Positioning System (GPS), addressed by Shah et al. (2018) to identify where the compartments with the residues are located, optimizing the collection routes, Pérez-Delhoyo et al. (2017) addresses GPS and RFID for urban planning. Also, the Geographic Information System (GIS) sensor was addressed by Pérez-Delhoyo et al. (2017), together with the application of RFID and GPS, in order to display the data collected using the other two technologies and to perform spatial analysis.

Among the sensors, the thermal camera was covered in only one article. Gade et al. (2016) performed the comparison with the use of the RGB camera and the thermal camera and concluded that the second has advantages over the first in Smart Cities, since they do not depend on the incidence of light during different periods, besides guaranteeing the citizens' privacy, a subject widely discussed in the literature of this model of cities.

As the third most discussed technology is the Internet of Things (IoT), mentioned as a technological trend in the ICT sector, and considered as one of the most promising to face the problems of the cities of the future (Alavi et al., 2018). According to Allam and Dhunny (2019) IoT is considered the main technology to promote smartness to cities. It represents the ability to have a multitude of heterogeneous devices communicating without physical connections (Costin & Eastman, 2019).

Among the most frequent technologies, Big Data is considered fundamental for the development of Smart Cities. The term denotes a data set too large for the traditional data processing systems (Bibri & Krogstie, 2017c) Thus, the Big Data Analytics (BDA) ensures the ability to manage and use large amounts of data effectively for data-driven decision-making

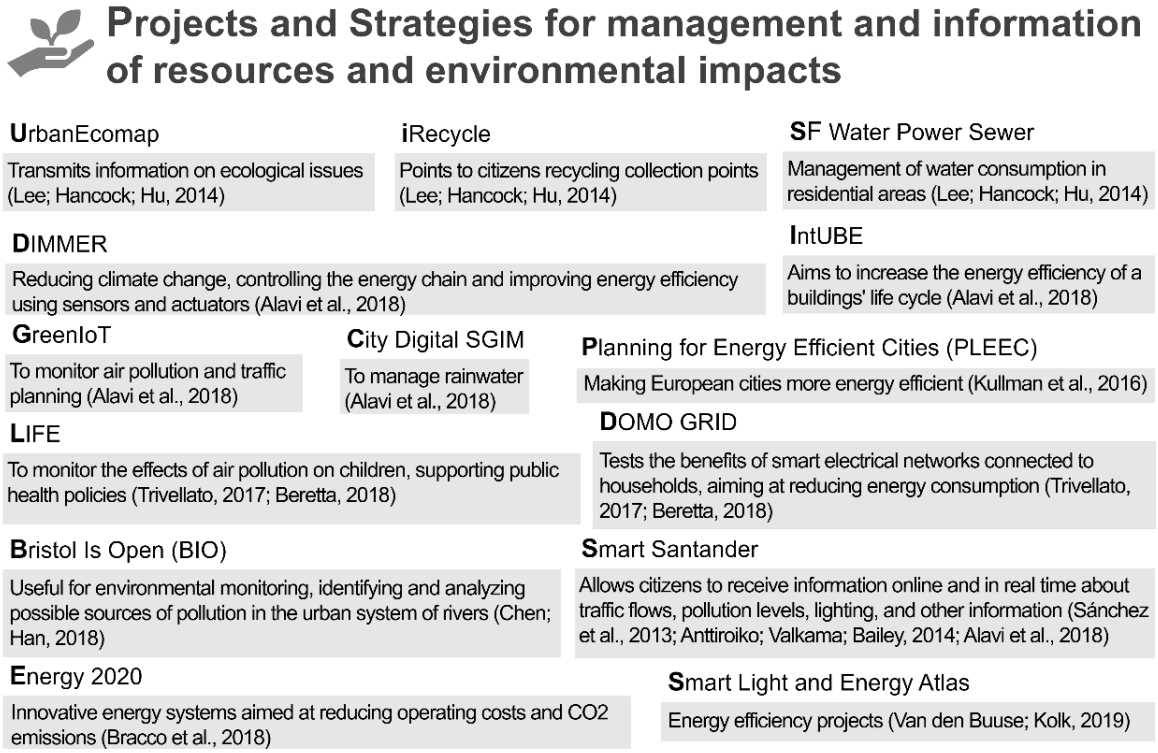
processes in urban areas (VISVIZI, LYTRAS, 2018). According to Bibri (2019), BDA play a significant role in terms of the sustainability of Smart Cities, allowing the management of the efficiency of operations and functions, of natural resources, the smart management of infrastructures and facilities, the improvement of the quality of citizens' life and well-being and improving mobility and accessibility. Although it is a key technology for the development of smart technologies, it is also a challenge for these cities, due to the amount of data generated in real time, and the characteristics of this data (Costin & Eastman, 2019).

In short, the technologies addressed as fundamental to the development of Smart Cities are digital technologies, such as ICT, in order to interconnect infrastructures, users and decision-makers, for the better provision of urban services. In addition, data infrastructure technologies, for collection, treatment and analysis of the growing number of data, are also considered fundamental in the context of cities where there is a dense amount of information and data being made available in real time, and from different sources and people.

From the technologies, the projects/strategies were mapped, to which the technologies were applied, helping to answer RQ3. The projects were organized according to their purpose. The first projects mentioned were related to the management of natural resources and the impacts generated on them, and the second projects were related to transport, mobility and security, as shown in Figures 9 and 10, respectively.

Figure 9

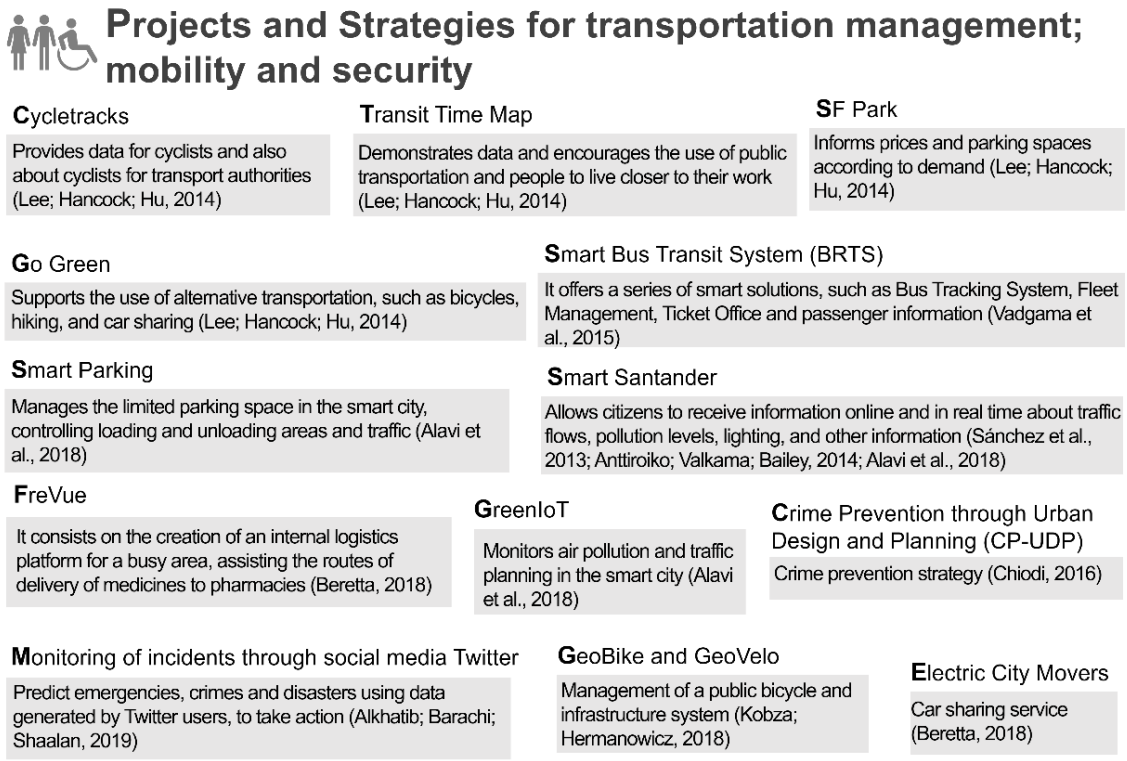
Projects/Strategies for management and information of resources and environmental impacts



Source: Authors.

Figure 10

Projects/Strategies for transportation management, mobility and security



Source: Authors.

Thus, it can be concluded that the technologies are applied in urban planning projects, mainly related to the efficiency of energy consumption and environmental resources and urban mobility and security, providing real-time data, which allows more assertive decision making. According to Angelidou et al. (2018), ICTs has a wide application in the areas of waste management and air pollution, being highly relevant to the process of implementing the “zero vision” strategy, such as zero carbon dioxide (CO2) emissions, zero fatal traffic accidents, and zero waste in cities. Thus, it is observed that the technologies of Smart Cities help this model of cities to achieve not only technological development, but also sustainable development.

4.3 Smart sustainable cities impacts for the triple bottom line

After characterizing what a Smart Sustainable City represents, its domains, requirements, challenges and the implemented technologies, it is important to identify what these technological implementations and the development of this model of cities result for the sustainable development. Thus, from the portfolio of articles, the impacts for the social, environmental and economic axis were identified, and the benefits most frequently mentioned for each of the three axes were identified, according to Figure 11. These results helped to answer RQs 2 and 3.

Figure 11

TBL benefits

Source: Authors.

From Figure 11 it is possible to observe that the social axis is the most addressed, being the dimension that represents the participation and engagement of citizens with technologies helping in decision making, generating innovation, inclusion, engagement and transparent governance (Beck et al., 2020). The main social benefits found were the improvement in quality of life, comfort and well-being, security for citizens and access to information. The second axis with the largest number of benefits mentioned was environmental, which according to Ahvenniemi et al. (2017), although environmental sustainability is one of the objectives of Smart Cities, its indicators are underrepresented in these cities. The most frequent environmental benefits found were the reduction in gas emissions, such as GHG and CO2, efficiency in the use of resources and environmental

protection. Finally, the economic axis was the least frequent, with the smallest number of benefits mentioned, those being the reduction of costs resulting from the implementation of a technology or application of a Smart project. According to Beck and Conti (2021), only income and profit do not define economic benefits of cities, indices such as unemployment, poverty and unequal income become indices and challenges in the economic dimension of Smart Cities.

In addition to the benefits mentioned, some authors have shown negative impacts from Smart solutions. Ahvenniemi et al. (2017) address the distribution of benefits generated by Smart Cities models, with the over-represented social axis, followed by economic sustainability, and, finally, under-represented environmental sustainability. On the other hand, Martin et al. (2018) and Yigitcanlar et al. (2019) concluded that Smart Cities initiatives tend to provide unsustainable forms of economic growth and consumerism, while neglecting social equity and environmental protection. Just as the authors mentioned the uneven distribution of benefits for the sustainability axes, the results obtained with this work also demonstrate an overvaluation of the social axis to the detriment of the others.

From these results, it can be inferred that, unlike the valuation of the environmental and economic axes at the expense of the social, in sustainable development projects, evidenced by different authors, such as Bhinge et al. (2015) and Corsi et al. (2020), this relationship in Smart Cities is the opposite, emphasizing social benefits to the detriment of the other axes, aiming mainly to result in quality of life for citizens. Thus, the application of actions to promote sustainable development in Smart Cities can be a strategy in order to minimize or equalize the distribution of benefits between the three axes.

In addition to the uneven distribution of benefits, negative impacts of the application of Smart technologies or projects were mentioned. Beretta (2018) identified that mobility projects can negatively impact the populations of smart cities, generating eco gentrification, as they benefit mobility and users in a specific area, excluding other areas and populations. Kramers et al. (2014) addressed the use of ICTs to reduce energy consumption in cities and concluded that their implementation alone does not guarantee the reduction, that is, the adoption of technology must be accompanied by political instruments and planning, considering all its effects throughout its life cycle, otherwise it may have a rebound effect. Likewise, Zawieska and Pieriegud (2018) approached that the application of Smart concepts and technologies in the field of transport alone does not mean a reduction in GHG emission levels.

Thus, from the identification of the impacts for the sustainability tripod, arising from the development of Smart Cities and their technological implementation, it was possible to relate them to the Sustainable Development Goals, as shown in Figure 12.

Figure 12

Smart sustainable cities impacts for sustainable development goals

Source: Authors.

As discussed earlier and shown in Figure 12, there is an uneven distribution of benefits in TBL (Bhinge et al., 2015), and in this study social impacts were the most recurrent. The main impacted SDGs, with the Smart actions that impacted the social axis, were: SDG 4, referring to actions to promote quality education, endorsing greater access to information, job creation, social inclusion, and improvement in the quality of life and well-being of the population, SDG 5, responsible for promoting gender equality, addressed by the impacts of social inclusion, improved health, public participation in decisions, integration and involvement of the population, and, SDG 11, referring to sustainable cities and communities, referring to the social benefits of improving security and privacy, integration and involvement of the population, improvement in the mobility and accessibility of citizens, safe houses and better habitability. Social benefits only did not impact two SDGs, SDG 7, referring to energies, and SDG 15, referring to life in water.

Followed by social impacts, the second axis with the greatest number of benefits was Environmental. The main SDGs impacted with the environmental benefits of Smart Cities were:

SDG 11 and 12, which refer to Sustainable Cities and Communities and Responsible Consumption and Production, respectively, both impacted through the conscious consumption of resources, reduction of gas emissions in the atmosphere, mitigation of climate change, improvement and environmental protection and improvement in the management and quality of resources, and SDG 12 also impacted through the environmental benefit of energy conservation. Of the environmental benefits generated by the practices of Smart Cities, eight SDGs were not addressed, namely SDGs 1, 2, 3, 4, 5, 10, and 16, being Objectives related more to social impacts, and SDGs 17, with a greater focus on partnerships and means of implementing sustainable objectives.

Finally, the economic benefits, which were the least recurrent in the studies that make up the portfolio. Among the SDGs most impacted by these benefits is SDG 8, referring to Decent Work and Economic Growth, addressed through the benefits of cost reduction, economic growth and development, new business opportunities and job creation. Among the sustainable axes, the benefits for the economic axis were those that had the least impact on the SDGs, failing to impact nine SDGs.

Thus, it is concluded that the practices promoted by Smart Sustainable Cities generate benefits for the three sustainable axes, in greater proportion for the social axis, followed by the environmental axis, and with less impact for the economic axis. In addition, it is observed that the results promoted by Smart Cities have a direct impact on the Sustainable Development Goals, therefore being a way to assist in the promotion and achievement of the 2030 Agenda's objectives. Thus, Smart practices, projects and technologies are in agreement with sustainable objectives, promoting both technological development and sustainable development.

5 Conclusions

Smart Sustainable Cities are cities that focus not only on technological development, but also on sustainable development. It aims to promote benefits to the three sustainable dimensions, although there is no balance in benefits around the three axes, using technological components, mainly the application of innovative digital technologies and ICTs. This is expected to provide more efficient urban services and infrastructure, quality of life for citizens, and more sustainable cities.

As mentioned by the SDGs, education, science and technology are means of implementing the SDGs, and consequently, tools to be explored in order to achieve sustainable development. Thus, the objective of this work was to map the technologies and projects applied in the context of Smart Sustainable Cities, aiming to disseminate these practices, allowing them to be replicated and promoting knowledge. In addition, the impacts that these

technologies and practices generate for Sustainable Development were singled out, identifying, for this, the SDGs reached by each mapped technology.

First, a characterization of Smart Sustainable Cities was done. Then, the technologies and projects/strategies were mapped out to highlight their impacts on the TBL, relating them to the SDGs. These activities answered the RQs 1, 2 and 3, as described in Table 2:

Table 2

How the RQs were met

Research Questions (RQ)	How the RQs were met
RQ1. *What are the requirements for a city to be considered Smart?*	From the context and definition of Smart Cities with a sustainable focus, it is observed that the implementation of technologies, especially ICTs, is one of the main requirements mentioned. However, only technological application is not able to promote "smartness" to the city, since if citizens do not use it, it does not fulfil its purpose. Thus, it is concluded that the requirement for a city to be considered Smart is the implementation of digital and computational technologies oriented to meet a need identified by the citizens, showing that the technology must work in favour of the citizen, not the other way around.
RQ2. *What are the most used technologies in Smart Cities and their impacts of technological development promoted by Smart Cities on Sustainable Development?*	From the analysis of the impacts generated by technologies for sustainable development, through the SDGs, it is observed that the Smart Sustainable Cities have a positive impact on the sustainability tripod, encompassing a large part of the SDGs. As evidenced, Smart Cities present benefits mainly for the Social axis, impacting a large part of the 17 objectives, not only addressing SDG 7 and SDG 15. The main SDGs addressed through social benefits were SDGs 4, 5 and 11. Environmental benefits mainly impacted SDGs 11 and 12, not covering almost half of the SDGs. Finally, the economic benefits of Smart Cities for sustainable development mainly impacted SDG 8, being the axis with the least number of benefits and, consequently, less impact on SDGs, not addressing 9 SDGs.
RQ3. *What are the most effective projects/strategies implemented in Smart Cities and which axes of TBL is mostly evidenced?*	As evidenced in studies focusing on sustainable practices, there is an appreciation of the Environmental and Economic axis over the Social axis; Smart practices present the unequal valuation between the axes of the TBL. However, the most addressed and valued axis is the Social axis, with the main benefit being the improvement in the quality of life and well-being of citizens, followed by the Environmental axis, with the main benefit of reducing atmospheric emissions, and, finally, the Economic axis, with the main benefit being cost reduction.

Source: Authors.

Thus, as a main result of this research, it is observed that Smart Sustainable Cities are models of cities that can assist in the promotion of sustainable development, and that from the implementation of technology centered and oriented to the needs of citizens, they promote sustainable benefits, services and more efficient infrastructure, helping to minimize or address the impacts generated by conventional city models. Therefore, it is a model of cities to be explored and replicated. However, the research highlighted the need for strategies and actions so that the impacts for the TBL are equal, minimizing or eliminating the unequal valuation of the three sustainable axes.

In addition, it is necessary to overcome the idea that intelligence is acquired only through technological application (Martin et al., 2019, Beck et al., 2020), it is necessary that these technologies are effectively implemented, that citizens use them, and that their application results in social, economic and environmental benefits. Furthermore, although the term theoretically presents numerous benefits, it cannot be considered as the only answer to the problems of cities (da Silva Neto & Nalini, 2017).

The present research presents the differential of relating the results of the application of technologies in Smart Cities with the SDGs, and in this way, presents the opportunity to transfer technology and knowledge to governments and decision makers. Regarding the contributions of the work, the study contributes to the academy by increasing the theoretical material on Smart Sustainable Cities. It also contributes to decision-makers, from cities' governance and companies' management, by disseminating knowledge obtained with the mapping of Smart technologies and practices, and the impacts for sustainable development that these technologies generate, allowing the replication of these results.

As a proposal for future research, we suggest exploring the use of indicators to assess how beneficial, for sustainable development, these technologies and practices can be. Also, we suggest a study that evaluates the impacts of the challenges faced by cities for citizens and for the social dimension of cities. The study is limited to encompassing only articles and reviews published in scientific journals, not encompassing works from other sources, such as conferences, dissertations or thesis, and books.

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Appendix

Table 1

Final portfolio

TITLE	INORDINATIO
Towards an effective framework for building smart cities: Lessons from Seoul and San Francisco	420,00
Definition methodology for the smart cities model	366,01
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Need for Interoperability to Enable Seamless Information Echanges in Smart and Sustainable Urban Systems	101,00
Backcasting in futures studies: a synthesized scholarly and planning approach to strategic smart sustainable city development	101,00
Can cities become smart without being sustainable? A systematic review of the literature	100,00
Data mining and machine learning to promote smart cities: A systematic review from 2000 to 2018	100,00
New key performance indicators for a smart sustainable city	100,00
On the sustainability of smart and smarter cities in the era of big data: an interdisciplinary and transdisciplinary literature review	100,00
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A novel Bluetooth low energy based system for spatial exploration in smart cities	96,00
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An exploration of smart city approaches by international ICT firms	94,00
Modern conceptions of cities as smart and sustainable and their commonalities	94,00
From measure to guidance: Galactic model and sustainable development planning toward the best smart city	94,00
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A stochastic optimization framework for planning of waste collection and value recovery operations in smart and sustainable cities	92,01
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Source: Authors.