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Current Trends and Future Prospects on Smart and Sustainable Cities

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► **To cite this version:**

Véronique Flambard, Sadia Benamrouz-Vanneste, Abir B. Karami. Current Trends and Future Prospects on Smart and Sustainable Cities. Smart Cities, 2023. hal-04581930

HAL Id: hal-04581930

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Current Trends and Future Prospects on Smart and Sustainable Cities

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Deadline for manuscript
submissions:

closed (30 April 2023)

Message from the Guest Editors

Dear Colleagues,

Some planetary boundaries have been crossed, making it urgent to act on climate change and biodiversity, among others. We are at a crossroads where imagining a desirable and possible future is necessary. Acting on sustainable cities and communities falls under the 11th UN SDG and responds to the growing challenge of urbanization worldwide.

In this Special Issue, we invite multidisciplinary contributions on current trends and perspectives in ecosystems, innovations, models and (possibly replicable) good practices in smart cities and territories that improve the environment, the economy, and social wellbeing. Advances in simulation methods and data analysis, forecasting techniques, scenario planning, future design, and complex system models are also particularly welcome as long as they can participate to improve critical thinking and decision making on cities' and territories' resilience and sustainable development.





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Message from the Editor-in-Chief

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Article

Smart Sustainable Cities: The Essentials for Managers' and Leaders' Initiatives within the Complex Context of Differing Definitions and Assessments

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Abstract: This study starts by questioning what smart cities are and how they are being planned for the future of the population. Faced with a wide range of information, the coexistence of multiple definitions, and differences between the theoretical concept and what is being carried out in the real world, it is recognized that entrepreneurs and public managers require more clarity regarding the essential attributes that need to be considered in the initiatives of a city that aims to be classified as smart. This study strives to identify and synthesize essential information, helping managers to define and develop projects and initiatives within the context of smart cities. Through a literature review, six widely cited and commonly used groups of indicators are selected, and the most frequent themes, indicators, and keywords are identified. The results are the essential elements founded and synthesized in a single visual scheme. Although this study has a practical purpose, it is also necessary to promote new policies focused on incentives for local initiatives to support and complement them due to the new decentralized and anthropocentric approach to smart sustainable cities.

Keywords: smart sustainable cities; indicators; strategy; planning



Citation: Schiavo, F.T.; Magalhães, C.F.d. Smart Sustainable Cities: The Essentials for Managers' and Leaders' Initiatives within the Complex Context of Differing Definitions and Assessments. *Smart Cities* **2022**, *5*, 994–1024. <https://doi.org/10.3390/smartcities5030050>

Academic Editors:
Véronique Flambard,
Sadia Benamrouz-Vanneste
and Abir Karami

Received: 11 July 2022

Accepted: 11 August 2022

Published: 17 August 2022

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1. Introduction

The world's population is growing rapidly and becoming concentrated in urban areas (Figure 1). By 2050, more than two-thirds of humanity may live in urban areas [1–3]. Nations are dealing with both rapid digital transformation and severe environmental impacts. How to adapt life on the planet in the face of these challenges has been broadly discussed.

In this context, the reflections on the development of cities, however, are not recent and have been on global agendas for some decades, anchored in world debates and forums. Consequently, international reports guiding worldwide policies and actions in different nations have been produced (Figure 2).

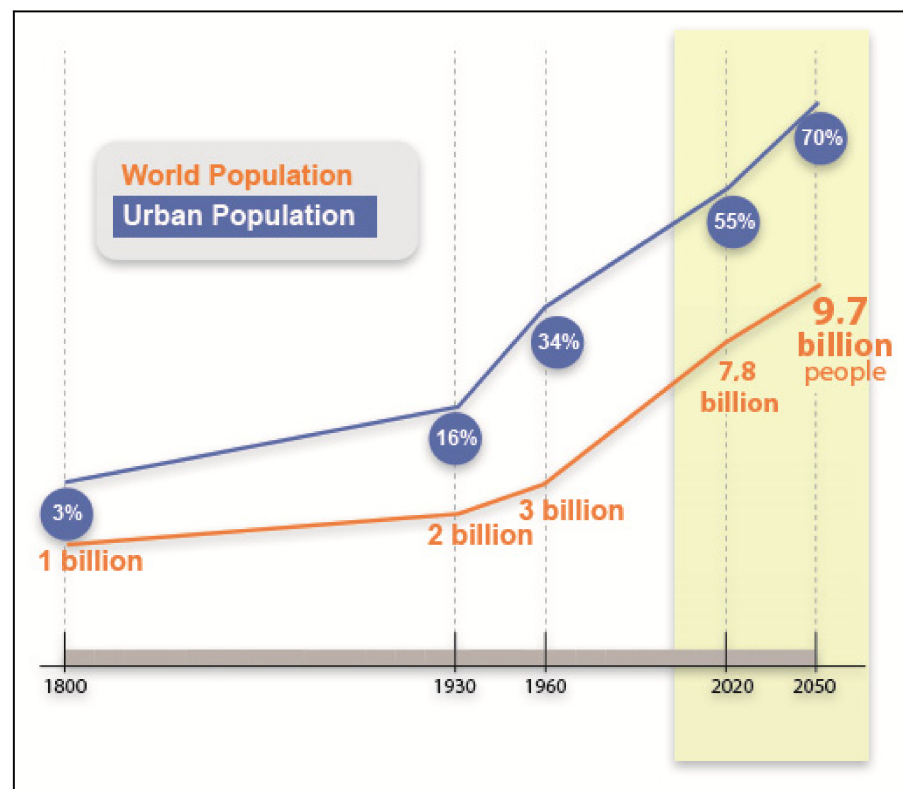


Figure 1. World population (past–present–future projections) Source: [4]. Adapted by the author.

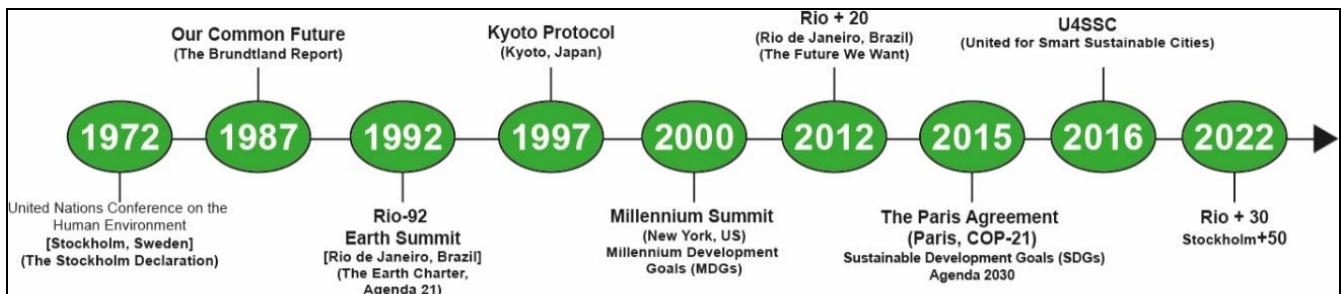


Figure 2. World summits and documents concerning the future we desire. Elaborated by the author, based on [5].

One example is the Brundtland Report, entitled “Our Common Future” [6]. It was published in 1987 by the United Nations (UN) through the World Commission on Environment and Development, chaired by Gro Harlem Brundtland. The report assumed a critical view on the development model adopted by the industrialized nations and reproduced by developing countries. It emphasized that economic and social progress cannot be based on indiscriminate exploration and nature degradation. Likewise, it indicated that poverty in the global southern countries and extreme consumerism in the countries of the north would be the fundamental causes of the unsustainability of development and the environmental crises. Although the report did not present any easy guidelines toward action, it revealed an idea force that established an agreement between generations, being used as the consensus definition of sustainable development, that is, “development that meets the needs of the present without compromising the ability of future generations to meet their own needs [6]”.

During the Earth Summit held in Rio de Janeiro in 1992 and led by the United Nations Conference on Environment and Development, also known as Rio-92, the leaders of 179 countries agreed upon and signed the Global Agenda 21. This was an action program

based on one document of 40 chapters, which, until that moment, could be considered the most embracing attempt to promote a new pattern of development on a planetary scale. “Agenda 21” was a term used in the sense of the desired development model for the 21st century. It could be defined as a planning tool for building sustainable societies in different geographical localities and reconciling methods of environment protection, social justice, and economic efficiency.

In 2000, during the Millennium Summit promoted by the UN in New York, the leaders of 191 countries signed a pact aiming for a peaceful, just, and sustainable future until 2015 and defined the Millennium Development Goals (MDGs). The agenda included eight MDGs, detailed in 18 targets and 48 indicators.

The current Sustainable Development Goals (SDGs) have succeeded and updated the MDG. SDGs’ construction began in 2012 after the Rio + 20 Conference. The process was completed in 2015 during the United Nations Summit for Sustainable Development when 193 UN members agreed on the proposed agenda entitled “Transforming Our World: The 2030 Agenda for Sustainable Development”. Known also as Agenda 2030, it consists of 17 SDGs, 169 targets, a section concerning the means of implementation, a renewed partnership world, and a mechanism for evaluation and follow-up [7,8].

The 17 SDGs must guide policies and activities for international cooperation until 2030 and are a global call to action to end poverty, protect the planet, and ensure that by 2030, all people enjoy peace and prosperity. SDG 11 aims to make cities and communities more inclusive, safe, resilient, and sustainable.

To support the implementation of the Agenda 2030 and to help the achievement of the SDGs, especially SDG 11, the UN launched the United for Smart Sustainable Cities initiative (U4SSC) in 2016. It is coordinated by the International Telecommunication Union (ITU), United Nations Economic Commission for Europe UNECE, and UN-Habitat. It is a global platform for the advocacy of public policy and encourages the use of information and communication technologies (ICT) to facilitate and ease the transition to smart sustainable cities [9].

As can be seen, plans for better futures are not new: the intentions and designs of desirable cities have been objects of debate for decades on a global scale. Table 1 synthesizes some of these plans, from the Brundtland Report to the initiative for smart cities.

Table 1. Initiatives and documents that make evident the desire for and design of better futures. Elaborated by the author, based on [5–9].

Document/Initiative	Description
Our Common Future (Brundtland Report)	It was introduced in 1987, providing a view of sustainable development.
Agenda 21	A document with 40 chapters elaborated during the Earth Summit (1992) to guide the planning of sustainable societies.
Kyoto Protocol	In 1997, during the United Nations Climate Change Conference in Kyoto, this international protocol was signed, aiming to reduce 5% of greenhouse gas (GHG) emissions.
8 Millennium Goals—MDG	In 2000, during the Millennium Summit, promoted by the United Nations in New York, leaders from 191 countries signed a pact aiming at a peaceful, just, and sustainable world until 2015.
Paris Agreement	In 2015 during the COP-21 in Paris, 195 countries signed this agreement to reduce the consequences of global warming.
17 Sustainable Development Goals—SDGs (Agenda 2030)	The process was initiated after the Rio + 20 Conference (2012) and completed in 2015 at the United Nations Summit for Sustainable Development in New York. SDGs shall guide national policies, activities, and international cooperatives after the ODM until 2030.
United for Smart Sustainable Cities (U4SSC)	A UN initiative created in 2016, coordinated by ITU, UNECE, and UN-Habitat and supported by 14 other UN bodies. It provides an international platform for information exchange and partnership building to guide cities and communities in achieving the UN SDG, especially goal 11.

Among these discussions, what is unprecedented is the rapid technological advance combined with digital transformations, the high amount of data and information generated, and the environmental concern at a global level. Additionally, these are frequent themes when talking about smart cities, a concept that has been developed in relation to both the increase in urbanization rates and to the growing use of ICT. In recent years especially, there has been a significant increase in the interest in smart cities (Figure 3) [10–12]. However, what are smart cities and how are they being planned for the future of the population?

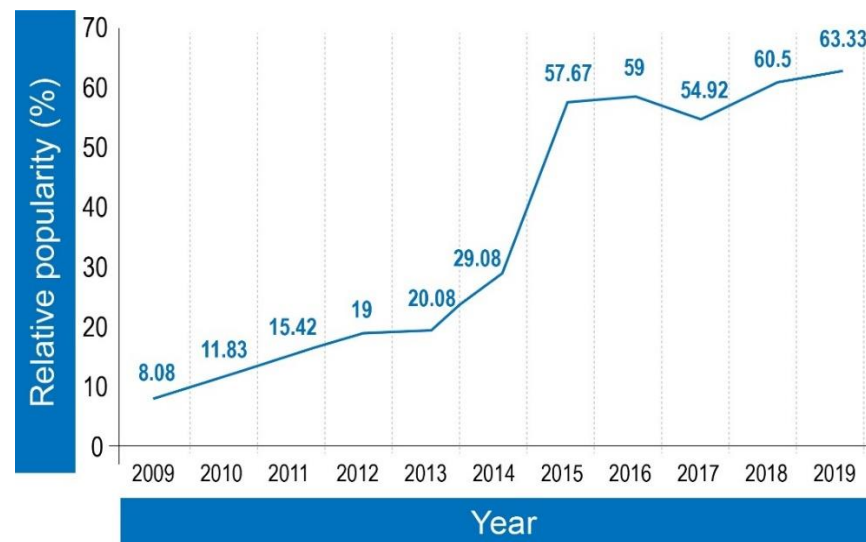


Figure 3. Volume of publications on smart cities (2009–2019). Source: [10]. Adapted by the author.

Based on this question and given the diversity of information currently available, this research focuses on identifying and presenting in a simple and synthetic manner the essential attributes that must be included in the projects and initiatives of a smart city to facilitate the action of entrepreneurs and government officials. The goal of this study is to contribute scientifically, bring new knowledge to the identified gaps, and enable collaboration with managers, who may have more clarity regarding what to take into account when planning initiatives aimed at smart cities.

The document is organized into six sections. The introduction presents the problematization, culminating in the research question. The Section 2 presents the literature review and previous studies. The Section 3 describes the methodology used. In the Section 4, the results obtained from the research carried out are presented. The Section 5 discusses the results, and the sixth contains the conclusion and recommendations.

2. Literature Review and Previous Studies

Some authors claim that the concept of smart city, together with the first academic publications on the subject, emerged in the 1990s [13,14]. In line with the process of searching for better places to live, Cocchia [14] attributed the development of this concept to the signing of the Kyoto Protocol in 1997, which motivated cities to seek “smart projects” to fulfill the signed agreements. These projects explored ways in which new information and communication technologies (ICT) could contribute to sustainable development [15,16].

Until 2008, the literature focused more on the conceptual aspects of smart cities, and “digital cities” and “information cities” were the most frequently mentioned terms. The term “smart city” appeared in the late 1990s [17] but became relevant in terms of the number of publications from 2010 onwards. Until then, the focus was on technological aspects. From 2012 onwards, the studies began to adopt a more holistic view, expanding the aspects addressed, especially those related to people in cities [18]. This differentiation of aspects, moving from a technocentric view to a more holistic perspective, can also be observed depending on the origin of the publication: North American publications tend

to have technology as a basis, and European publications utilize a broader perspective encompassing different dimensions, such as human, ecological, technological, and governance aspects [13]. Currently, there are two mainstream approaches to this concept: the technology and ICT-oriented approach and the people-oriented approach [19,20]. More recently, it has been argued that cities cannot be truly smart without being sustainable [21].

Regarding the classification of the city in terms of its smartness, the terminology has been evolving since the beginning of the 1990s, along with some other categories of cities that essentially have coincident missions and purposes, such as virtual cities, web cities, cities of knowledge, broadband cities, digital cities, mobile or wireless cities, green or ecological cities, sustainable cities, cities for people, and alive cities [11,22].

Regarding the concept of smart cities, although the term has gained prominence in recent years, there is still no single, widely adopted definition [12,18,19,23–33]. The use of the term shows some confusion regarding its meaning and application, which is evident when comparing definitions and practical implementations [2,34].

In recent years, the definition suggested by Giffinger [35], which focuses on the European model of smart cities, and the one adopted by the U4SSC, have been recurrently used. The first is recurrent in academic publications and proposes that a smart city must perform well in six dimensions (governance, economy, people, life, environment, and mobility) and is built from the “smart” combination of talents and activities of self-determined, independent, and conscious citizens [35]. The second, present in documents of global guidelines focused on practice and regulation [36,37], understands that “a smart sustainable city is an innovative city that uses ICTs and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects” [38].

Complementarily, in an analysis of 84 definitions of smart cities [18,21,23,39], and regardless of the breadth and diversity of concepts, some words remain recurrent: quality of life, services, citizens, and ICT.

The coexistence of more than one definition and the fact that the concept is still diffuse [40] are probably influenced by the difficulty of tracing a pattern that fits all cities. Needs, political structures, histories, socioeconomic profiles, habits, and cultures shape cities, making them unique and different from one another [23,41]. However, even in the face of the lack of consensus regarding a definition for the term, one objective remains common: to improve the quality of urban life [2,42].

In general, it can be perceived that, until recently, the concept of smart cities was closely linked to technologies. Ideas and themes related to ICT and the Internet of Things (IoT) were very present as mediators of the planning, development, implementation, and evaluation of urban transformation processes. Currently, the concept remains linked to technologies, which should aim to raise the quality of life so that it represents the primary component (Figure 4) [43]. In other words, in smart cities, only those technologies that improve human well-being are considered relevant.

In recent years, however, the discussion about smart cities has moved beyond their being techno-centric or life-centric. It has been argued that technology is not enough if the citizen cannot use it or perceive its applicability [44]. There is no point in making significant investments in technology if the citizen is unwilling to adopt it. This discussion corroborates a more current view of smart cities, which is no longer driven by a largely techno-economic approach but has shifted towards a decentralized, anthropocentric approach focusing on ways by which to foster collaboration and community involvement [24,45].

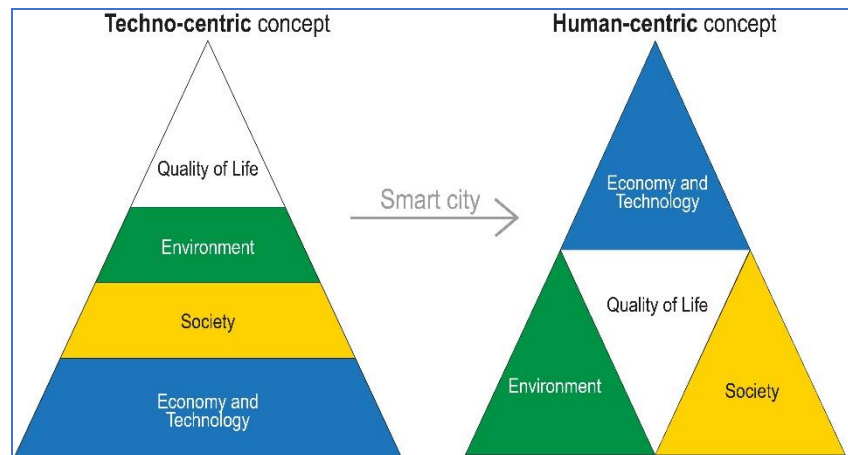


Figure 4. The concept of the smart city from the traditional techno-centric conception to a human-centric conception. Source: [9]. Adjusted by the author.

Likewise, the concern with the scarcity of natural and productive resources, energy resources, and urban density provokes stimuli to processes of change so that the emergence of intelligent and engaged cities, governments, and citizens is possible. Concern about environmental and climate issues, in particular, has been growing in recent years. Companies, governments, and individuals have adopted more conscious attitudes in their activities. Additionally, a better understanding of the role of technology in smart cities allows it to enable social, environmental, economic, and cultural progress [18,46]. From this point of view, sustainability and improving the quality of life are the main objectives of smart cities, more so than the technology itself [16,47–50]. Thus, sustainable cities may be understood as integrating socio-cultural, economic, and environmental aspects and could function as an umbrella, where other concepts, such as the smart city, are located below it. The primary goal of these would be to improve the sustainability of cities through the application of ICT, the collaboration of key stakeholders, and the integration of different themes [2].

It is understood, therefore, that the use of technologies, the concern with sustainable development, and the search for quality of life are recurring factors in the different concepts. Thus, within the scope of this research, a smart city is not considered a final destination, but an approach, or culture, that uses available technologies as a tool that may improve the quality of life in cities in a socially, environmentally, and economically sustainable manner (Figure 5).

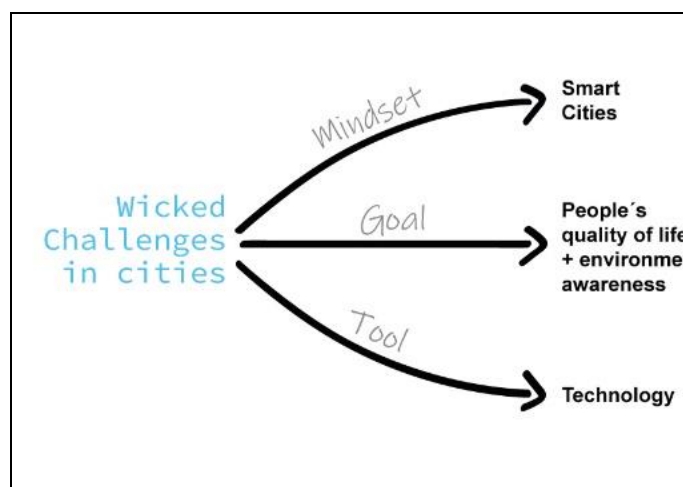


Figure 5. The essential of the smart city’s concept.

Although the discussions are comprehensive and cover the primary objectives for cities—including the unprecedented presence of the use of ICT, the digital transformation that the world is experiencing, the amount of data produced, and the growing environmental awareness—it is not clear in the literature how to classify whether or not a city is a smart city. Although it is clear that cities have their own characteristics, those that call themselves smart cities lack universality or standardization [23]. Even though many studies have focused on smart cities, knowledge about the criteria that can be used to define a city as smart or to measure its degree of smartness remains limited [10].

According to the literature review focused on the assessment of smart cities, the benefits of such assessments can be of use to authorities, investors, funding agencies, researchers, and citizens and can include the following: performance monitoring; investment attraction; the identification of strengths and weaknesses; a better understanding of socio-environmental and technical implications of projects; benchmarking analysis for learning; stimulating discussions; the prioritization of funding allocation; the identification of new business opportunities; the development of studies to increase performance; the simplification of the complexity of the concept; public awareness of the benefits; the development of skills to make decisions about future investments; and the promotion of citizen engagement [2,35,51–59]. However, it is unclear which attributes should be considered and prioritized to structure a smart city project.

Previous studies about models or frameworks to help plan projects for smart cities are mostly restricted to a specific theme or territory. Mobility [60–63], data [64–68], urban planning [69–72], energy [73–75], security [76–79] and economics, partnerships and innovation [80,81] are examples of prevalent themes in articles about smart city's projects. A significant number of studies combine a theme and a specific region [82–93].

Some articles do not correlate smart city projects to a specific theme, instead keeping a broader vision, but the goal is to evaluate, scale or replicate projects and not to support a decision to start a new project [94–99]. Hearshana, R. [100] points out how the conditions of governmental organizations may influence technology enactment in smart city projects, but the focus is on the adopter and not on the project's planning. Holzmann, V. [101] focuses on future managers that will plan a project for the city and not on the project's aspects.

Attaran [29] corroborates with the necessity of having a more general and integrated smart city model, comprehensively for a variety of purposes and applications. The proposed diagram connects the different themes, identifies the existing relationships, and is closely related to this study; however, it is based on the six dimensions of smart cities proposed by Giffinger [35], which focuses on the European model of smart cities, and sustainable development aspects of the city as a whole are under-represented. As a methodology, the authors analyze each of the six dimensions and then propose a model based on the conclusions. The study from Angelakoglou et al. [102] has the energy transition as a core focus. However, despite the specific theme, they provide a broad view of key performance indicators (KPI) related to smart cities that may contribute to the present study. Furthermore, different assessments were analyzed through an iterative approach that required the active involvement of various stakeholders. Therefore, the results are relevant to this study to promote comparability.

According to the review, there is a lack of knowledge regarding the starting point for planning a new smart city project. It is related to helping managers have a holistic view of the territory and perform suitable decisions on where to begin to face real-world problems, of a specific city, within the available resources.

Although the literature gap concerning how to design and implement strategies for smart city development represents an important line of investigation [31] in which researchers are investing significant efforts [56,103–110], the studies developed have not been able to fill the gap between theory and practice. Therefore, this study is focused on this line and has a practical purpose. It aims to identify and synthesize essential elements that should be considered to help prioritize and plan a smart city project. The result should be comprehensive for managers and entrepreneurs to act locally and maintain a global understanding of the city.

3. Methodology

The research began from the initial question, “what are smart cities and how are they being planned for the future of the population?” Based on a literature review regarding the definition of smart cities, it was concluded that there is no single and official definition for smart cities and that there is a diversity of information available. According to previous studies, a gap between theory and practice has not yet been fulfilled. This situation has led to confusion regarding the practical application of the concept in projects aimed at smart cities because there is a gap concerning the essential elements required to design a project for smart cities. The results of this step are presented in the literature review section of this article. Based on these findings, the current research question was elaborated as follows: given the diversity of the available information, what is essential when elaborating a smart city project? Our goal was to identify and present in a simple and synthetic way the essential elements that must be considered for the elaboration of projects and initiatives of smart cities, facilitating the action of entrepreneurs and governments. This study seeks to contribute scientifically, bringing new knowledge to the identified gaps, and to enable collaboration with managers, who may have more clarity on what to take into account when planning initiatives aimed at smart cities.

The definition of which groups of indicators would be analyzed was based on reviews of smart city indicators found in academic articles available from the Web of Science and Scopus databases [2,16,52,111–114]. This analysis included studies without thematic restrictions and those that were carried out from 2015 onwards.

According to the review of the literature, rankings and assessment studies of smart cities provide information on the characteristics of cities that make it possible to classify their smartness level. Moreover, the attributes present in them provide, in a practical way, guidelines for classifying a city as smart or not, as well as for indicating the resources they have or should have and, thus, contribute to medium- and long-term planning [111].

Huovila [115] carried out a comparative analysis of more than 400 indicators used in international documents to assess smart cities, and they identified a lack of balance between the different indicators, especially those related to sustainability and “smartness” [2]. This result may have implications for practical implementation and the reliability of comparisons between cities. It also highlights that the sets of indicators must be combined with the needs and objectives of the cities, thereby avoiding a poor evaluation of the city’s development in cases where there is no alignment with the strategies devised by the managers.

An analysis of 16 indicators aiming to identify the similarities and differences of smart and sustainable cities [16] found that, although environmental sustainability is considered an essential aspect of smart cities, environmental indicators are under-represented. The author suggests that the use of indicators should not be limited to measuring the efficiency of smart solutions but should also include their impact and contribution towards the ultimate goals such as environmental, economic, or social sustainability.

An analysis of 34 sets of indicators [113] identified an imbalance in the distribution of indicators, a lack of attention paid to local contexts, and measures of engagement with key stakeholders, and that only a quarter of these tools link results to action plans. Subsequently, having found few analyses regarding the typology and structure of the evaluation schemes [114], 34 sets of indicators were analyzed again in order to provide better information to the end user for the evaluation process.

Based on this review, the selected sets of indicators for this research had the following criteria: rankings with evaluations of more than 100 cities from different countries and cultures; global standards applicable to any city, regardless of size and origin; academic publications containing indicators with high reach and recurring application; and material whose data are open for consultation. These criteria take into account the fact that there is no standardization of a single concept and the importance of considering the particularities of each city.

This research, therefore, covered the following six groups of indicators:

- The smart cities scheme proposed by Giffinger [35], composed of 6 themes and 34 indicators.
- The Cities in Motion Index (IESE) [116], composed of 9 themes and 101 indicators.
- The Connected Smart Cities ranking (Urban Systems) [117], composed of 11 themes and 75 indicators.
- ISO 37122 (International Organization for Standardization—ISO) [118], composed of 19 themes and 80 indicators.
- The Smart and Sustainable Cities Maturity Model (ITU) [119], with 3 dimensions, 19 themes, and 103 indicators.
- The Bright Cities ranking [120], composed of 10 themes.

The following step consisted of analyzing the selected groups, with the following as the units of research:

- Identification and selection of the most frequent themes in the field of smart cities.
- Identification and selection of indicators related to each of the selected themes.

A comparative analysis of the themes was carried out to identify the similarities and frequencies. The most frequently recurring themes were selected as essential.

The analysis for the selection of indicators was focused on those present in the selected themes. After processing the data, especially those concerning synonyms and the identification of key terms, the frequencies at which the words appeared in the themes were evaluated. Additionally, a word cloud was generated with the terms.

As a result, the essential information in the groups of indicators was identified.

The final step consisted of aggregating the results so as to present the essential information regarding the construction of projects aimed at smart cities.

Figure 6 contains a flowchart of the macro-steps of this study.

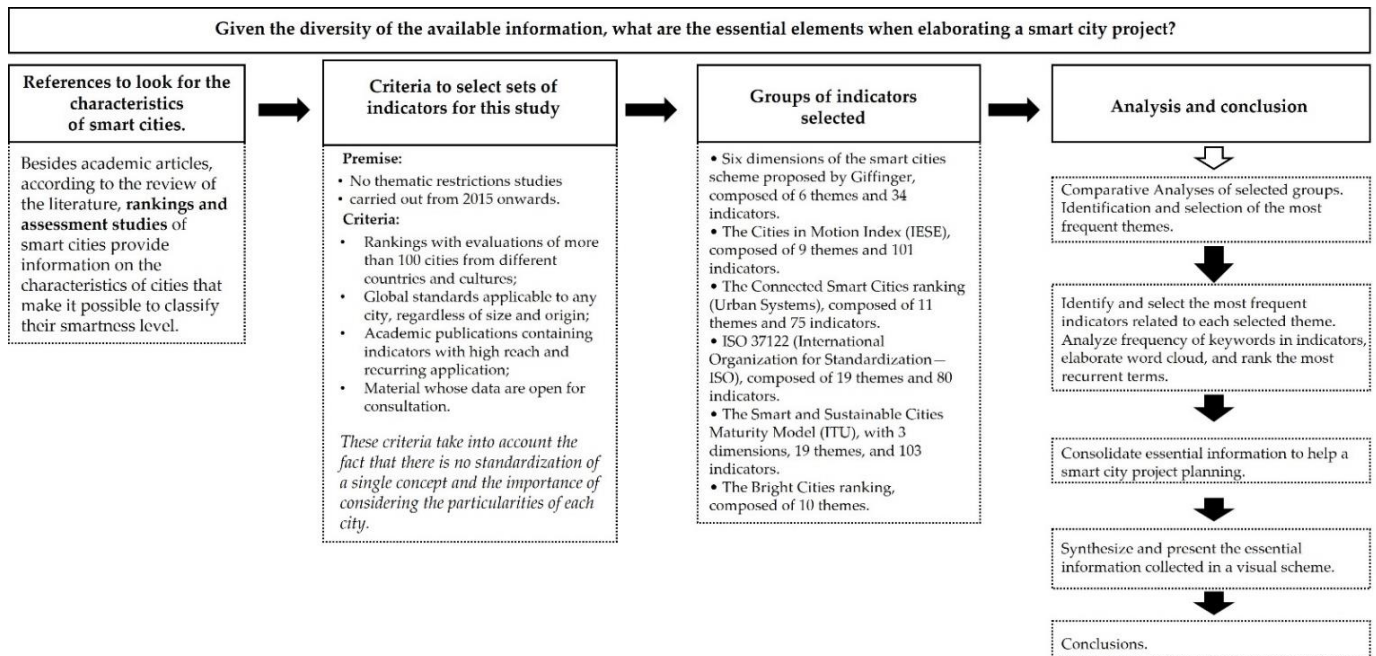


Figure 6. Study flowchart.

4. Results

4.1. Groups of Indicators Analyzed

Giffinger [35] mapped the six characteristics that he considered the most relevant and necessary to be present in cities for them to be considered smart (i.e., economy, people, governance, mobility, environment, and life) and also identified indicators for each of them. This model (Figure 7) was designed with medium and large European cities as parameters.

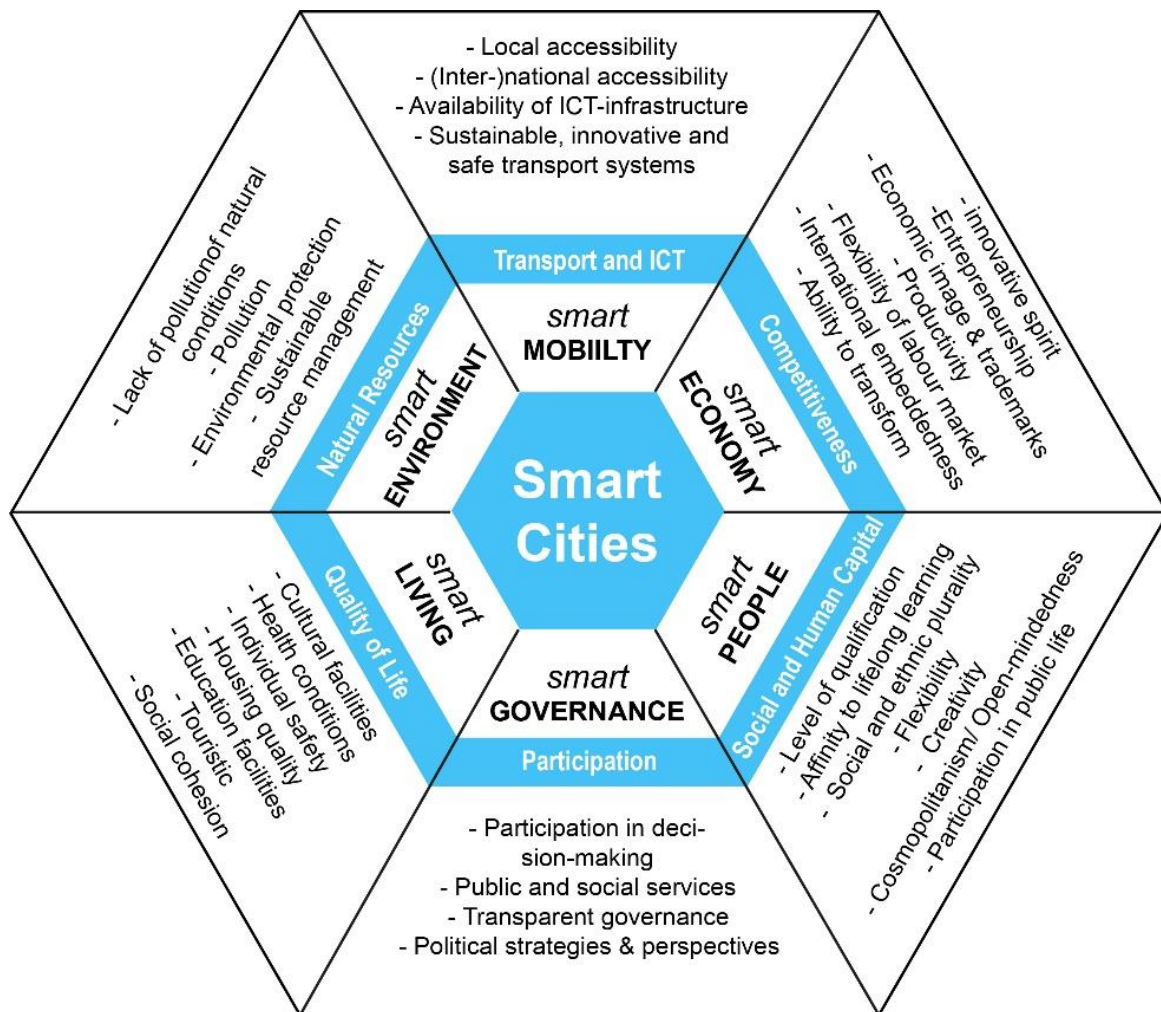


Figure 7. Smart cities' dimensions and indicators according to Giffinger. Source: [35]. Adapted by the author.

The IESE Business School of the University of Navarra has published the IESE Cities in Motion ranking since 2014 [116]. This ranking is present in practically all of the reviews consulted, and it compares cities of different origins (Figure 8).

These models would make sense if the solutions generated effectively provide a harmonious and balanced composition among all their dimensions and attributes. However, it is challenging to plan solutions that fit into just one of the themes. For example, the pandemic caused by COVID-19 had a high impact on governance, the economy, and people's lives, in addition to causing changes in other aspects: the failure of public safety management, which involves both lighting infrastructure and street policing, negatively impacts the image of a place, reducing the flow of tourists and resulting in economic losses and financial losses for the three sectors of society; the lack of basic sanitation and the deficiency in the management of residues imply an increase in expenses for the management of the consequences in public health; and the population's level of schooling is directly related to the fertility rate, indicating that there is a link between low education and an increase in childhood and adolescence pregnancies and all the related complications, including those referring to the increase in poverty levels. In other words, a holistic and systemic view is needed for these variables and for the solutions derived accordingly, which, thus, must be planned in an integrated manner.

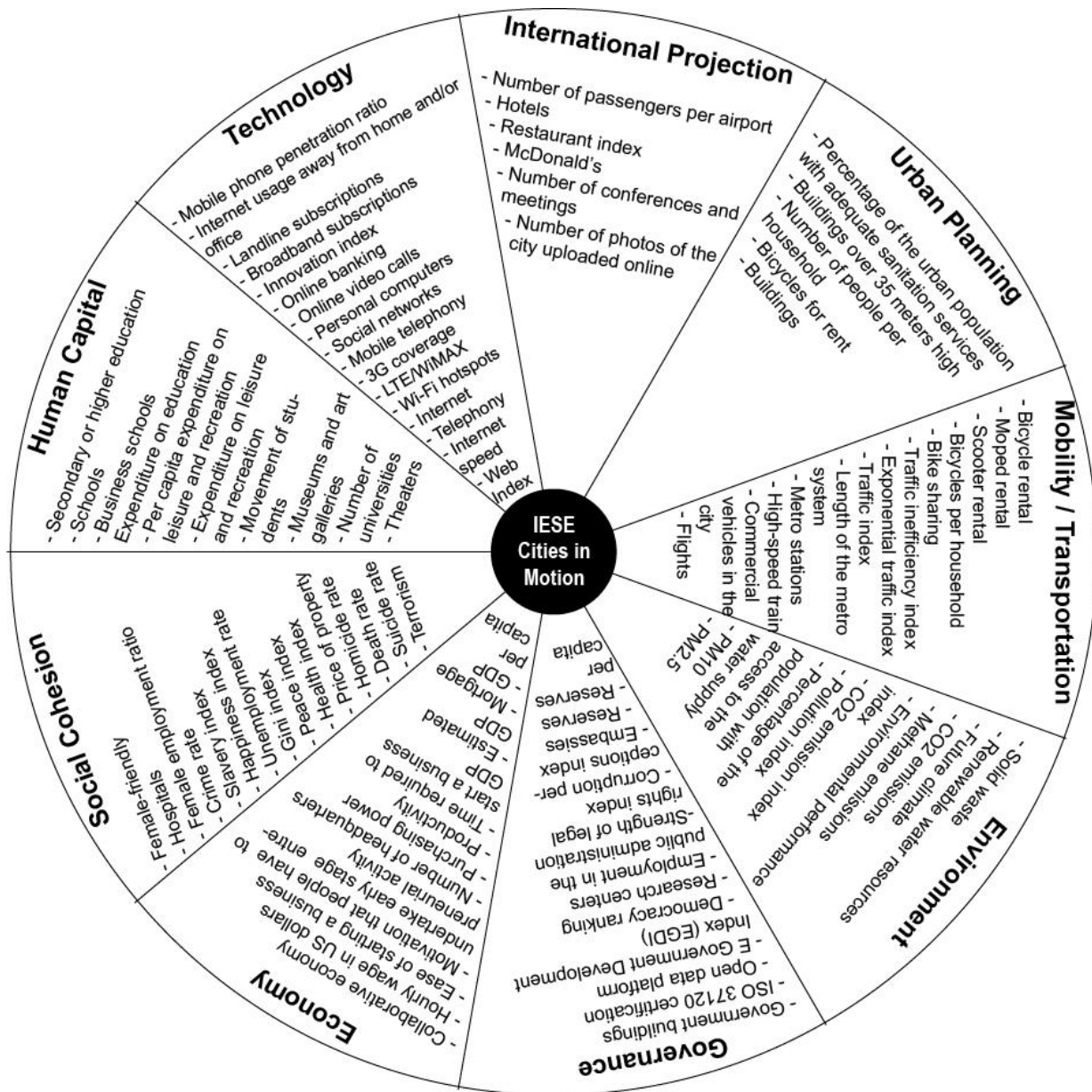


Figure 8. Cities in Motion ranking by IESE. Source: [116]. Adapted by the author.

The Connected Smart Cities ranking [117] has already analyzed more than 800 Brazilian cities with more than 50,000 inhabitants since 2015. To identify themes and indicators, this ranking takes into account, among other studies, the IESE Cities in Motion [116]; Innovation Cities, Innovation Cities Program [121]; ARCADIS Sustainable Cities Index [122]; the World Council on City Data [123]; ISO 37120—sustainable development of communities—indicators for city services and quality of life; ISO 37122—sustainable cities and communities—indicators for smart cities; and ISO 37123—sustainable cities and communities—indicators for resilient cities [118]. This ranking allocates variables in more than one theme, indicating their connections and allowing an integrated reading. Figure 9 shows how many indicators of each thematic axis influence others. The greater the external influence, the greater the size. Mobility, for example, has eleven indicators: it is influenced by a safety indicator, and it has seven of its own that exert external influence. Among the safety indicators, three are specific and influence other topics, and one is the result of the influence of the environment theme. Governance, in turn, appears as a theme resulting from other indicators since 60% of its indicators are originally from other areas. It has twelve

indicators in total; it is influenced by seven indicators from other themes and influences only the technology and innovation themes. This possibility of reading, considering the influences, facilitates the identification of driving themes and prioritizing actions. However, it does not provide guidelines for action.

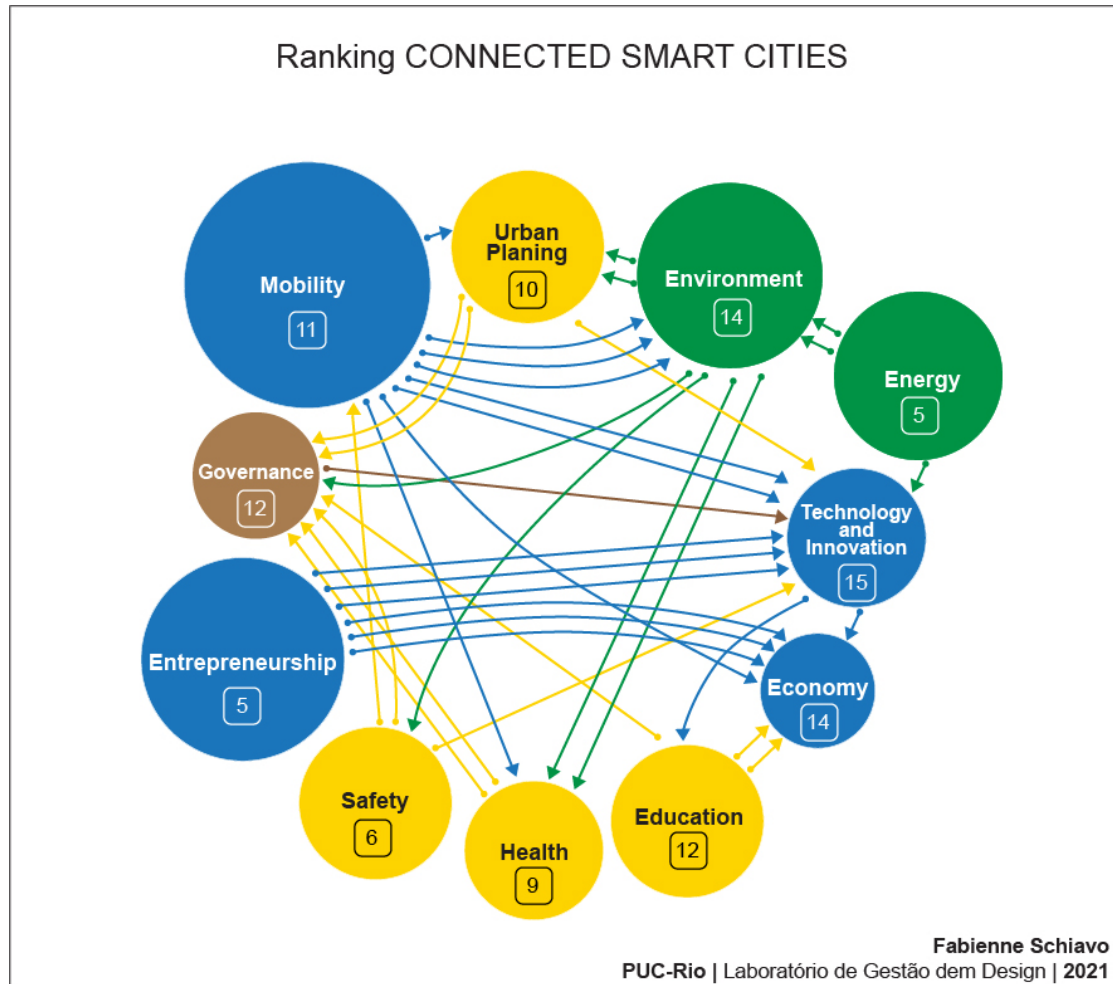


Figure 9. Themes and influences within the Connected Smart Cities ranking. Source: Connected Smart Cities Report [117]. Influence chart created by the author.

The ISO 37122 (Indicators for Smart Cities) is an international standard that considers sustainability as a general principle and the “smart city” as a guiding concept in the development of cities. When used with ISO 37120 (Indicators for Urban Services and Quality of Life), this standard helps cities identify indicators for the application of management systems and for the implementation of smart city policies, programs, and projects. Allowing an integrated vision with the issues that the indicators reflect, the sustainability purposes that they contribute enable and facilitate the planning of initiatives aligned with the city’s strategic goals (Figure 10).

The smart sustainable cities maturity model created by the International Telecommunications Union (ITU) organizes the indicators according to the following dimensions of sustainability: economic, social, and environmental (Figure 11). However, it does not allow the reading of inter-relationships.

In addition to these, there is also the “Bright Cities” set of indicators. However, only the themes were considered in the analysis as the indicators’ data are not available for consultation.

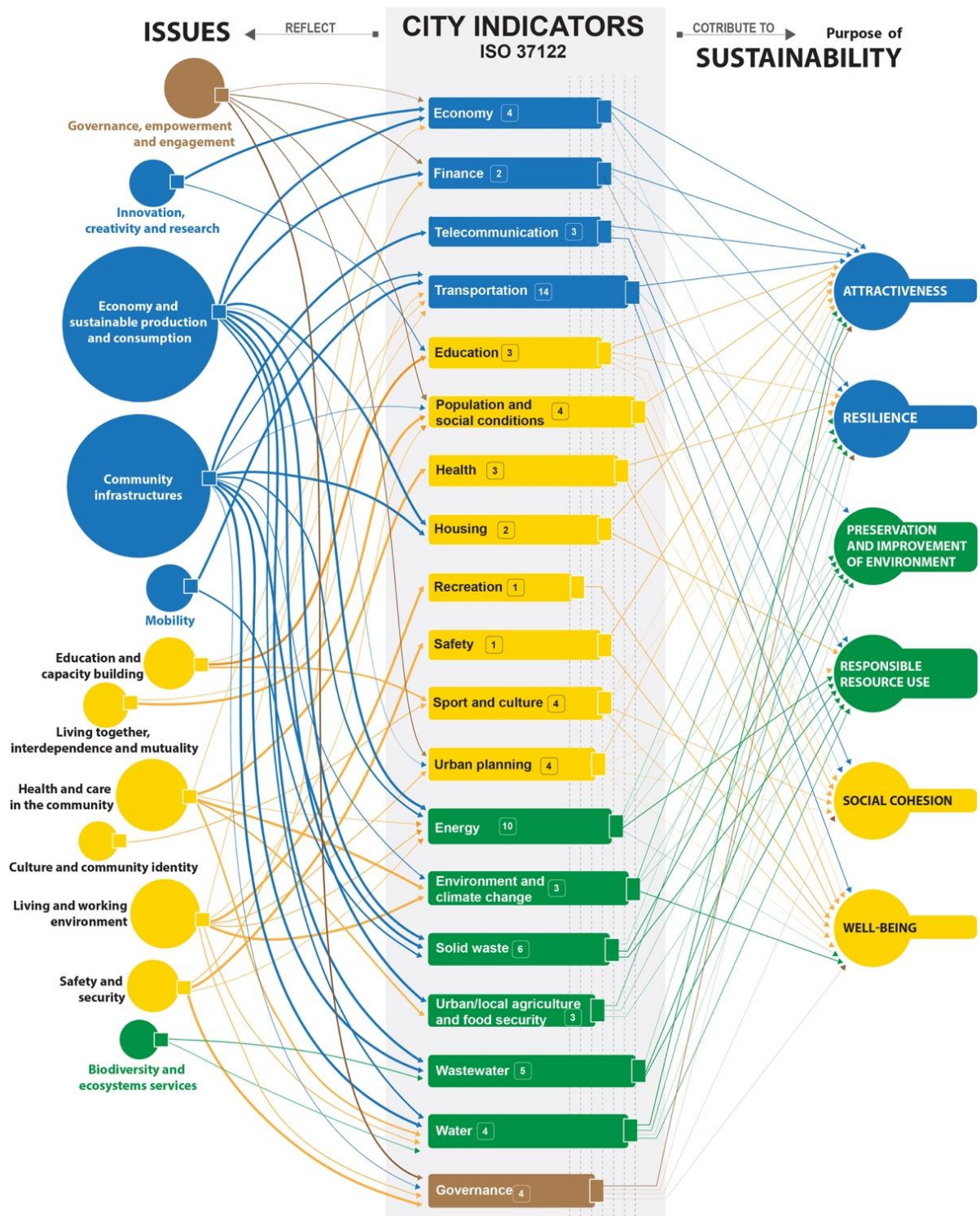


Figure 10. Themes, influences, and contribution to sustainability within ISO 37122. Source: [118]. Influence chart created by the author.

It could be clearly perceived that, from the perspective of reading and analysis, there are three types of sets of indicators: those that are simply presented without correlations or categorization; those that classify the indicators in macro dimensions (ITU); and those that indicate inter-relationships (Connected Smart Cities and ISO 37122).

Table 2 resumes the individual analyses presented in this article.

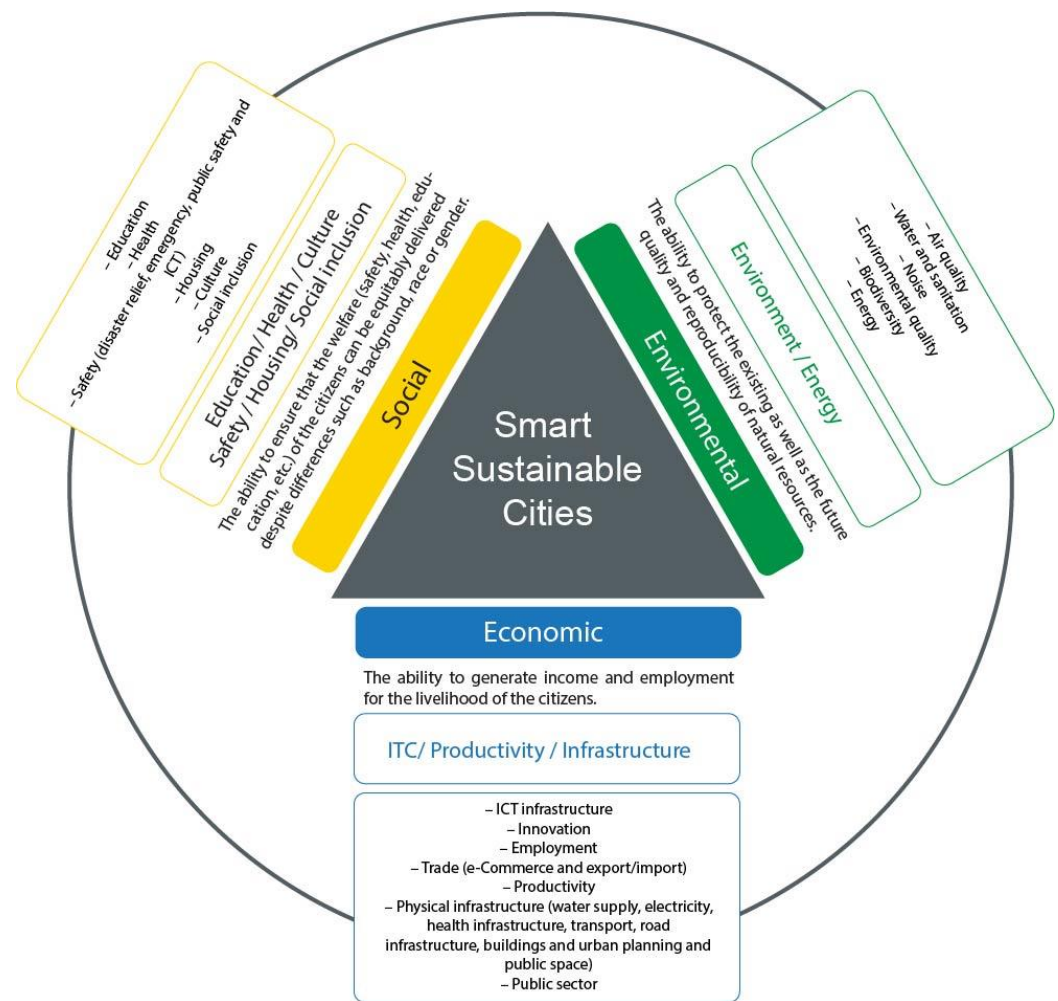


Figure 11. The tree dimensions of the smart sustainable cities maturity model and its categories. Source: [119,124]. Adapted by the author.

Table 2. Groups of indicators analyzed.

Groups of Indicators	Themes/Indicators	Analysis (Pros and Cons)	Types of Groups of Indicators (from the Perspective of Reading and Analysis)
The six dimensions of smart cities (Giffinger)	6/34	<ul style="list-style-type: none"> • The six dimensions proposed by Giffinger are most frequent in academic studies. • This model was designed with medium and large European cities as parameters. Thus, indicators may not be entirely adequate for cities from the global south. • There is no connection among themes. 	Indicators without correlations or categorization
The Cities in Motion Index (IESE)	9/101	<ul style="list-style-type: none"> • This ranking is recurrent in academic articles and compares cities of different origins. In addition, it has been published since 2014, enabling historical analysis. • There is no connection among themes. 	Indicators without correlations or categorization

Table 2. Cont.

Groups of Indicators	Themes/Indicators	Analysis (Pros and Cons)	Types of Groups of Indicators (from the Perspective of Reading and Analysis)
The Connected Smart Cities ranking (Urban Systems)	11/75	<ul style="list-style-type: none"> This ranking has already analyzed more than 800 cities with more than 50,000 inhabitants in Latin America (LA). Nonetheless, indicators may not be entirely suitable for cities outside LA. It has been published since 2015, enabling historical analysis. It has used relevant studies in its composition. It allocates variables in more than one theme, indicating their connections and allowing an integrated reading. 	Present indicators and indicate inter-relationships
ISO 37122 (International Organization for Standardization—ISO)	19/80	<ul style="list-style-type: none"> It is an international standard from a well-established organization. It allows an integrated vision with sustainability purposes. It is complex, and its adoption may require specialists. 	Present indicators and indicate inter-relationships
The Smart and Sustainable Cities Maturity Model (ITU)	19/103	<ul style="list-style-type: none"> It is an international model from a well-established organization. The model organizes the indicators according to the sustainability dimensions. It does not allow the reading of inter-relationships. 	Classify the indicators into the sustainability dimensions

4.2. Comparative Analyses

The first comparative analysis was based on the themes addressed. The results indicate that there is no unity among the different groups, corroborating the findings of A. Huovila [115] and C. Patrao [2].

The consolidation of the themes (Table 3) indicates that, generally, the recurring themes within the scope of smart cities are education, health, safety, environment, economy, governance, mobility, and technology and innovation.

Education, health, safety, and the environment are topics considered by all. Governance, mobility, economy, and technology and innovation are also recurring themes and are considered in five of the six analyzed references.

In another group, there were themes considered in four of the six references: urban planning, entrepreneurship, energy, solid waste, housing, and culture. Here, it is essential to emphasize that entrepreneurship is considered a theme by some, while by others it is incorporated into economy. The same happens with solid waste, which can be found within the theme of the environment and also within the theme of culture, sometimes inserted into education.

Subsequently, there are the following themes present in two of the six references that are considered to be of low relevance: water, sewage, and population. Although not frequent as a thematic axis of their own, water and sewage are indicators commonly included in the evaluation and can be found within the environment axis.

Finally, the following topics occasionally appear: international projection, finance, telecommunications, infrastructure, and recreation. The latter, however, also appears as an indicator of the economy theme.

Table 3. Comparison of themes within the six groups of indicators analyzed.

	Connected Smart Cities	IESE	Bright Cities	ISO 37122	Maturity Model (ITU)	Giffinger	Frequency %
Education	X	X (human capital)	X	X	X	X (life)	100%
Health	X	X (social cohesion)	X	X	X	X (life)	100%
Infrastructure					X		17%
Mobility urban/transport	X	X	X	X		X	83%
Environment	X	X	X	X	X	X	100%
Urbanism/urban planning	X	X	X	X			67%
Safety	X	X (social cohesion)	X	X	X	X (life)	100%
Technology and innovation/ICT	X	X	X		X	x (econ.)	83%
Economy	X	X		X	X (dim.)	X	83%
Entrepreneurship	X		X			x (econ.)	50%
Governance	X	X	X	X		X	83%
Energy	X		X	X	X		67%
International projection		X					17%
Finance				X			17%
Telecommunication				X			17%
Waste solids	X (env.)	X (env.)		X			50%
Water	X (env.)			X			33%
Sewage	X (env.)			X			33%
Housing				X	X	X (life)	50%
Population/social conditions				X		X	33%
Recreation				X			17%
Culture/sport				X	X	X (life)	50%
Productivity					X		17%
Social inclusion					X	X (pop.)	33%
Life						X	17%

Table 4 consolidates the frequent themes, organizing them according to the dimensions of sustainability. In this case, the governance theme becomes transversal to the three dimensions.

Table 4. Most frequent themes within the six groups, organized by sustainability dimensions.

	Sociocultural Dimension	Environmental Dimension	Economic Dimension
More recurrent themes	Education Health Safety	Environment	Economy Mobility Technology and innovation
	Governance (Transverse Dimension)		

From the eight most recurrent themes, the indicators related to each were gathered to identify the common parameters. The research considered five groups of indicators—two rankings with a history of five years or more—and open data from the following: Connected Smart Cities and Cities in Motion, the smart sustainable cities maturity model (ITU), the six dimensions of Giffinger, and ISO 37122.

Within the education theme, the most frequent indicators were public, school, education, and culture.

The recurrent indicators for education, that is, those that appeared in at least 30% of the citations, were the following: public, school, education, culture, student, online, and management (Figure 12).

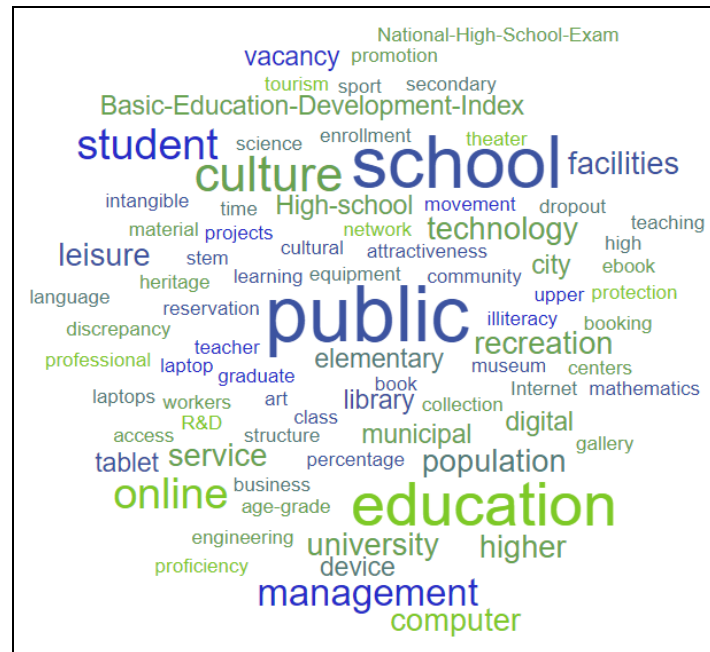


Figure 12. Most frequent indicators within the theme of “education”.

Recreation and culture are considered by some as part of the “education” theme and by others as a separate theme. In this research, they were considered part of education.

Within the health theme, the most frequent indicators were the following: online, health, public (management/network), and doctor.

The recurrent health indicators, that is, those that appeared in at least 30% of the citations, were the following: online, health, public, doctor, network, job, record, female, bed, municipal, and management (Figure 13).

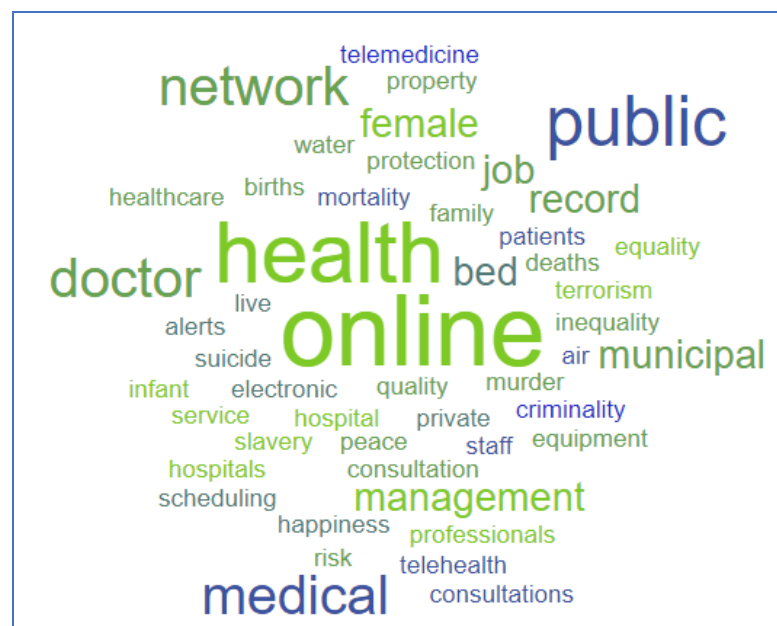


Figure 13. Most frequent indicators within the theme of “health”.

Within the safety theme, the indicators referring to murder and safety were the most frequent.

The recurring safety indicators, that is, those that appeared in at least 50% of the citations, were the following: murder, safety, solution, management, traffic, monitoring, and public and natural disasters (Figure 14).



Figure 14. Most frequent indicators within the theme of “safety”.

Within the environment theme, indicators referring to water and waste were the most frequent.

The recurring environmental indicators, that is, those that appeared in at least 30% of the citations, were the following: water, waste, monitoring, city, quality, smart, air, collection, solution, and sewage (Figure 15).

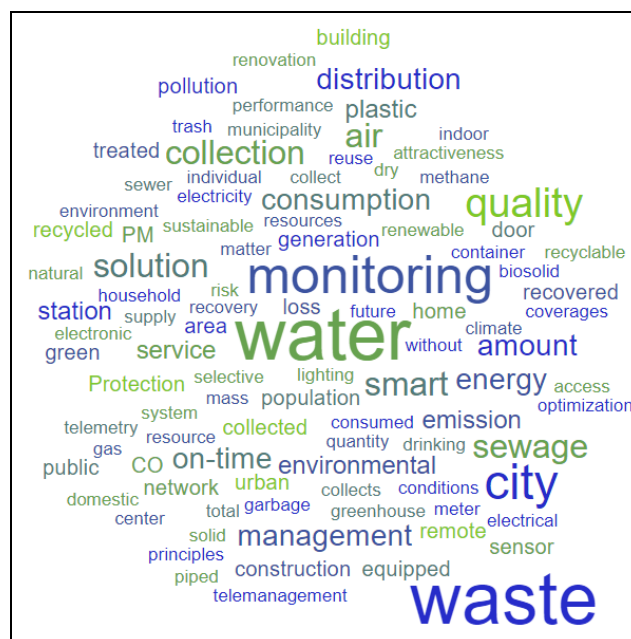


Figure 15. Most frequent indicators within the theme of “environment”.

The “environment” theme in particular contained more indicators than other themes. Extending the frequency analysis to terms that appeared in at least 20% of the citations, the

following were added: distribution, amount, on-time, management, energy, consumption, service, station, plastic, environmental, and emissions (CO₂ or methane).

Within the economy theme, the most frequent indicators were the following: business, quantity, and growth.

The recurring economic indicators were the following: business, quantity, growth, GDP, workers, income, infrastructure, technology, productivity, and entrepreneurship (Figure 16).



Figure 16. Most frequent indicators within the theme of "economy".

Entrepreneurship is considered by some as part of the economy and by others as a separate theme. This research incorporated it into the economy theme.

Within the mobility theme, the most frequent indicators were the following: system, public transport, and city.

The recurring indicators of mobility, that is, those that appeared in at least 30% of the citations, were the following: system, public transport, city, vehicle, traffic, bike, on-time, and population (Figure 17).

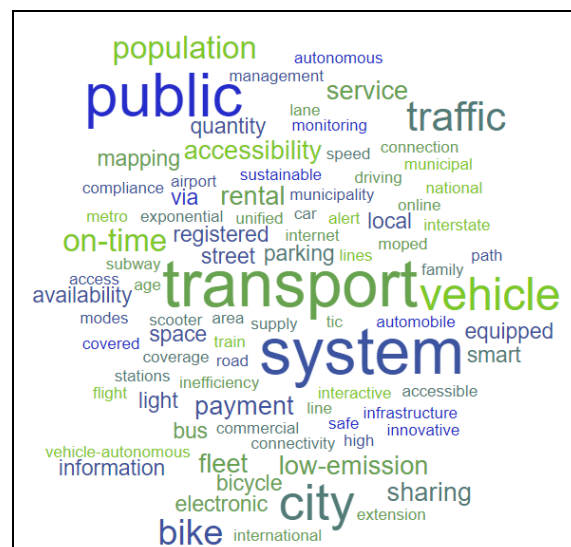


Figure 17. Most frequent indicators within the theme of "mobility".

The following terms were also relevant, appearing in at least 25% of the citations: accessibility, rental, fleet, service, payment, sharing, and low-emission.

Within the technology and innovation theme, the most frequent indicators were the following: internet, coverage, worker, and broadband.

The recurring indicators of technology and innovation, that is, those that appeared in at least 50% of the citations, were the following: internet, coverage, worker, broadband, municipality, speed, cell phone (mobile), online, and subscription (Figure 18).

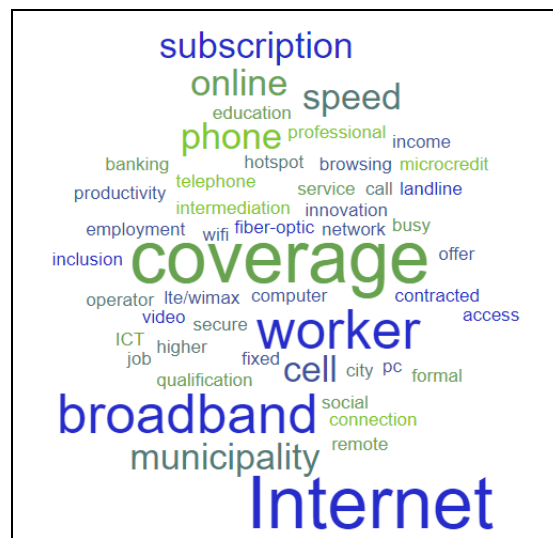


Figure 18. Most frequent indicators within the theme of “technology and innovation”.

Within the governance theme, the most frequent indicators were the following: city, service, population, open data, participation, and online.

The recurring governance indicators, that is, those that appeared in at least 50% of the citations, were the following: city, service, population, open data, participation, online, economy, transparency, website, agility, services, public, platform, city hall, and management (Figure 19).

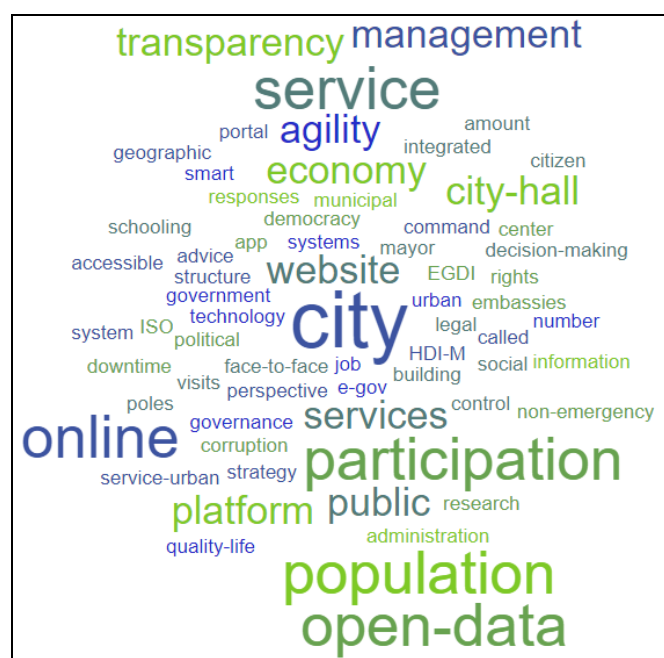


Figure 19. Most frequent indicators within the theme of “governance”.

4.3. The Synthesis

Below are the analyses of the indicators present in each theme. To compare the indicators and find the similarities, the keywords of the indicators were used. Table 5 synthesizes the information analyzed.

Table 5. Consolidation of the most frequent indicators within all eight themes.

Sociocultural Dimension		Environmental Dimension		Economic Dimension	
Theme	Indicators	Theme	Indicators	Theme	Indicators
EDUCATION	Public School Education Culture Student Online Management			ECONOMY	Business Quantity Growth GDP Workers Income Infrastructure Technology Productivity Entrepreneurship
HEALTH	Online Health Public Doctor (Public) Network Job Female Record (electronic medical record) Bed Municipal (Public) Management	ENVIRONMENT	Water Waste Monitoring City Quality Smart Air Collection (waste collection) Solution Sewage	MOBILITY	System Public transport City Vehicle Traffic Bike On-time Population
SAFETY	Murder Safety Solution Management Traffic Natural disaster Monitoring Public			TECHNOLOGY AND INOVATION	Internet Coverage Worker Broadband Municipality Speed Cell phone Online Subscription
Transverse Dimension					
Theme			Indicators		
GOVERNANCE			City Service Population Open data Participation Online Economy Transparency Web site Agility Services Public Platform City hall Management		

Among the most frequent, the most recurrent terms were the following: public, online, management, and city.

Given the diversity of information available, it is understood that the following are standard guidelines for smart cities: maintaining a public-centric approach; prioritizing online tools; prioritizing innovative ways of management; and focusing on cities' issues ("think globally, act locally").

5. Discussion

According to this research, it has become clear that the smart city is not defined by any single rigid concept. Instead, it makes more sense to associate a smart city with a mindset. In other words, a smart city indicates a direction combined with a management culture. Technology, in turn, is a tool, and people's well-being is the goal.

This research has focused on clarifying, for the benefit of managers and entrepreneurs, what should be considered and prioritized to structure a smart-city project.

The city was one of the terms most present in the indicators analyzed, reinforcing the importance of defining the territories in which one is acting. This result is in line with the findings of [23,41]. Therefore, this indicates that an initial stage of understanding regarding the city—its inhabitants and frequent visitors, needs, political structures, history, socioeconomic profile, habits, and culture—is fundamental for the planning of any initiative because, according to the review, it is precisely due to each location having its own characteristics that prevents a single definition of a smart city and the development of a model to be copied.

Along with the "city", "public", "management", and "online" constitute a group of the most recurrent terms within the sets of the indicators analyzed. This result is in line with the most frequent words in the different definitions of smart cities [18,21,23,39]—quality of life, services, citizens, ICT, and the fact that there is even a common objective among the lack of consensus on a definition—for the improvement of the quality of urban life [2,42]. Therefore, it makes sense to think of cities as spaces for citizens to inhabit with a good quality of life and to be able to exercise their duties and enjoy their rights with dignity. New technologies, in turn, can contribute to possible solutions that were previously unimaginable, such as the use of drones for monitoring or the use of artificial intelligence in management, effectively accelerating the achievement of the goals of smart cities. In smart cities, technologies are, therefore, tools to achieve something. Their usage, however, is not enough to classify a city as smart.

If the goal is to improve the quality of life through sustainably adopting technologies, then it is necessary to understand what this means before planning any initiatives. The World Health Organization [125] defines quality of life as an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards, and concerns. It involves well-being, social relationships, health, education, housing, sanitation, and other life circumstances. On the other hand, health is understood as a state of complete physical, mental, and social well-being and not merely the absence of disease and infirmity. According to the results of this research, the goal of smart cities is, hence, the state of complete well-being. According to Martin Seligman's theory, this condition is supported by five pillars (Figure 20): positive emotions, engagement, relationships, meaning/purpose, and achievements [126], and it is related to the concept of flourishing.

Positive emotions refer to feeling good. They are a kind of common thread for well-being and satisfaction. They broaden the consciousness of individuals and stimulate new avenues through which one can explore thoughts and actions. They are responsible for feelings of joy and pleasure.

Engagement has to do with the state of being fully involved in the activities one performs. It concerns the conscious involvement of an individual with some occupation or work in which he/she uses his/her senses. It is usually associated with a challenge and is that moment when the individual does not feel time passing (having entered a flow

state). It occurs when there is a positive match between the person and the activity he/she is performing, and that activity should challenge the person's abilities.

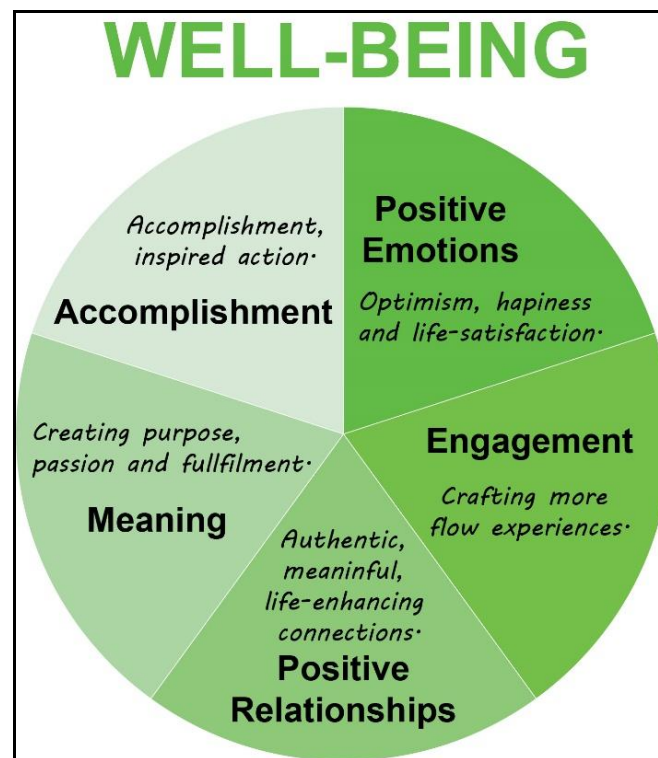


Figure 20. PERMA model for Seligman's well-being theory. Source: [126]. Adapted by the author.

Relationships are associated with genuine connections between people. Positive relationships with family members, partners, friends, co-workers, and other people give a sense of support and connection. It is common for happy people to be sociable. Moments of intense emotion often occur when people join together. Positive relationships are the foundation of positive institutions (family, business, and community).

Meaning concerns one's meaning or purpose in life. It is the individual's connection to something greater than one's self. According to [126], people linked to some kind of spirituality always appear happier and with greater well-being. Another way to connect with "something bigger" is through volunteer work.

Achievements are related to the feeling of conquest. They refer to achieving established objectives. They can be momentary (unrelated to a greater purpose) or a life milestone (imbued with meaning). Achieving life goals contributes to increased well-being.

Figure 21 compiles the most relevant information gathered in the research that should be considered when thinking about initiatives for smart cities:

- The central objective, which is well-being, and towards which all initiatives must be directed (a human well-being-centered approach);
- The economic, environmental and sociocultural dimensions of sustainability that must be managed and kept in balance, allowing the territory to sustain itself over time;
- The eight themes that must be worked on in a dynamic and integrated manner, considering the influences they exert on each other;
- Keywords to facilitate outlining specific objectives for each theme;
- The indicators that support the management of each theme and city, allowing continuous monitoring, situational diagnosis, iterative action, impact assessment, and corrective actions.

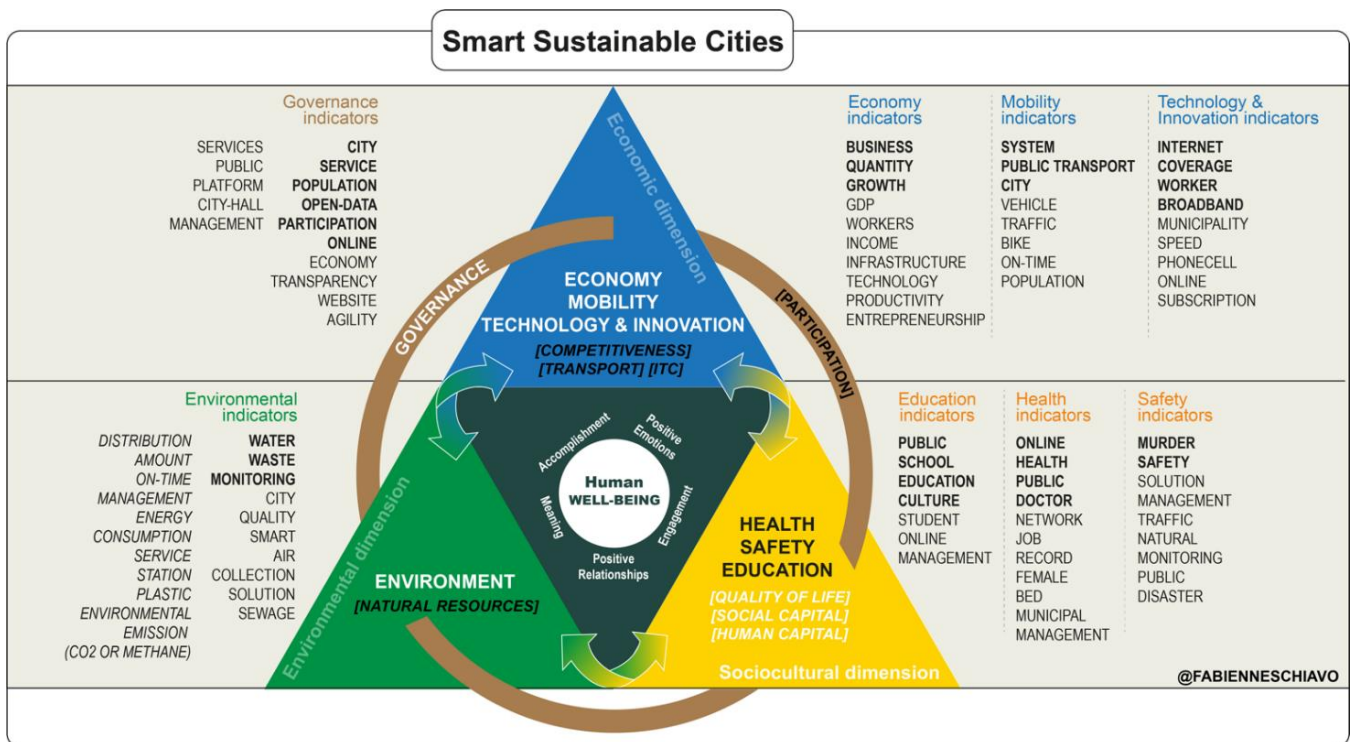


Figure 21. Synthetic scheme to plan initiatives for smart sustainable cities—a new proposal.

The proposed compilation of information differs from the study by Angelakoglou et al. [102], with the energy transition as a core focus. In the new one, “energy” was considered part of “environment,” and “propagation” was not relevant among the set of indicators studied. ICT appears as a transversal to “economy”, “mobility”, “technology”, and “innovation” and not as a single theme. Governance appears transversal to all. Finally, “social” is a dimension that includes health, safety, and education.

Compared to the model proposed by Attaran [29], the new one organizes information within the sustainable logic and indicates inter-relations among themes. The existent model may be combined with the suggested one in the later stages of the project.

This new scheme synthesizes the essential attributes that must be included in the projects and initiatives of smart cities and aim to facilitate the action of entrepreneurs and government officials.

The information is described and organized as follows:

- In the middle is the central objective, to which every initiative must be directed. For this reason, the model is labeled a human-well-being-centered approach.
- The social, environmental, and sociocultural dimensions of sustainability act as a cluster to all other information. The form of a triangle is associated with the triple bottom line approach to sustainability [127]. It is always necessary to keep a balance among all of them, enabling the sustainability of the territory. The scheme also points out their inter-relations, indicating that an integrated view is essential as they influence each other.
- It contains the eight recurrent themes: environment, education, health, safety, economy, mobility, technology, and governance. Seven are organized according to the dimensions of sustainability, and governance is transversal to all others.
- It brings the key terms for each dimension and the transversal theme: natural resources; competitiveness; transport; ICT; human capital; social capital; quality of life; participation. These terms help to formulate questions for the diagnosis and orient objectives.

- The indicators for each theme are described in order of frequency, close to the main structure. They may guide the project's planning and monitoring tools according to the diagnosis of the city.

In order to maintain a human-well-being-centered approach, the initiatives must include the following: causes relevant to the population of the territory; the development of networks that allow the relationship and promote the participation and engagement of the population; and decentralization so that there is a more significant number of small projects achievable, as opposed to a large and complex project, thereby enabling small achievements. In addition, a sense of belonging, accomplishments, and action concerning the causes of cities will trigger positive emotions.

In short, a smart city is a culture and indicates a direction; technology is a tool; and well-being is an objective.

To move in this direction, the following is necessary:

- Knowing the particularities of the city: its needs, strengths, vocation, and identity.
- Creating with and for the people who live in the city.
- Having purposes that positively impact people's lives.
- Using technologies to accelerate achievements and enable sustainable development.
- Developing innovative projects: small achievable initiatives, anchored in causes, capable of creating a network of people who are involved and have roles, thus promoting positive emotions both throughout the process and in the achievements, generating well-being.

Finally, after consolidating the attributes that must be contemplated in projects and initiatives for smart cities within a single guideline, a new question emerges: how should one think about the use of technology with the purpose of citizens' well-being, which is the ultimate objective of sustainable smart cities? It is not enough to simply "fit" technologies into old solutions without the participation of citizens. The connection between new technologies and well-being requires innovative approaches, including taking local culture and people's participation into account. The hypothesis is intrinsically characterized by creativity and encourages a holistic view and systemic approach with a focus on the human being, participatory and collaborative methods, and iteration, thus contributing to the ways in which global challenges are faced and to making cities smarter and more sustainable. This should thus be a new research scope.

6. Conclusions

This study has achieved the objective of identifying the essential elements that must be considered in the projects and initiatives of a city that seeks to be ranked as smart, and these elements have been synthetically structured to facilitate the action of entrepreneurs and governments.

The work here not only qualitatively reports a mismatch of the attributes of smart cities but also provides a comparative analysis that supports practical applications of smart city projects.

Within the main results and findings, the following are highlighted:

- There is no official definition of a smart city, but there are recurrent terms covering different concepts: quality of life, services, citizens, and ICT.
- In smart cities, only those technologies that improve human well-being are considered relevant.
- In smart cities, investing in technology makes sense if the citizens are able to use it or perceive its applicability.
- In smart cities, decentralized, anthropocentric, and collaborative approaches that facilitate the engagement of their communities are prevalent.
- Global smart city indicator sets need to be used and interpreted in conjunction with local realities. In other words, the themes and indicators must be prioritized consider-

ing the needs and strategies of the cities. They cannot be used in the same manner for every city.

- A holistic and systemic view is needed for the variables that qualify smart cities and related solutions: connection and integration are needed.
- The groups of indicators are based on official data, which often no longer represent the reality of each city and may result in an inappropriate diagnosis for the planning of local strategies.
- There is a lack of a project vision when considering new approaches to old problems, creatively adopting technology, and seeking well-being in the city.
- For smart cities, it makes more sense to develop projects within achievable dimensions, executed by an engaged community and anchored in a known cause or purpose.

Given that the current view of smart cities is no longer driven by a largely technoeconomic approach but has shifted towards a decentralized, anthropocentric approach, new policies focused on incentives for local initiatives must be promoted. The public sector must incentive decentralization and, thus, decrease the dependence on the government and increase local solutions that fit real-world challenges. Moreover, adopting a holistic and systemic view of the territory will facilitate integrating the efforts of the public and private sectors, social organizations, and the academy. The public sector of each city must lead the adoption of a global vision of the territory to facilitate the practical adoption of “think globally and act locally.”

From a practical perspective, this study provides project managers with the essentials that must be considered, analyzed, and combined when planning initiatives toward a smart, sustainable city. These elements are essential, especially at the start point. However, according to the findings, they should not be used in the same way for every city, only official data are not sufficient to define a frame of the city, and citizen engagement is relevant. Thus, we recommend further study on methods to frame local diagnostic, where the elements identified in this study help structure the city framing.

Although the attributes of smart cities are relevant, the design dimension should be given greater consideration in future studies, as it is transversal to the essential themes. These projects, aimed at improving people’s well-being in cities, must foresee small, achievable initiatives involving partnerships between people, companies, governments, and causes. These projects should be designed for communities or neighborhoods with cultural or socioeconomic similarities, composing a network and making it possible to obtain real and current data and promote the engagement of local people during the process. As a proposal for future work, we suggest developing methods for planning projects and initiatives that not only use past data, but also include real-time data, as well as the participation of citizens and the main stakeholders involved in each theme, prioritizing the relevant available technologies.

Author Contributions: Conceptualization F.T.S. and C.F.d.M.; methodology, F.T.S.; software, F.T.S.; validation, F.T.S. and C.F.d.M.; formal analysis, F.T.S.; investigation, F.T.S.; resources, F.T.S.; data curation, F.T.S.; writing—original draft preparation, F.T.S.; writing—review and editing, F.T.S.; visualization, F.T.S.; supervision, C.F.d.M.; project administration, F.T.S.; funding acquisition, F.T.S. All authors have read and agreed to the published version of the manuscript.

Funding: The authors thank for the financial support provided by the Brazilian funding agencies CNPq, CAPES, FINEP and FAPERJ. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

A Fuzzy Rule-Based System to Infer Subjective Noise Annoyance Using an Experimental Wireless Acoustic Sensor Network

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Abstract: Over the last few years, several works have been conducted on the design and development of wireless acoustic sensor networks (WASNs) to monitor acoustic noise levels and create noise maps. The information provided by these WASNs is based on the equivalent noise pressure level over time T ($L_{eq,T}$), which is used to assess the objective noise level. According to some authors, noise annoyance is an inherently vague and uncertain concept, and $L_{eq,T}$ does not provide any information about subjective annoyance to humans. Some fuzzy models have been proposed to model subjective annoyance. However, the use of fuzzy rule-based systems (FRBS) that have been adapted to acoustic sensor node resource limitations in real WASN to provide the degree of subjective noise annoyance in real-time remains a largely unexplored region. In this paper, we present the design and implementation of an FRBS that enables the sensor nodes of a real WASN deployed in the city of Linares (Jaen), Spain to infer the degree of subjective noise annoyance in real-time. The hardware used for the sensor nodes is a commercial model, Arduino Due. The results demonstrate that the sensor nodes have sufficient processing capacity and memory to infer the subjective annoyance in real-time, and the system can correctly detect situations that can be considered more annoying by humans.

Keywords: wireless acoustic sensor networks; subjective noise annoyance; fuzzy rule-based system; real deployments



Citation: Fernandez-Prieto, J.-A.; Canada-Bago, J.; Birkel, U. A Fuzzy Rule-Based System to Infer Subjective Noise Annoyance Using an Experimental Wireless Acoustic Sensor Network. *Smart Cities* **2022**, *5*, 1574–1589. <https://doi.org/10.3390/smartcities5040080>

Academic Editors: Véronique Flambard, Sadia Benamrouz-Vanneste and Abir Karami

Received: 10 October 2022
Accepted: 5 November 2022
Published: 9 November 2022

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1. Introduction

Noise pollution is one of the main environmental problems in urban areas and affects millions of people worldwide. Different studies [1,2] have demonstrated that long-term exposure to environmental noise affects human social behavior, health (ischemic heart disease, hearing loss, risk of hypertension, etc.), sleep disturbance, and children's cognition. In Europe, more than 100 million people are exposed to damaging levels of environmental noise pollution. Since noise pollution is a serious health issue, the European Commission (EC) adopted an Environmental Noise Directive [3] and the subsequent Common Noise Assessment Methods methodological framework (CNOSSOS-EU) in 2002, requiring member states to obtain real and accurate data on noise sources to provide and publish an accurate mapping of noise levels throughout all urban centers with more than 250,000 citizens and to produce local action plans every five years. Some examples of cities that provide these noise maps are Madrid, Munich, London, Rome, and Helsinki.

The traditional method for obtaining accurate and real data on noise levels is by collecting noise samples by professionals using instruments called sound level meters placed in the area to be mapped. This procedure has some drawbacks, such as the lack of real-time data, the expensive costs of instruments and personnel, the fact that the measurements are carried out only locally and sparsely, and the inability to scale with the demand for higher data granularity in time and space, as recommended by the EC [4]. In this scenario, wireless sensor networks (WSNs) and wireless acoustic sensor networks

(WASNs) [5] play a key role, and currently, they are becoming a reality in smart cities as an alternative that can address these drawbacks and inconveniences. WSNs are the base of the Internet of Things (IoT) that all together give rise to the smart city, which includes the application of “Noise Urban Maps: Sound monitoring in bar areas and centric zones in real time”. The range of applications of WSNs is very wide and includes intelligent agriculture, environmental monitoring, public security, public health, transport, etc. [6,7]. WASNs are defined as networks composed of a large number of acoustic sensor nodes. Each node is a resource-constrained device that consists of a processing unit with limited computability and memory, sensing devices (one or more microphones), a communication device, and a limited power source, usually in the form of a battery. Over the last few years, several studies and projects have been proposed to design and develop WASNs for monitoring noise pollution and creating maps of noise levels, as shown in Section 2.

The current noise indicators used to provide information about the objective noise levels are based on the sound pressure level (SPL) and on the equivalent sound pressure level over time T , $L_{eq,T}$ [8]; therefore, noise exposure assessment depends solely on these measurement results (measured in dB). The SPL determines the intensity of the sound that generates a sound pressure (i.e., the sound that reaches a person at a given moment). It is measured in dB, and it ranges from the 0 dB threshold of hearing to the 120 dB threshold of pain. $L_{eq,T}$ is defined as follows:

$$L_{eq,T} = 10 \log_{10} \left(\frac{1}{T} \int_0^T \frac{p(t)^2}{p_0^2} dt \right) \quad (1)$$

where $p(t)$ represents the root mean square instantaneous sound pressure level produced by an acoustic wave, $p_0 = 2 \times 10^{-5}$ Pa is the reference value corresponding to the minimal audible acoustic signal for a human at 1 kHz, and T is the temporal interval.

$L_{eq,T}$ can be calculated using the sensor nodes of a WASN, and it provides adequate information about the objective noise level. However, it does not provide any information about subjective annoyance [9,10]. There is no direct correlation between the current indicators and the subjective noise annoyance.

Therefore, new indicators, which provide information related to the subjective impact of noise annoyance, are needed. These indicators can express people’s feelings through subjective measures [11]. In addition, “annoyance maps could be generated to provide information not only about the objective noise level but also about the subjective impact of the noise pollution” [12].

According to [13,14], noise annoyance is inherently a vague, imprecise, and uncertain concept. These authors argue that noise annoyance models should identify a fuzzy set [15] of possible effects rather than seek a very accurate crisp prediction and that fuzzy rule-based models are considered the most appropriate candidates for this task.

Although some fuzzy models have been proposed to model noise annoyance [13,14,16,17], all of the models need a large number of computer resources to be executed. Therefore, they have not been directly implemented into WASN acoustic sensor nodes due to their resource constraints, and it is necessary to design a fuzzy approach adapted to them, reducing the number of necessary resources. An approach could focus on sending the raw acoustic sensor data to a web server or a cloud platform, executing a fuzzy model and processing with almost unlimited resources. However, the amount of raw measurement data and data rate needed is too large for Low Power Wide Area Networks (LPWANs), such as Sigfox or LoRaWAN, and therefore, data processing must be performed in the acoustic sensor nodes to reduce the data rate.

In this work, we present the design and implementation of an adapted fuzzy ruled-based system (FRBS) [18] that allows the acoustic sensor nodes of a real WASN to infer the degree of subjective noise annoyance in real-time. Each sensor node of the WASN, deployed in the city of Linares (Jaén), Spain, executes an FRBS, which consists of a fuzzification interface, a knowledge base (KB), an inference engine, and a defuzzification interface.

The rest of the paper is structured as follows: Section 2 discusses the related work and motivation and Section 3 describes the FRBS designed and implemented. The experimental results are provided in Section 4, and some conclusions and future works are presented in Section 5.

2. Related Work and Motivation

Over the last few years, several works have devoted their attention to the design and use of WASNs to monitor noise levels and create noise maps [19–24]. In [12], the authors presented a review of the main approaches to date, which focused on the design and development of a WASN for environmental noise monitoring in smart cities. The authors argue that “although WASN are becoming an incipient reality, very few projects have been deployed in some smart cities around the world (most of them as pilots)”. Examples of real projects based on WASN have been described by [21,25–28]. In a previous work [29], we presented the design and implementation of a complete low-cost system for a WASN deployed in the city of Linares (Jaén), Spain. The complete system covered the network topology design, hardware, and software of the sensor nodes, protocols, and a cloud server platform.

However, in our previous work [29], and all these previous works and real projects, the measurements and the information provided by the WASN were based on $L_{eq,T}$ [8] or $L_{Aeq,T}$ (applying the A-weighting filter, which is a frequency filter that picks up the frequencies where the human ear is most sensitive). These parameters do not provide any information about subjective annoyance in humans [9,10]. According to [11], “even with similar values of $L_{eq,T}$, people can feel the noise differently according to its frequency characteristics”. In this sense, subjective annoyance and road traffic noise have been studied in [30].

Since noise annoyance is inherently a vague, imprecise, and uncertain concept [13,14,31], fuzzy models have been proposed to model noise annoyance. In [16], the authors describe the noise-human response, and a fuzzy logic (FL) model is developed by comprehensive field studies on noise measurements. The model has two subsystems: the first has 549 linguistic rules and the second has 52 linguistic rules. In [13], a framework is proposed to model noise annoyance based on the mathematical theory of fuzzy sets and FRBS, providing the theoretical background for building these models. The resulting model is tested on two large-scale social surveys augmented with exposure simulations. In [17], the authors describe an exposure assessment method of occupational noise based on FL. They conclude that the fuzzy method assists in obtaining a clear approach to the risk assessment of noise exposure, and FL assessment results are more useful for analysis than a conventional assessment. However, in [14,31], the authors proposed an expert system using a fuzzy approach to determine the effects of the noise environment on annoyance. The rules were proposed by a human expert and are based on linguistic variables. Annoyance is considered to be a function of noise levels, exposure duration, noise level in habitat, and age. The model was implemented using Maple 12 software.

One of the main characteristics of these systems is the capacity to incorporate human knowledge in the presence of a lack of accuracy and uncertainty or imprecision. Therefore, these models represent an alternative to express people’s feelings by subjective measures instead of objective measures based on $L_{eq,T}$ (measured in dB) or $L_{Aeq,T}$ (measured in dBA). All the previous fuzzy models referenced have been implemented using simulation software, which requires a large number of computer resources, and none of them have been implemented in a real-life scenario.

Although considerable research has been devoted to modeling subjective annoyance using fuzzy models, FRBS adapted to sensor node limitations in a real WASN to provide the degree of subjective noise annoyance in real-time remains a largely unexplored region. In [32], we presented a preliminary approach and basic results about how to integrate an FRBS into a resource-constrained device to calculate a fuzzy noise indicator. The

experiments were carried out in a laboratory using a Sun SPOT device, which is obsolete at present.

In this work, we improve the previous approach by (a) optimizing the design of the FRBS to be executed in the current sensor node hardware; (b) introducing new input variables; (c) improving the algorithm to calculate the SPL and $L_{Aeq,T}$; and (d) determining the frequency characteristics of the noise. In addition, the experiments were performed in a real scenario by giving real measurement inputs to the FRBS in a real WASN deployed in the city of Linares (Jaén), Spain, which has been running continuously for three months. In this way, we compare the evolution of the sound pressure level (used as the objective noise level) with the progress of the subjective noise annoyance on different days and in real situations.

3. The Proposed Fuzzy Rule Based-System

A FRBS is a rule-based system in which FL is used as a tool for representing different forms of knowledge about the problem at hand [18]. These systems are an extension to classical rule-based systems because they deal with “IF-THEN” rules whose antecedents and consequents are composed of FL statements (fuzzy rules) instead of the classical logic ones. FRBS incorporates the human knowledge of an expert using FL. Two different kinds of approaches have been proposed within the FRBS: Mamdani FRBS [33,34] and Takagi–Sugeno–Kang FRBS [35]. The main difference between them lies in the consequent knowledge rules. The Mandani approach is composed of a linguistic variable, and in the Takagi–Sugeno–Kang approach, it is expressed as an analytical function of the input variables.

The FRBS proposed in this paper to calculate the degree of subjective noise annoyance is based on the structure of the Mandani FRBS [33,34]. It consists of the following components: a fuzzification authentication interface, a knowledge base (KB), an inference engine, and a defuzzification interface. The fuzzification interface adapts the actual input values to the fuzzy system. The knowledge is stored in a KB that is composed of three elements: membership functions, a set of “IF-THEN” rules, and linguistic variables. These rules are defined through consequences and antecedents. The rules have the following form:

$$\text{IF } X_1 \text{ is } A_1 \text{ and } \dots \text{ and } X_n \text{ is } A_n \text{ THEN } Y \text{ is } B$$

where X_i are the input variables, A_i is a fuzzy set associated with the input variables, Y is the output variable, and B is a fuzzy set related to the output variable.

The inference engine infers the fuzzy output using the input variables and the KB. Finally, the defuzzification interface adapts the value of the fuzzy output to a real output value.

To design the FRBS to be executed in the sensor nodes of the WASN, some simplifications are needed to minimize the computational requirements. We propose the use of the following modifications to the structure of the Mandani FRBS: (a) a reduced number of fuzzy sets is defined in each variable; (b) the input and output interfaces only admit linear conversions; (c) a First Infer Then, Aggregate (FITA) inference engine is needed, and (d) the inference engine works with numerical values of variables, fuzzy sets, and rules instead of linguistic labels.

Figure 1 shows the structure of the FRBS proposed, which is implemented into the acoustic sensor nodes of the real WASN to provide in real-time the degree of subjective noise annoyance in the area where each acoustic sensor node is placed.

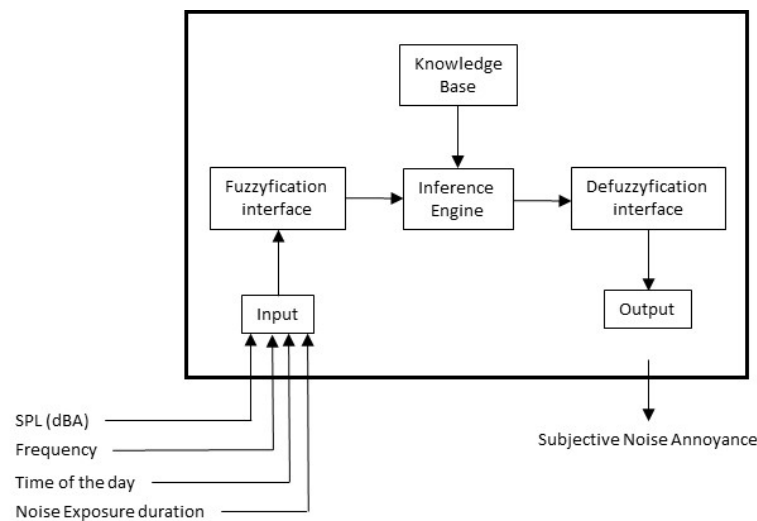


Figure 1. Structure of the FRBS proposed which is executed in the sensor nodes.

The output variable of the system is the subjective annoyance. As input variables, we considered four variables as the most representative ones described in the literature that affect people's perception of subjective noise. There are other variables that have been used in the literature, such as age. This variable can be used for a theoretical model or even if the exact age range is known (in the place where a sensor node is going to be located), for example, a nursery or a home for elderly individuals. However, it is not valid for our real system, where the sensor nodes are placed in different streets of the city, as it is impossible to know the age of the people passing through each location.

The proposed FRBS has the following input variables:

- (1) SPL, sound pressure level value. In a previous work [29], we presented the architecture of an algorithm to calculate SPL (dB), $L_{eq,T}$ (dB), and $L_{Aeq,T}$ (dBA) in real-time adapted to the sensor nodes of a WASN. These parameters do not provide any information about subjective annoyance in humans. Implementation details of the algorithm can be found in that reference.
- (2) Noise exposure duration, i.e., its persistence over time.
- (3) Frequency. According to some studies [36,37], noise frequency components directly impact subjective noise perception in humans. The algorithm we implemented, which is executed in the sensor nodes, determines the critical spectral band, i.e., the frequencies with a higher energy and their degree of importance with respect to background noise or less crucial frequencies.
- (4) Time of day when the noise occurs. The END regulation [3] distinguishes three hourly time slots for noise measurements, establishing three indicators: (a) L_{day} , A-weighted average sound level over the daytime period 07:00–19:00; (b) $L_{evening}$, A-weighted average sound level over the evening period 19:00–23:00; and (c) L_{night} , A-weighted average sound level over the night period 23:00–07:00.

Figure 2 shows the fuzzy sets defined for all input variables and the output variable. Table 1 presents the KB set of rules used. This knowledge is based on an expert and peoples' opinions aggregated from different experiments. Different sound pressure levels were generated in the lab (50 dBA, 60 dBA, 70 dBA, 80 dBA, 90 dBA, and 100 dBA), and from these and the other variables, persistence over time (5 s, 10 s, 15 s, 20 s, 25 s, and 30 s), the fundamental frequency of the noise (different tones from 20 Hz to 8 kHz), and the time of day, the subjective noise annoyance level was determined, indicating whether the annoyance was very low, low, medium, high, or very high.

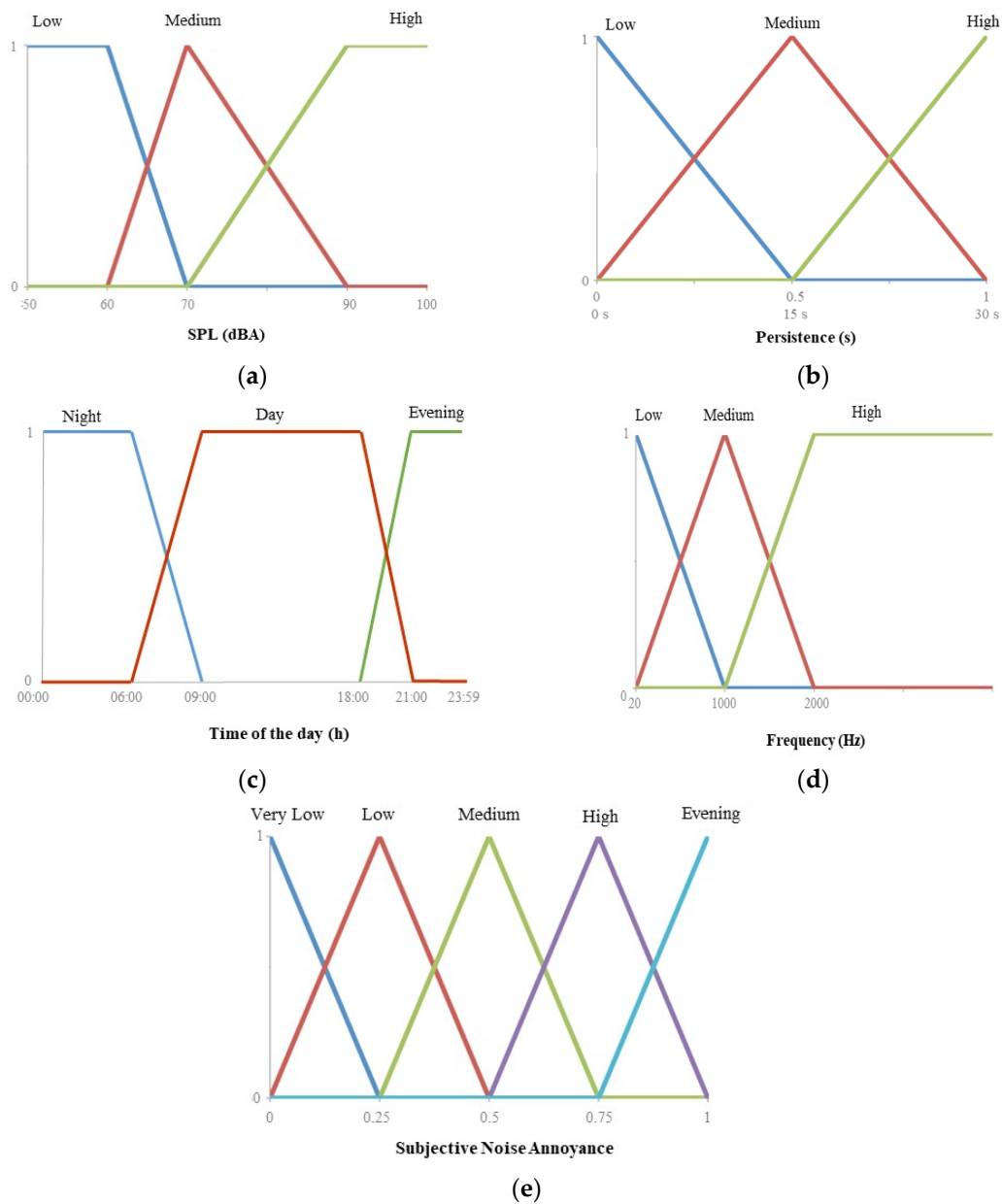


Figure 2. (a–e) Membership functions defined in inputs and output variables. (a) SPL; (b) Persistence; (c) Time of the day; (d) Frequency; and (e) Subjective noise annoyance.

Table 1. Set of IF-THEN rules.

SPL	Persistence	Frequency	Time of Day	Subjective Noise Annoyance
L	L	L	D	L
L	L	M	D	VL
L	L	E	E	L
L	L	H	D	VL
L	L	L	N	H
L	M	L	D	VL
L	M	L	N	H
L	M	E	E	L
L	M	M	D	L
L	M	H	D	VL
L	M	L	E	M

Table 1. Cont.

SPL	Persistence	Frequency	Time of Day	Subjective Noise Annoyance
L	H		D	L
L	H	L	N	H
L	H		E	L
M	L		E	M
M	L		D	L
M	L	L	N	VH
M	L	M	N	H
M	L	H	N	H
M	M	L	E	M
M	M		D	M
M	M	L	N	VH
M	M	M	E	M
M	M	M	N	VH
M	M	H	E	M
M	M	H	N	H
M	H	L	E	L
M	H	L	D	M
M	H	L	N	H
M	H	M	E	M
M	H	M	D	H
M	H	M	N	VH
M	H	H	E	H
M	H	H	D	H
M	H	H	N	VH
H	L		D	M
H	L		E	H
H	L		N	VH
H	M		E	H
H	M	M	D	M
H	M	M	N	VH
H	M	H	D	M
H	M	H	N	VH
H	H		E	H
H	H	L	D	H
H	H	M	D	H
H	H		N	VH
H	H	H	D	VH

VL: very low; L: low; M: medium; H: high; VH: very high; D: day; E: evening; and N: night.

4. Results

As the main result, we can say that an FRBS has been designed and implemented in the acoustic sensor nodes of a real WASN deployed in the city of Linares (Jaén), Spain, which has been running continuously for three months, to provide the degree of subjective noise annoyance in real-time.

The FRBS software was developed in the C programming language and implemented in a standard hardware model (i.e., commercial sensor node) of the Arduino platform. In particular, the acoustic sensor node is the Arduino Due device [38], which is based on a 32-bit ARM core microcontroller and is designed to develop solutions related to sensor networks. The microphone used is based on a commercial design [39], and it is integrated with an operational Maxim MAX4466 specifically designed for acoustic solutions. The choice of this device is mainly due to its technical specifications, in terms of the processor and memory, which allow for the execution of the FRBS and the algorithm to calculate SPL, $L_{eq,T}$ (dB), or $L_{Aeq,T}$ (dBA) in real-time. These technical specifications are as follows: Atmel SAM3X8E ARM Cortex-M3 processor 32-bit, clock speed of 82 MHz, 96 Kb of SRAM, and 512 Kb of flash memory. Figure 3 shows the acoustic sensor nodes. For sensor nodes

one and three through seven, we used the Arduino Due and the Ethernet shield, and the power consumption was approximately 180 mA. For sensor node two, the Arduino Due and the 3G module, the consumption was approximately 320 mA. Finally, for sensor node nine, using the Arduino Due and the Sigfox module, the consumption was approximately 125 mA. All of the nodes were powered through passive Power over Ethernet (PoE), using 12-V 1-A power adapters and PoE injectors. The electrical plugs were at a maximum distance of 20 m. To prevent problems derived from occasional power outages, the 3G acoustic sensor node was equipped with a battery of 50,250 mAh ($3350 \text{ mAh} \times 15 \text{ modules}$), so it has an autonomy of approximately 157 h.

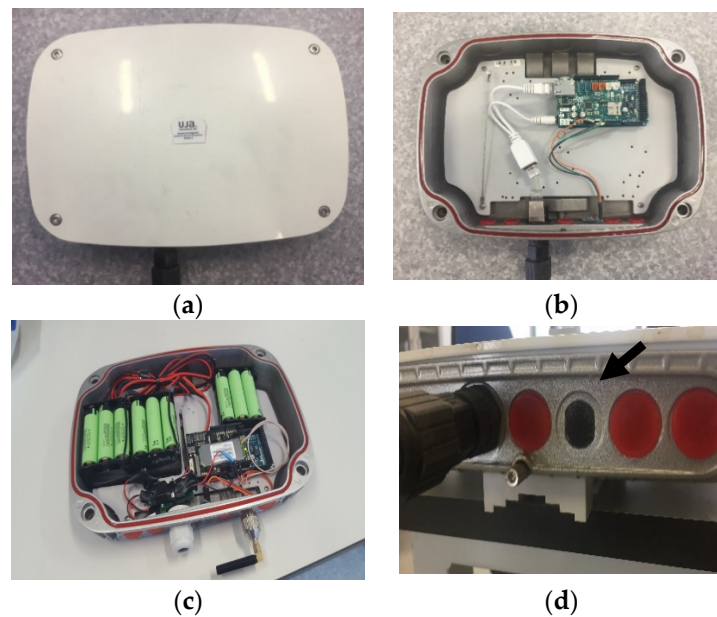


Figure 3. (a–d) The acoustic sensor nodes. (a) Enclosure box; (b) Wi-Fi acoustic sensor node; (c) 3G acoustic sensor node; and (d) Electret microphone.

It is not possible to execute the FRBS and the algorithm to calculate the SPL on other devices of the Arduino platform, i.e., MKR Family or MEGA. However, any other device with similar or better characteristics to Arduino Due can be used.

The computation time to infer the degree of subjective noise annoyance based on the FRBS has been calculated. Using the KB composed of the inputs and output variables and rules defined in Figure 2 and Table 1, the device computes approximately 150 inferences per second, which is equivalent to a reaction time of 6.5 ms. Therefore, the device has enough processing capacity to infer the output value using this KB, and both the number of input variables and the number of rules can be increased for more accuracy.

On the other hand, a WASN was deployed in the city of Linares (Jaén), Spain. This WASN is composed of nine acoustic sensor nodes, each executing the proposed FRBS and obtaining subjective noise annoyance every second. The acoustic sensor nodes were located in those streets of the city that were considered the most critical from the perspective of noise pollution. Figure 4 shows the exact locations of the measurement points in the streets, and Figure 5 shows some locations where the acoustic sensor nodes were installed.



Figure 4. Locations of the measurement points in the streets of the city of Linares (Jaén).



Figure 5. (a–d) Acoustic sensor nodes deployed in the city.

Figure 6 presents the network topology for the deployed WASN. The City Council of Linares, through the area of urban planning, established those locations of the city that were considered the most critical from the point of view of noise pollution.

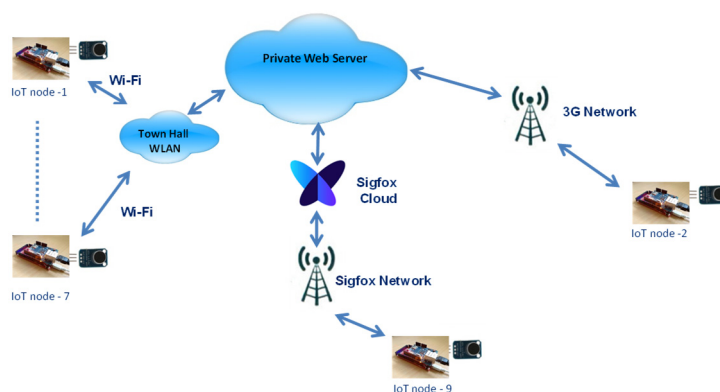


Figure 6. The network topology for the WASN deployed in the city of Linares (Jaén).

Due to the existence of the corporate Wi-Fi network that the City Council of Linares deployed in the city, as well as the absence of power supply restrictions, we proposed using this Wi-Fi network. After analyzing the coverage, it was detected that, in seven of the nine locations, it was possible to use this Wi-Fi network. However, in two locations (nodes two and nine), there was no coverage. For these two locations, we decided to use 3G and Sigfox technologies, respectively.

In addition to the FRBS software and the algorithm to calculate SPL and $L_{Aeq,T}$, all the acoustic sensor nodes include communication software, which is implemented to send data to a Web Server. The sensor nodes with Wi-Fi and 3G connectivity calculate the subjective noise annoyance every second, and every 30 s, send the average value to the webserver. In the case of Sigfox connectivity, the acoustic sensor node calculates the subjective noise annoyance every second, but in this case, the average value is sent every 10 min to the webserver. This is because the Sigfox network only permits sending 140 messages per day. More details about the protocols, network topology, and technologies used in the WASN can be found in our previous work [29].

As the experiments were performed by giving real measurement inputs to the FRBS, we can compare the evolution of the SPL (used as the objective noise level) with the progress of the subjective noise annoyance on different days or situations. Each acoustic sensor node provides the temporal evolution of the SPL (in dBA) during a selected time interval, the degree of subjective noise annoyance, and the $L_{Aeq,T}$ (in dBA). Figure 7 shows the temporal evolution of the SPL throughout the day from 00:00 to 23:59 h at Isaac Peral Street. The $L_{Aeq,T}$ for that day was 70.9 dBA.

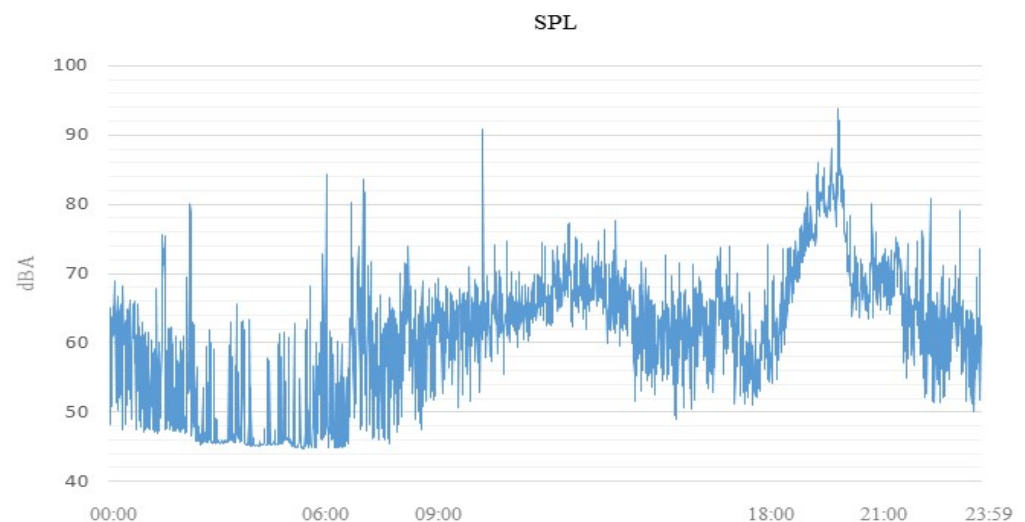


Figure 7. The temporal evolution of the SPL over the whole day at Isaac Peral Street.

Figure 8 shows the progress of the subjective noise annoyance as the output of the FRBS during the same day. The noise annoyance values are in the range $\{0, 1\}$, where value 0 means no annoyance and value 1 means maximum annoyance.

As can be observed, the system can correctly detect situations that can be considered more annoying by humans. For example, the subjective noise level increases during the night with respect to SPL, and during the day, the differences are smaller. Nevertheless, we can observe that from 6:00 h onwards, although the SPL starts to increase slowly as the city starts to wake up, the subjective noise level slowly decreases.

Figures 9 and 10 show the temporal evolution of the SPL and the subjective noise annoyance of another whole day in a different location. In this case, we can see that the subjective noise is the greatest at night. During the day, noise peaks are detected, however, their impact is less on annoyance, and during the transition from evening to night, although the SPL starts to decrease, the annoyance starts to increase slowly.

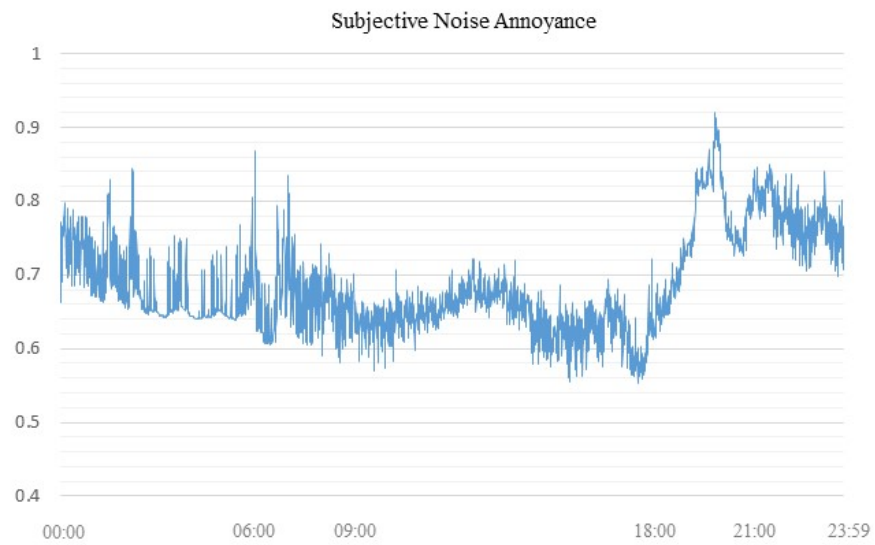


Figure 8. Progress of the subjective noise annoyance as an output of the FRBS.

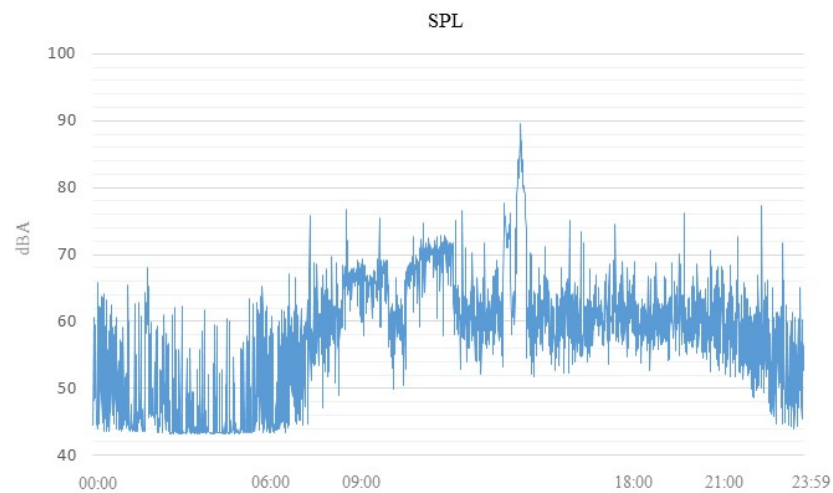


Figure 9. The temporal evolution of the SPL over a whole day at Julio Burel Street.

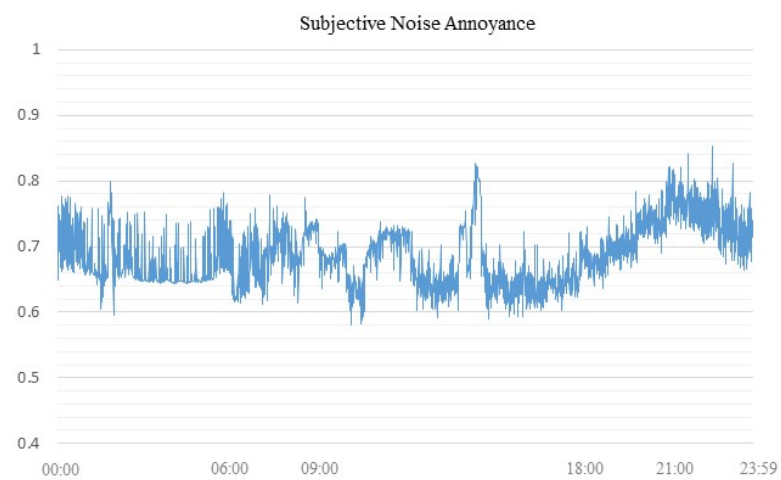


Figure 10. Progress of the subjective noise annoyance as an output of the FRBS at Julio Burel Street.

Appendix A contains one result in a whole day for each node of the implemented system.

5. Conclusions and Future Works

We present the design and implementation of an FRBS, which has been executed into the acoustic sensor nodes of a real WASN deployed in the city of Linares (Jaén), Spain, to provide the degree of subjective noise annoyance in humans in real-time. The FRBS has four input variables as the most representative described in the literature: SPL, frequency, persistence, and time of the day; and one output variable: the grade of subjective noise annoyance. The hardware used for the acoustic sensor nodes was a commercial model, Arduino Due. The system can correctly detect situations that can be considered more annoying by humans. Results show that the subjective noise level increases during the night with respect to SPL, and during the day, the differences are smaller. During the day, noise peaks are detected but their impact is less on annoyance. In most of the locations, from 6:00–7:00 h onwards, although the SPL starts to increase as the city starts to wake up, the subjective noise level slowly decreases. During the transition from evening to night, although the SPL starts to decrease, the annoyance starts to increase slowly. In non-noisy locations, where the values of SPL do not exceed 55–60 dB, noise annoyance is observed to be lower and its temporal evolution is practically flat, with a slight increase in the evening hours.

The results demonstrate that the performance of the Arduino Due is very good. It has sufficient processing capacity and memory to infer the output values using a KB composed of 5 variables and 48 fuzzy rules. The device computes approximately 150 inferences per second, which is equivalent to a reaction time of 6.5 ms. Therefore, both the number of input variables and the number of rules can be increased, as the reaction time is very small for this use case. In addition, the device is able to calculate the SPL (in dBA, applying the A-weighting filter) every 1 s, which allows us to know the variability of the noise in a specific place. It was not possible to execute the FRBS and the algorithm to calculate the SPL on other devices of the Arduino platform, i.e., MKR Family or MEGA. However, any other device with similar or better characteristics to Arduino Due can be used.

In addition, a real WASN was deployed in the city of Linares (Jaén), Spain, in which each acoustic sensor node of the network executed the FRBS to obtain the subjective noise annoyance every 1 s. The system has been working continuously for three months without any problems except for occasional power outages and the consequent restart of the devices. Therefore, we consider that FRBS integrated into the acoustic sensor nodes of a WASN is a valid approach to providing information about the subjective impact of noise pollution and generating annoyance maps.

The system can be integrated into the authority's decision processes and help to reduce noise impact. The system proposed allows continuous measurements over long periods of time (weeks/months), providing information based on the objective noise indicators included in the END regulation [3] as well as on the subjective noise annoyance. This allows preventive and corrective actions to be taken, for example, installation of noise barriers, the establishment of hourly traffic restrictions, setting speed limits, transport infrastructure planning, new urban area planning where people are going to live, changing the noisiest street pavements to more porous and quieter ones, etc. In addition, as the system provides information in real-time, corrective actions can be taken in real-time, for example, reorganization of vehicular traffic on the streets or the detection of situations where the noise derived from a leisure activity (i.e., a bar) is too high.

Regarding future research, as we demonstrate that the acoustic sensor node has enough processing capacity and memory, it should aim to improve the KB, increasing the number of input variables and the number of fuzzy rules. In addition, due to the occasional loss of connection from the Wi-Fi and 3G network to the internet, some data were lost. To solve this problem, we are currently working on the implementation of a fog-computing platform between the sensor nodes and the webserver. The fog server will only be in charge of data storage and retransmission to the webserver.

Author Contributions: Conceptualization, J.-A.F.-P., J.C.-B. and U.B.; methodology, J.-A.F.-P. and J.C.-B.; software, J.-A.F.-P. and J.C.-B.; validation, J.-A.F.-P. and J.C.-B.; formal analysis, J.C.-B.; investigation, J.-A.F.-P., J.C.-B. and U.B.; resources, J.-A.F.-P. and J.C.-B.; data curation, J.-A.F.-P. and J.C.-B.; writing—original draft preparation, J.-A.F.-P.; writing—review and editing, J.-A.F.-P. and U.B.; visualization, J.-A.F.-P.; supervision, J.-A.F.-P. and J.C.-B.; project administration, J.-A.F.-P.; funding acquisition, J.-A.F.-P. and J.C.-B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the Programa Operativo FEDER and Consejería de Economía y Conocimiento de la JUNTA de ANDALUCIA (Spain), Project Ref. 1380677, and the APC was completely funded by the same Program.

Data Availability Statement: Restrictions apply to the availability of these data. Data were collected from urban residential areas of the city of Linares and are available from the authors with the permission of Excmo. Ayuntamiento de Linares and Junta de Andalucía.

Acknowledgments: We would like to thank the support provided by Excmo, Ayuntamiento de Linares, especially for the technical support given by the ICT department.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

This Appendix A, Figures A1–A7, contains the measurements for a whole day for each node of the implemented system.

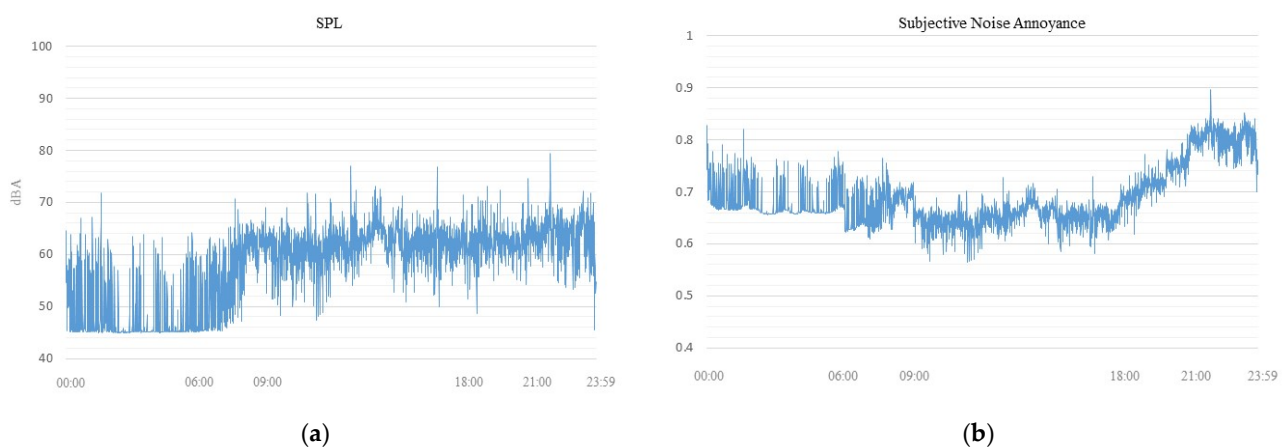


Figure A1. Ubeda Street: (a) The temporal evolution of the SPL over a whole day; (b) subjective noise annoyance as an output of the FRBS.

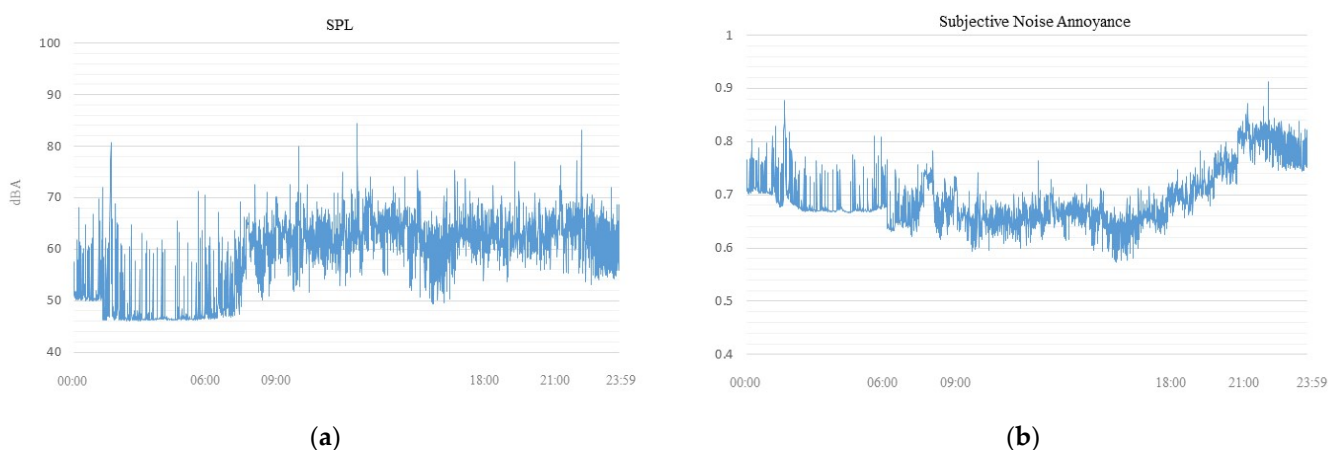


Figure A2. San Francisco Square: (a) The temporal evolution of the SPL over a whole day; (b) subjective noise annoyance as an output of the FRBS.

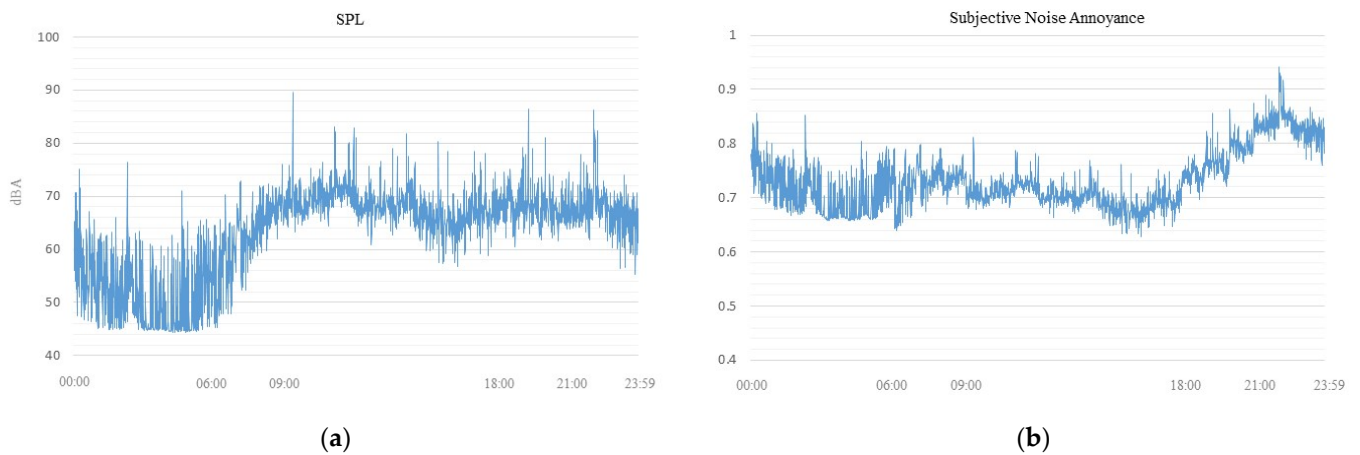


Figure A3. Santa Margarita Square: (a) The temporal evolution of the SPL over a whole day; (b) subjective noise annoyance as an output of the FRBS.

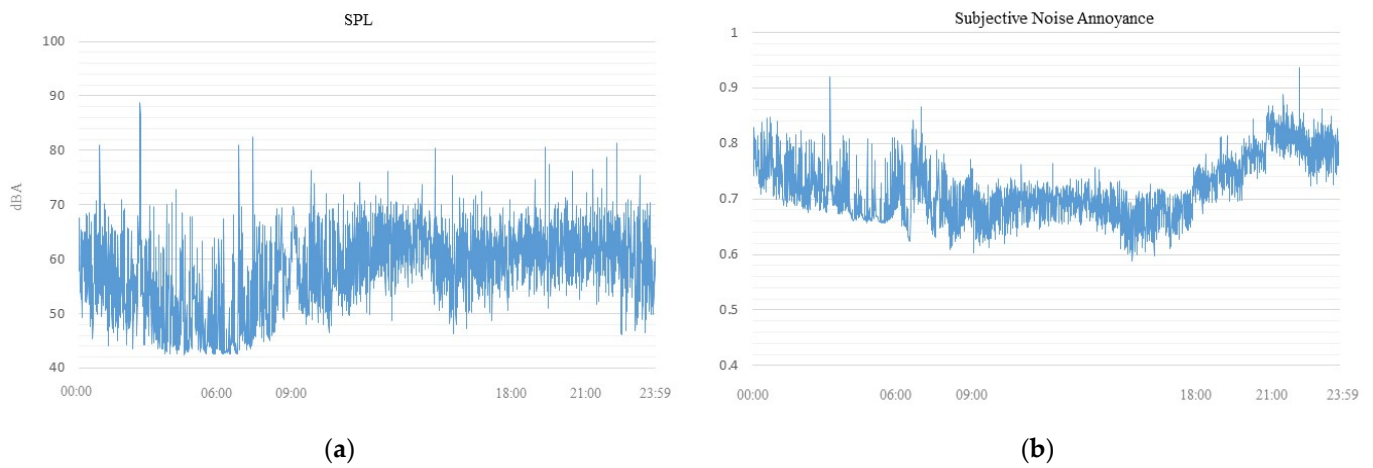


Figure A4. Cervantes Street: (a) The temporal evolution of the SPL over a whole day; (b) subjective noise annoyance as an output of the FRBS.

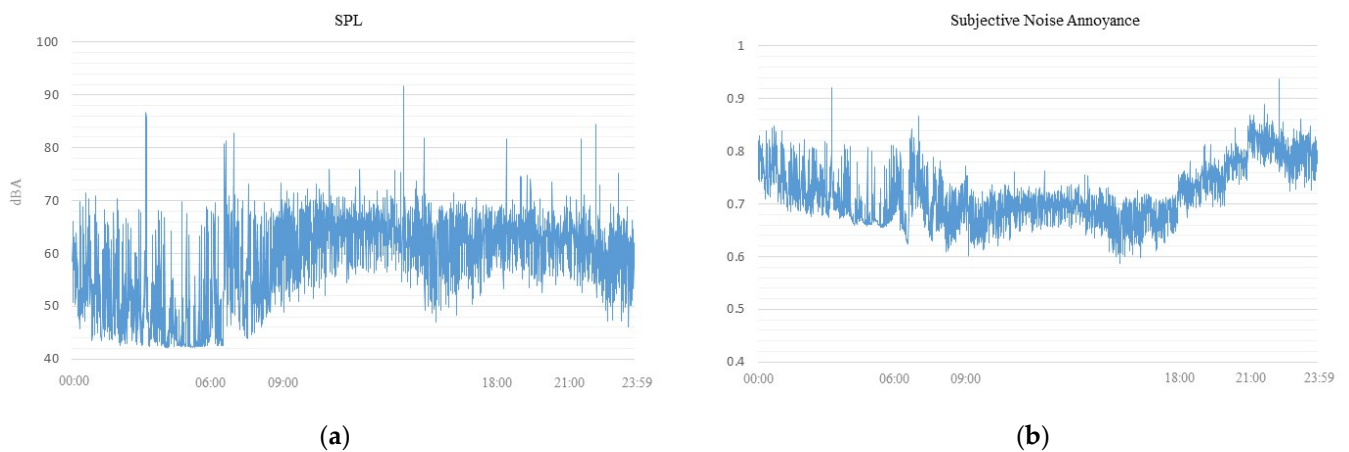


Figure A5. Andaluca Avenue: (a) The temporal evolution of the SPL over a whole day; (b) subjective noise annoyance as an output of the FRBS.

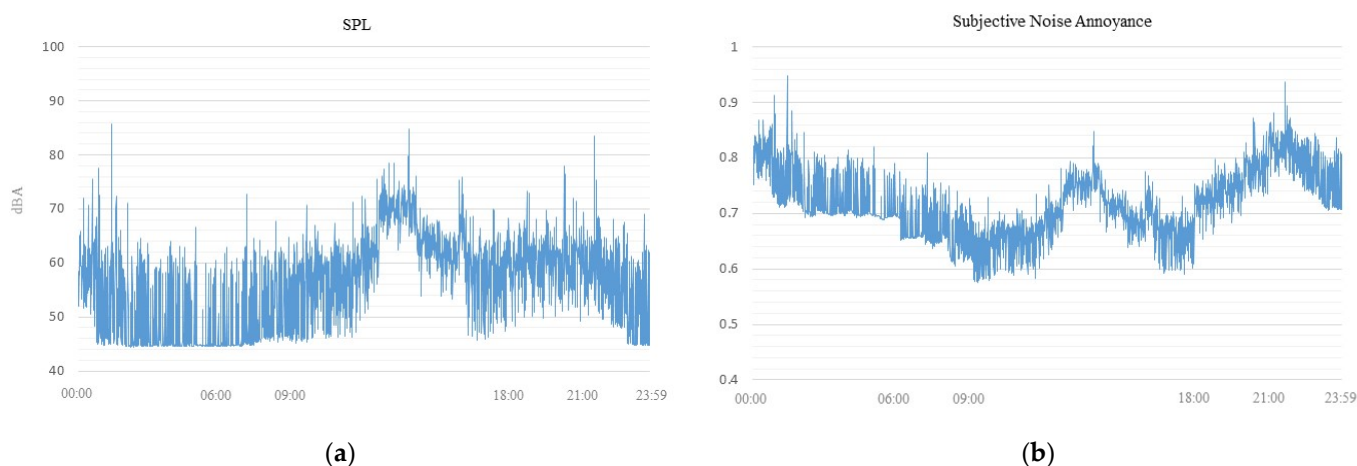


Figure A6. Ayuntamiento Square: (a) The temporal evolution of the SPL over a whole day; (b) subjective noise annoyance as an output of the FRBS.

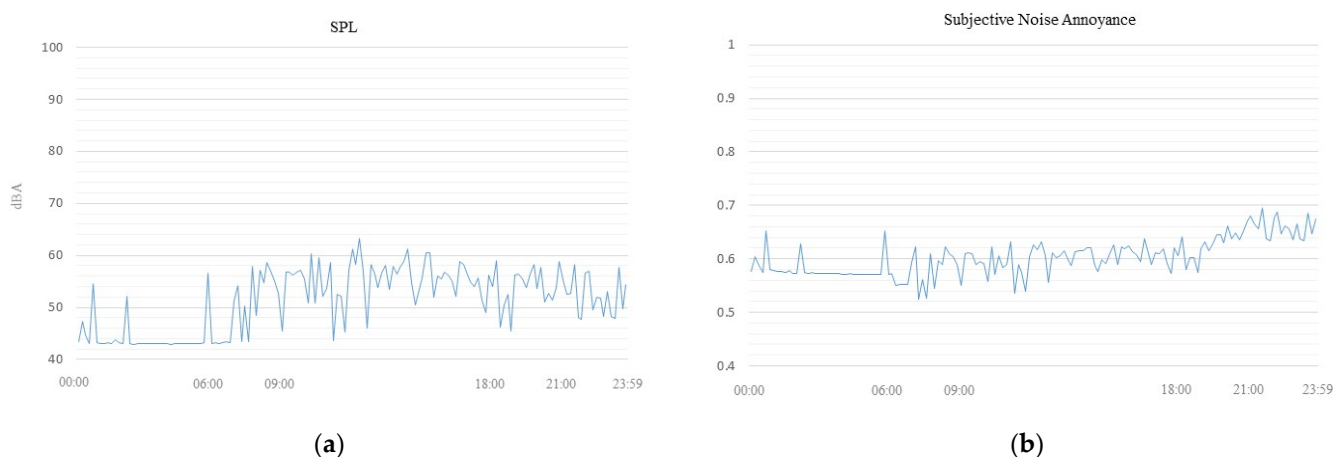


Figure A7. Noruega Street-Sigfox network: (a) The temporal evolution of the SPL over a whole day; (b) subjective noise annoyance as an output of the FRBS.

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Article

Getting Smarter: Blockchain and IOT Mixture in China Smart Public Services

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Abstract: Due to tremendous technological breakthroughs, an increasing number of cities are transforming into “smart cities” utilizing the Internet of Things (IOT), artificial intelligence, or other information technologies. The Chinese government announced that the development of “digital cities smart cities” was a national priority. The goal of this study is to examine the success variables that can influence IOT service adoption aspirations while also serving as a mediator for enhanced security via blockchain technologies. A conceptual model is created with a strong theoretical underpinning and body of literature. The final sample consisted of 1008 participants. This study uses the partial least squares structural equation modelling (PLS-SEM model) to test and analyze the impact of identified variables on the continuous usage intention (CUI) of IOT-based public services. Our findings show that blockchain adoption in smart cities fully mediates the effect of the IOT on CUI and shed the light on the importance of the trust, empowerment, and social influence since the continuous usage intention of the IOT in smart cities is mainly influenced by these factors and enhanced by the application of blockchain.

Keywords: blockchain; IOT service adoption; structural equation modelling; continuous usage intention



Citation: Boustani, N.M.; Xu, Q.; Xu, Y. Getting Smarter: Blockchain and IOT Mixture in China Smart Public Services. *Smart Cities* **2022**, *5*, 1811–1828. <https://doi.org/10.3390/smartcities5040090>

Academic Editors: Véronique Flambard, Sadia Benamrouz-Vanneste and Abir Karami

Received: 11 November 2022

Accepted: 16 December 2022

Published: 19 December 2022

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1. Introduction

Technology has made considerable strides in recent years to support and regulate all facets of life and services. A fully digitized civilization is developing. Government officials want to develop smarter cities where individuals may build more interconnected gadgets and move beyond what was formerly thought to be the limits of human ability. The ways in which people engage and communicate over time, location, and distance are evolving.

The term “Internet of Things” (IOT) refers to a theory or a technology that links all devices and enables internet-based communication between them. IOT devices may be thought of as anything that can be linked to the internet. Researchers and scientists are working to advance the field by developing revolutionary networked systems that enable little items to instantly exhibit superintelligence. Representatives of the government continue to work on implementing policies that will enhance public safety and quality of life.

A city combines communication, water and energy distribution, transportation networks, and infrastructure. Reviewing different smart city definitions and practices throughout the world reveals that most smart cities are defined by three key characteristics: technology (hardware and software infrastructures), people (creativity, diversity, and education),

and institutions (governance and policy). A “smart city” makes use of technology-based planning to modernize the quality of life and lower energy use.

The aim of this paper is to discuss the success elements of IOT-based smart technology innovations for the citizens’ continuous usage intention of IOT-based public services in emerging nations and to answer the following research questions: What societal factors are common when IOT services are adopted? How might blockchain technology be utilized to enhance high levels of security perception for citizens? What are the results of important elements that increase the adoption of IOT-based public services by Chinese citizens?

The context of this study was triggered by the fact that the rising urbanization of the world’s population raises several economic, environmental, and social problems that significantly affect the way of life and quality of life for a large number of people. The concept of a “smart city” provides a chance to address these difficulties and provide a greater quality of life through enhanced intelligent services given the high population density in urban regions; therefore, the Republic of China was chosen since, the Chinese government announced that the development of “digital cities smart cities” was a national priority [1–3].

As may be seen in Rudolf Giffinger’s model, several models typically relate to the same elements. The Smart Economy, Smart Mobility, Smart Environment, Smart Habitats, Smart Lifestyle, and Smart Administration are the six pillars of the smart city. In urban regions with huge populations, mobility is one of the most difficult issues to deal with. By managing infrastructure and public policies connected to the whole transportation system more effectively, smart mobility is enhancing the comfort and safety of commodities and people [4]. It is quite common for people and linked objects to connect anytime, anywhere, with anybody, and with anything [5].

A smart community actively chooses to use technology as a catalyst to address its social and commercial concerns. Rebuilding and revitalizing a feeling of place and, consequently, a sense of civic pride, is the true potential of smart cities [6]. It is a city that connects its social, commercial, IT, and physical infrastructures in order to tap in to the city’s collective intelligence [7]. A smart city develops connected, livable, and sustainable urban centers utilizing all available technology and resources in an intelligent and coordinated way [8]. In order to establish a sustainable, greener city, competitive and inventive commerce, and improved life quality, smart cities link people, information, and city aspects utilizing modern technology [9].

Strong stakeholder and public participation in the development of Smart Cities is the driving force behind the creation of suitable technological solutions that can best address citizen needs [10,11]. This study defines a “smart city” as one where technology, infrastructure, and social consequences all coexist in urban settings to create more useful technology that improves user experience.

Researchers have focused on topics related to blockchain systems and their integration with the IOT and cloud systems in recent years [12]. The B-IOT, or blockchain technology for the IOT, intelligent transportation systems, was described by Rateb et al. [13]. Mamoshina et al. (2018) [14] discussed integrating next-generation artificial intelligence technologies with the blockchain to decentralize and speed up medical research.

Even in our modern society, there is a growing need for Intelligent Transport Systems (ITSs), for instance, since private traffic’s ease comes at a hefty cost in terms of depleting road resources. All areas of technology that ITS will fundamentally alter, such as traveler information management and vehicle control design, depend heavily on human aspects, which are essential to ITS [15].

Numerous researchers have concentrated on various blockchain-based applications. Panarello et al. [16], for instance, analyzed several application areas and divided usage patterns into either device manipulation or data management, development solutions, or difficulties linked to integrating the blockchain into the IOT. Boustani [17] analyzed the impact of blockchain on the banking sector causing a threat to the existing financial ground in a developing country. Blockchain-IOT security was evaluated by Banarjee et al. [18],

who also found a variety of IOT dataset problems that need to be resolved. The authors investigated the current IOT security approaches in depth in terms of intrusion detection and prevention, application classification, network structure classification, predictive security, and self-healing before discussing the blockchain's potential use in securely exchanging data in IOT databases [19].

All modifications to patient information would be validated, merged with other transactions, and added as blocks to longer chains under this blockchain-based standard [20]. The blockchain can help combat dangers such as integrity-based assaults that are overgrowing. Although there is a movement to build a full blockchain node onto IOT devices [21,22], this is currently difficult because of the IOT's restrictions.

In this research, a conceptual model built on a solid body of literature and theoretical background is established in an effort to provide factors for the success of IOT services in the public sector and the mediating role played by blockchain adoption to increase the acceptance of the IOT in smart cities, which is a novel topic tested in Chinese smart cities. A questionnaire was developed in order to study the influence of identified components on continuous usage intention, and it was quantitatively evaluated on users of IOT services.

There are still few research contributions in the literature that focus on the influence of blockchain adoption in smart cities on the continuous usage intention of IOT-based public services. This paper is among the first known to test the mediation effect of blockchain adoption. Our analysis proves that the IOT is expected to have a positive influence on Continuous usage intention (CUI) through blockchain adoption in smart cities.

The authors first present the methods used, the models' variables, and hypothesis tested using SEM (structural equation modeling), and then analyze the impact of identified variables on the continuous usage intention, developed in Section 2. In Section 3, the authors present the results; then, in Section 4, a thorough discussion of the findings and several crucial elements for the fusion of blockchain technologies contributing to the creation of a secured smart society are presented. By establishing a conceptual model that emphasizes the role of perceived security and public value in enhancing the citizens' engagement with IOT services, the authors also discuss blockchain security enhancement solutions, summarizing the key points that can be used for developing various blockchain-based intelligent systems. Finally, the researchers conclude in Section 5 with potential future directions for the technology.

2. Materials and Methods

2.1. UTAUT and Blockchain Adoption

The authors developed a research model based on the Unified Theory of Acceptance and Use of Technology (UTAUT), one of the technology acceptance models [23]. The UTAUT has been used by many information success researchers in the past to pinpoint the factors that influence continuous usage behavior in EGS.

Our paper aims to discuss the successful elements of IOT-based smart technology innovations for citizens' continuous usage intention of IOT-based public services in emerging nations. The results of this study will aid the government in overcoming the socio-technical challenges of IOT-based public services' consequences in order to provide citizens with better e-services.

The government frequently brings up the Internet of Things (IOT) when discussing the potential uses of linked gadgets. If policymakers can convince citizens to participate in the discussion, governments are the best testing grounds for actual, practical, and useful IOT applications [24]. Understanding when and how these technologies will assist the government economically and socially is necessary in order to comprehend the significance of IOT in public services.

The actual benefit of the IOT for the public sector is the potential for data aggregation from several sources [25], allowing the government to gather information on citizens' living conditions. The Internet of Things (IOT) lends itself naturally to applications in smart buildings, smart transportation, and smart water management, as well as the capacity

to monitor programs that can increase public safety. In densely populated cities, traffic congestion is a serious issue. IOT traffic applications have a lot of potential real-world solutions to this issue. Real-time data input is utilized by traffic signals to reduce traffic congestion [26].

Da Nang city's Internet of Things-based traffic initiative regulates traffic signals in accordance with traffic flow [27]. To gather, combine, and store traffic data, IOT frameworks employ traffic cameras and wireless networks. This information may be used to promptly solve various issues and accidents that cause traffic jams [28].

The Unified Theory of Acceptability and Use of Technology (UTAUT) is used to create the strongest link between the level of acceptance and ongoing use of the IOT by citizens [23]. It is now the most popular idea for determining whether new technology will succeed in terms of adoption and long-term usage intentions [29].

UTAUT has shown that it might be a valuable instrument for gauging the success and acceptability of new technologies such as the IOT because it is frequently used to assess the usage of information systems in public sector services within various geographic contexts. In order to acknowledge the high capacity of the UTAUT model in projecting the usage of the IOT, as well as its frequency of use in public sector research, we agreed to utilize the UTAUT model by expanding relevant variables in this study.

2.2. Data Collection

A questionnaire was designed to collect the data. Our questionnaire aimed to collect data to research the impact of the Internet of Things (IOT) in improving people's continuous usage intention of the IOT through blockchain adoption. A total of 1500 people were contacted by mail or phone and prompted to fill out the questionnaire. The final sample consisted of 1008 participants, eliminating unengaged respondents and questionnaires with missing values. The participants were randomly chosen from a list on the Credamo platform (Credamo is a professional research and modelling integrated Chinese data platform). The Credamo platform is an online Chinese survey platform with more than 3 million registered participants. Data were collected from June to September 2022.

The construct was divided into:

- Part 1: Sociodemographic (12 items)
- Part 2: Information Privacy Value (4 items)
- Part 3: Public Trust Value (4 items)
- Part 4: Social Influence Value (4 items)
- Part 5: Digital Society Affinity Value (4 items)
- Part 6: Public Value (4 items)
- Part 7: Continuous Usage Intention (4 items)
- Part 8: Citizens Empowerment Value (4 items)
- Part 9: Blockchain implementation impact (5 items)

A five-point Likert scale was used to measure the participants' opinions regarding the different variables under study: 1 (totally disagree), 2 (disagree), 3 (neither agree nor disagree), 4 (agree), and 5 (strongly agree). For the purpose of this study, all the variables were carefully examined, tested, and studied using SmartPLS software to test the suggested partial least squares structural equation modelling (PLS-SEM) model and to analyze the impact of identified variables on the continuous usage intention.

2.3. Hypothesis Statements

2.3.1. Public Trust Value (PTV)

Public trust and acceptability in IOT services will be essential to create public value [30,31] as it enriches government performance [32]. Digital public sector platforms have entered many different cultures [33], and as diminished public trust eventually leads to diminished public perceptions of values, public trust values play a crucial part in the creation of a smart society. The likelihood of public trust is a valuable predictor of citizens' behavioral intention to utilize digital services [34]. According to Alshehri et al. [35], public trust is

regarded as a potent construct in research studies on EGS and emphasizes the positive social interaction effect on citizens' propensity to utilize EGS. The acceptance of IOT services and their effective integration into digital societies depend on the general public's confidence in emerging technology.

H1a: *Public trust value (PTV) is a first-order dimension of the IOT.*

2.3.2. Social Influence Value (SIV)

Social influence presents a personal perception of some product or certain service that could be highly influenced by others' perceptions. The social influence could profoundly impact people's daily behavior, especially in technology adoption. According to the Unified Theory of Acceptance and Use of Technology (UTAUT), the social influence factor could impact consumer adoption of new technology. Some studies have shown that factors related to social influence could positively affect IOT technology adoption [36,37].

H1b: *Social influence value (SIV) is a first-order dimension of the IOT.*

2.3.3. Digital Social Affinity Value (DSAV)

Affinity was found to be a key factor influencing customers' probable usage intention in a study by Bigne et al. [38]. The current study explains digital society affinity as citizens' perceived importance of e-gov IOT services in the public sector. The word "affinity" describes how citizens view the importance of the media in their life [39]. It was created based on Rogers' [40] earlier concept of compatibility, which he described as "the extent to which a new idea is perceived to be compatible with prospective adopters' current beliefs, previous interactions, and needs." Governments all around the world are very concerned about how to incorporate public values into the technological and socioeconomic architecture of digital societies [33]. Affinity is defined in the current study as "the value or belief that people place on the digital society." Since it has the potential to be one of the most accurate metrics for the effectiveness of public sector IOT services in digital societies, the affinity with the digital society should be investigated.

H1c: *Digital social affinity value (DSAV) is a first-order dimension of the IOT.*

2.3.4. Public Value (PV)

Public value is the overall value created by the government for the people through various initiatives that involve the people in the value-generation process. Citizens' perceptions of the public benefit of using IOT services are implied when they think that IOT will significantly improve the effectiveness of public services. The perceived value of citizens against IOT utilization in the public sector will depend on how valuable and private they believe their information to be [41]. By boosting the effectiveness of IOT services, public trust enhances governmental performance [30,31], which may successfully result in the development of public value. According to a study of Harrison et al. [42], we have combined social influence with public worth. An individual's social identity qualities work together to form social influence, which has a substantial impact on how likely they are to use government services [42,43].

Previous research has demonstrated that some forms of public participation are more conducive to civic empowerment (i.e., public effect) than others, although agreement on these conclusions has been difficult to come by. According to Buckwalter [44], public participation is more conducive to public empowerment (i.e., public influence) and presents a special chance to enhance the way that citizens interact with the government.

According to Chatfield and Reddick [45], the IOT is a particularly popular feature in digital societies because it enables real-time sensing technologies that can unleash the potential of an intelligent government. AI and the IOT have the ability to offer beneficial public services in many different domains [46].

H1d: *Public value (PV) is a first-order dimension of the IOT.*

2.3.5. Citizen Empowerment Value (CEV)

Giving citizens participatory power in various areas of policymaking is what the concept of “citizen empowerment” is all about [47]. In addition, the ability of citizens to participate in developing IOT services for e-government is evaluated using this idea. Further, it would enable us to assess residents’ ardent support for the development of citizen-centered service orientation [41,48]. The provision of communication tools, such as the internet, mobile applications, websites, and government portals, is not the sole factor in fostering citizen involvement. To citizens, civic culture continues to be a crucial component of the implementation of the participation process. Engaging citizens in the public policymaking process attempts to make a difference in society by fostering discussion and sharing individual opinions about public policy [49].

H1e: *Citizen empowerment value (CEV) is a first-order dimension of the IOT.*

2.3.6. Blockchain Applications

Blockchain applications play a vital role in numerous IOT-oriented applications, and IOT could utilize blockchain technology as a security solution to ensure the data’s integrity [50,51]. Moreover, Blockchain application can enhance the usage of smart contract in insurance fields for instance or even during pandemics [52]. According to the study of Endale Mitiku Adere [53], the IOT is widely used, for instance, in smart home scenarios and the healthcare sector, and blockchain technology “reinforces IOT data’s privacy, integrity, and security and improves the trust in transactions among untrusted IOT devices.”

H2: *The IOT is expected to have a positive influence on blockchain adoption in smart cities.*

H3: *Blockchain adoption in smart cities is expected to have a positive influence on Continuous usage intention (CUI).*

H4: *The IOT is expected to have a positive influence on Continuous usage intention (CUI) through blockchain adoption in smart cities.*

2.4. The Conceptual Model

First, for the model, the IOT was taken as the independent variable, CUI was taken as the dependent variable, and blockchain adoption in smart cities was taken as the mediating variable.

Second, in the model, the IOT was taken as a high-order formative variable, and CUI and blockchain adoption in smart cities were taken as the reflexive variables. Therefore, for the formative variable IOT, five hypotheses, namely H1a to H1e, PTV, SIV, DSAV, PV, and CEV, the first-order dimensions of the IOT, were proposed to verify whether the IOT is a formative variable.

The proposed conceptual framework is presented in Figure 1 below:

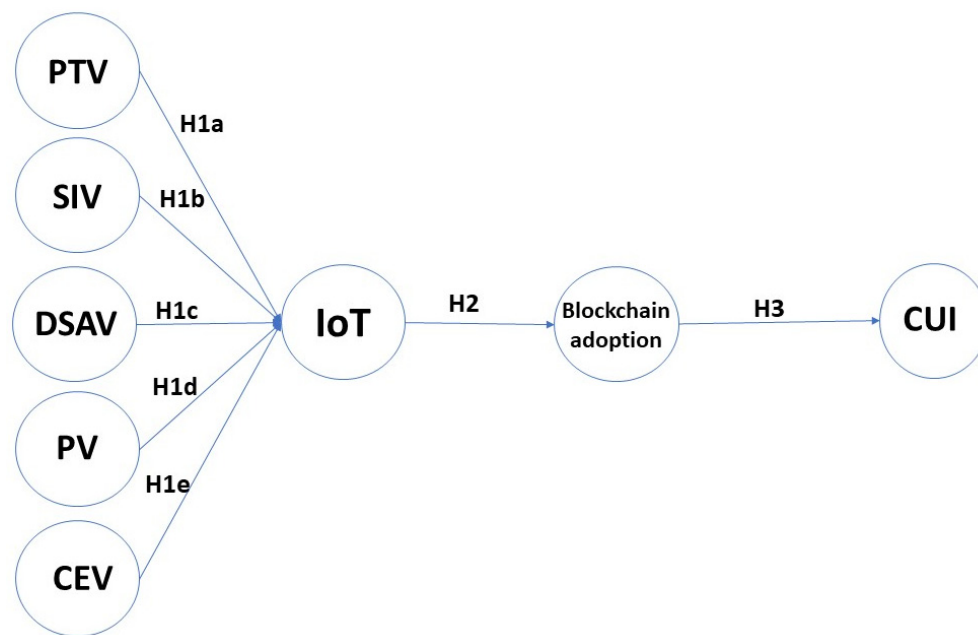


Figure 1. Conceptual Framework.

3. Results

3.1. Sample Characteristics or Sociodemographic

According to the sample of 1008 participants, 61.9% of participants were feminine, and 38.1% were masculine. Overall, 95% of the participants lived in urban areas of China. Most participants (78.17%) were educated with a bachelor's degree, and the majority (84.72%) were between the age of 18 and 39. The top three working fields of participants were manufacturing (18.45%), information and communication (15.97%), and education (11.31%).

3.2. Model Validation

3.2.1. Data Analysis Technique

This study used partial least squares (PLS) to estimate the proposed hypotheses. PLS is a multivariate approach adopted to assess the measurement scale's reliability and validity and estimate Structural Equation Models (SEM) [54]. PLS provides predictive tools to evaluate and validate exploratory models and efficiently estimates path models' coefficients characterized by small sample size [55]. PLS is an appropriate multivariate data technique due to its high capacity to achieve acceptable power at small sample sizes [56]. The path model in PLS has two components: a measurement model and a structural one. PLS enables the assessment of the reliability and validity of the constructs used and the estimation of the structural model path coefficients [54]. It uses bootstrapping, a resampling technique that generates a set of subsamples based on the original one, to calculate confidence intervals of the model parameters [55]. Smart-PLS 3 software with a bootstrapping of 5000 samples was used to conduct the statistical analysis [57].

Partial least squares structural equation modelling (PLS-SEM) is an alternative to the covariance-based structural equation modelling (CB-SEM) commonly used in Lisrel, AMOS, and EQS applications.

PLS-SEM is advocated when the research objective is to explore theoretical extensions of established theories, where latent variable models contain formative structures, and where sample sizes are relatively small but structural models are complex. It does not make distributional assumptions. It is argued that the highly statistical power of PLS-SEM enables better identification of the relationships between latent variables compared to CB-SEM [58].

3.2.2. Reflective Measurement Model Evaluation

The higher-order latent variable studied, the IOT, is a formative variable, and the underlying argument is that higher-order reflective variables are redundant [59]. It can be argued that the IOT should be considered as a formative variable using the decision rules developed by Jarvis et al. [60]. In this study, PTV, SIV, DSAV, PV, and CEV are the dimensions of the IOT. For example, changes in the structure (IOT) do not necessarily lead to changes in all structure dimensions.

The method for measuring relationship quality as a second-order formation variable in this study is that recommended by [61], namely the repeated indicator B model, in which all indicators of first-order variables used to form second-order variables are repeated as formation measures of second-order variables.

The validity and reliability of the measurement model for reflectively measured latent variables are examined first:

Assess internal consistency reliability using composite reliability (CR) scores. CR scores should exceed 0.6 for exploratory research, preferably 0.7 for established measurement scales [62]. Note that Hair et al. [58] recommend this as a better measure than Cronbach's Alpha (the alternative measure of internal consistency).

As for the Structural Model R2 Values, the R2 value is a measure of the model's predictive power in relation to endogenous variables (latent variables that are predicted by other latent variables). Values of 0.75, 0.5, and 0.25 can be described as substantial, moderate, or weak [58] From Table 1, it can be seen that substantial values were obtained, with CUI being slightly less than moderate.

Table 1. R2 in Structural Model.

	R Square	R Square Adjusted
Blockchain adoption in smart cities	0.549	0.549
CUI	0.423	0.423
IoT	0.990	0.990

Structural Model Effect Size f2 Values

The effect size metric indicates whether an exogenous (independent) latent variable has a significant effect on the R2 values of the model [62]. Values for f2 of 0.02, 0.15, and 0.35 are representative of small, medium, and large effects. The f2 values are summarized in Table 2 and small or greater effect sizes are highlighted in bold, showing the insignificant impact on R2 values and strongly corresponding to the insignificant paths identified above. Note that f2 values for formative variables should be ignored as formative variables have been fully explained previously.

Table 2. Structural Model Effect Size f2 Values.

Path	f-Square
IoT -> Blockchain adoption in smart cities	0.217
Blockchain adoption in smart cities -> CUI	0.734
CEV -> IoT	1.994
DSAV -> IoT	2.422
PTV -> IoT	2.335
PV -> IoT	3.036
SIV -> IoT	2.271

For Convergent Validity, the authors first looked at the outer loadings (known as indicator reliability) As a minimum, the outer loadings of all indicators should be statistically

significant. In addition, the standardized outer loadings should be greater than 0.708. For “Formative Convergent Validity,” the authors tested whether the formatively measured construct (IOT) is highly correlated with a reflective measure of the same construct using other measures. Ref. [58] stated that the strength of the path coefficient linking the two constructs is indicative of the validity of the designated set of formative indicators in tapping the construct of interest, such that the loading of the formative to the reflective construct is at least 0.7 and preferably > 0.80 , which translates into an R^2 value of 0.64 ($0.802^2 = 0.64$)—or at least 0.50 ($0.72 \approx 0.50$) [58]. Second, the authors looked at the Average Variance Extracted (AVE). AVE values should be greater 0.5 [58]. It can be seen that all variables in the measurement model have an $AVE > 0.5$.

The authors dropped several items that did not meet validity or reliability requirements. The table below shows scores for retained variables in terms of loadings, CR scores, and AVE scores. As can be seen from the Table 3, all the tests described in the methodology chapter regarding reliability and convergent validity were met (in particular, composite reliability scores all exceeded 0.7, and AVE scores all exceeded 0.5).

Table 3. Reliability and Convergent Validity of Reflective Measures.

Factor	Construct Items	Loading	<i>p</i> Values	CR	AVE
Public trust value (PTV)	Q2.2	0.778	0.000	0.817	0.598
	Q2.3	0.755	0.000		
	Q2.4	0.787	0.000		
Social influence value (SIV)	Q3.2	0.746	0.000	0.798	0.552
	Q3.3	0.750	0.000		
	Q3.4	0.764	0.000		
Digital social affinity value (DSAV)	Q4.1	0.815	0.000	0.843	0.642
	Q4.3	0.799	0.000		
	Q4.4	0.789	0.000		
Public Value (PV)	Q5.1	0.723	0.000	0.802	0.574
	Q5.2	0.744	0.000		
	Q5.4	0.804	0.000		
Citizen empowerment value (CEV)	Q8.1	0.786	0.000	0.820	0.603
	Q8.3	0.779	0.000		
	Q8.4	0.764	0.000		
Blockchain adoption in smart cities	Q7.1	0.784	0.000	0.833	0.625
	Q7.3	0.828	0.000		
	Q7.5	0.759	0.000		
Continuous usage intention (CUI)	Q6.1	0.755	0.000	0.786	0.551
	Q6.2	0.735	0.000		
	Q6.4	0.736	0.000		

Discriminant validity refers to the degree to which each latent construct is truly distinct from other constructs empirically, capturing phenomena or aspects of the model that are not captured by other constructs. Discriminant validity should be assessed using the HTMT criterion. HTMT values should all be below 0.9 [58]. Sometimes, for some variable pairs, the value may exceed 0.9. We can ignore any pairs, including a second-order formative variable [63]. We would deal with the problem by removing measures for variables in the remaining pairs which have weaker loadings [58] (or by changing the measurement model with new constructs [58]). Table 4 shows that the criteria are met.

Table 4. Discriminant Validity of Reflective Measures.

	Blockchain Adoption in Smart Cities	CEV	CUI	DSAV	IOT	PTV	PV
CEV	0.857						
CUI	0.209	0.382					
DSAV	0.899	0.463	0.866				
IOT	0.729	0.768	0.056	0.441			
PTV	0.850	0.633	0.670	0.815	0.343		
PV	0.651	0.560	0.150	0.884	0.791	0.578	
SIV	0.852	0.485	0.872	0.309	0.076	0.891	0.418

3.2.3. Formative Measurement Model Evaluation

For “Formative Convergent Validity,” the authors tested whether the formatively measured construct (IOT) is highly correlated with a reflective measure of the same construct using other measures, such that the loading of the formative to the reflective construct is at least 0.7, and the R2 value of the reflective construct is at least 0.5, preferably >0.64. [58]. First, the authors looked at the outer loadings (known as indicator reliability) and added the adequate references as well. So, as a minimum, the outer loadings of all indicators should be statistically significant. In addition, the standardized outer loadings should be greater than 0.708 (generally, 0.70 is considered close enough to 0.708 to be acceptable) [58]. Ref. [58] stated that the rationale behind this rule can be understood in the context of the square of a standardized indicator’s outer loading, referred to as the communality of an item. An established rule of thumb is that a latent variable should explain a substantial part of each indicator’s variance, usually at least 50%; this means that an indicator’s outer loading should be above 0.708 since that number squared (0.7082) equals 0.50 [58].

As illustrated in Figure 2 below, a minimum loading of 0.7 between the formative and reflective latent variables for the IOT was attained in accordance with Hair et al.’s [58] recommendations.

3.2.4. Structural Model Evaluation Results

The estimation results are presented in Figure 3. The estimation results of the path coefficients are shown in Table 4. The results show that PTV, SIV, DSAV, PV, and CEV had significant positive effects on the IOT and demonstrate that the IOT is a formative variable composed of them. This provides support for hypotheses H1a, H1b, H1c, H1d, and H1e.

Furthermore, Table 5 shows that the IOT has a significant positive effect on blockchain adoption in smart cities ($\beta = 0.741, p < 0.05$), and blockchain adoption in smart cities has a positive and significant effect on CUI ($\beta = 0.651, p < 0.05$). Hypotheses H2 and H3 are supported. Table 3 also shows that the IOT influences CUI through blockchain adoption in smart cities ($\beta = 0.482, p > 0.05$). Blockchain adoption in smart cities is assessed as mediating the influence of the IOT on CUI. H4 is supported.

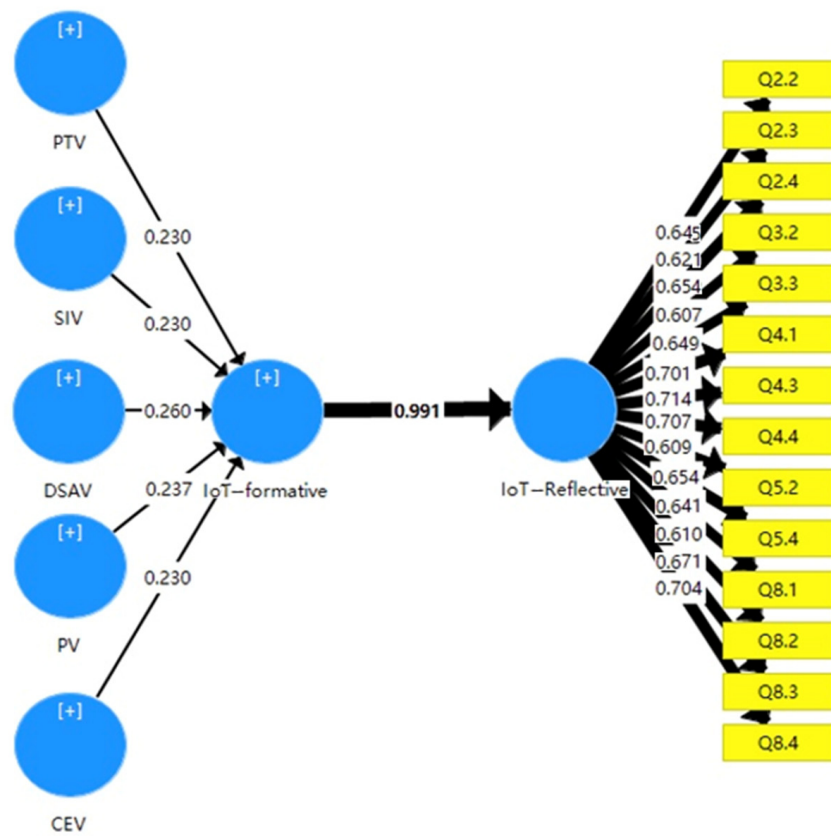


Figure 2. IOT Formative Convergent Validity.

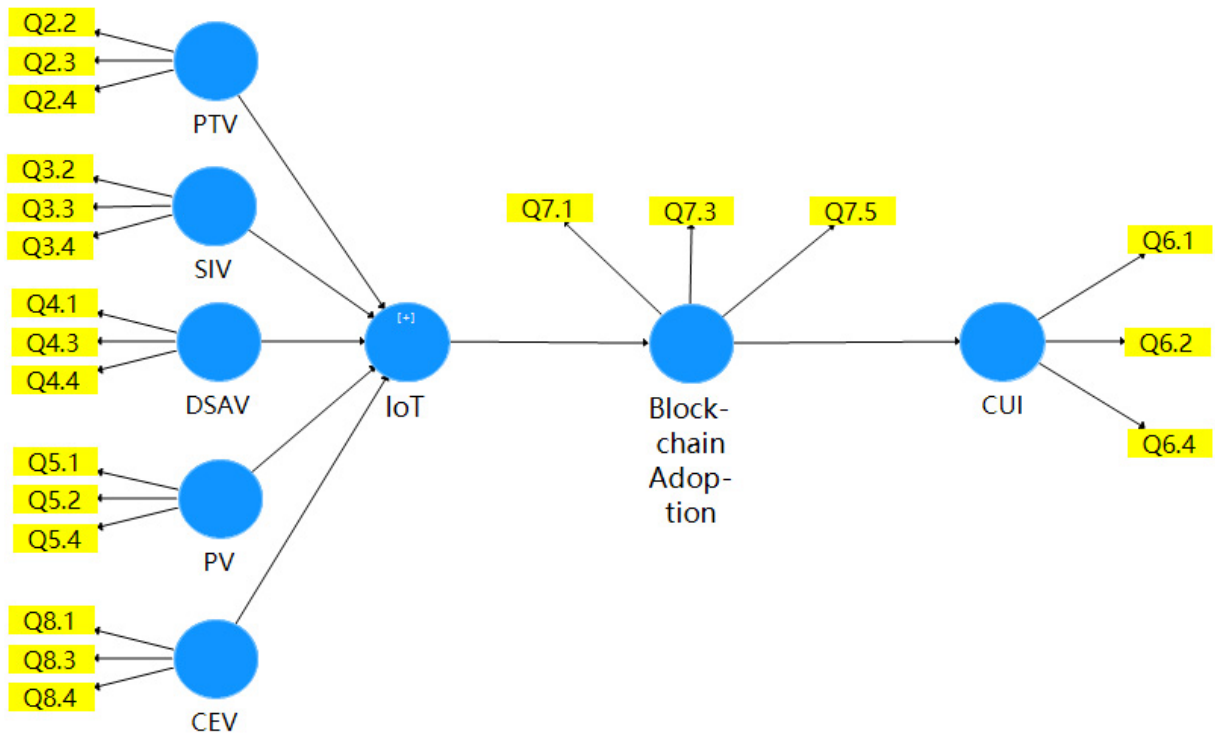


Figure 3. Estimation result.

Table 5. Structural Model Results.

Relationships	Hypothesis	Loading	Standard Deviation (STDEV)	<i>p</i> Value	Hypothesis Verification
PTV → IOT	H1a	0.222 ***	0.009	0.000	Supported
SIV → IOT	H1b	0.220 ***	0.009	0.000	Supported
DSAV → IOT	H1c	0.261 ***	0.012	0.000	Supported
PV → IOT	H1d	0.249 ***	0.011	0.000	Supported
CEV → IOT	H1e	0.231 ***	0.010	0.000	Supported
IOT → Blockchain adoption in smart cities	H2	0.741 ***	0.023	0.000	Supported
Blockchain adoption in smart cities → CUI	H3	0.651 ***	0.029	0.000	Supported
IOT → Blockchain adoption in smart cities → CUI	H4	0.482 ***	0.034	0.000	Supported

*** ($p < 0.001$).

The results of the mediating effect of each variable in the model through the other variables (individual paths). A mediating effect exists if the coefficient of the indirect effect is significant at $p < 0.05$. In particular, as shown in the Table 6, blockchain adoption in smart cities fully mediates the effect of the IOT on CUI.

Table 6. Mediation Analysis Results.

	Loading	Standard Deviation (STDEV)	T Statistics	<i>p</i> Values
CEV → IOT → Blockchain adoption in smart cities → CUI	0.112 ***	0.007	16.826	0.000
DSAV → IOT → Blockchain adoption in smart cities → CUI	0.126 ***	0.007	18.041	0.000
PTV → IOT → Blockchain adoption in smart cities → CUI	0.107 ***	0.008	14.101	0.000
PV → IOT → Blockchain adoption in smart cities → CUI	0.120 ***	0.012	10.220	0.000
SIV → IOT → Blockchain adoption in smart cities → CUI	0.106 ***	0.008	13.402	0.000
IOT → Blockchain adoption in smart cities → CUI	0.482 ***	0.034	14.021	0.000

*** ($p < 0.001$).

4. Discussion

The Internet of Things (IOT) has arisen as a field with enormous potential influence with the development of smart networks such as smart homes and cities. According to the European Commission, it is expected that there will be between 50 billion and 100 billion devices connected to the Internet by 2020 [64]. First, IOT usage and its public nature raise some security and privacy issues. Integrity, confidentiality, location privacy, authentication, non-repudiation, confidentiality, anonymity, certificate revocation, and certificate verification are some of the difficulties that must be overcome.

According to questions related to social influence value, the authors found that (1) people with influential personality using IOT services will influence IOT services adoption; (2) IOT services adoption would help people feel accepted by the society; (3) peers' opinion is important to influence IOT services adoption.

Blockchain has contributed significantly to the effective improvement of connection through the IOT during the last few years. Blockchain technology confronts various technological obstacles, many of which are connected to security and privacy, trust, scalability, and commercial risks, even though it has enormous implications for future smart network settings. Numerous academics have concentrated on smart contracts' security issues, including those in Ethereum, bitcoin, and wallet contracts [65,66].

In addition, data may be gathered in real time from several different areas, simplifying the decision-making process [67,68]. This technology is becoming standard as time goes on, moving from being a premium feature. Every gadget will come with it pre-installed, and ultimately, people will feel pressured to acquire and incorporate it into their daily lives. Moreover, citizens will continue to use it, as found in this research, because they know the utility of blockchain implementation and its advantages.

On the security level, there are such a lot of unresolved problems and obstacles. Both physical presence and technology mechanisms and instruments are necessary for security, which might lessen the level of trust among users. Considering all the many people whose lives are influenced by technology as algorithms and AI are integrated into our daily lives, the mediating role of blockchain will increase their trust and reduce the perception of an unsecured environment, as shown in this paper, where most respondents are aware of the importance of technology, IOT in their e-services procedures, and blockchain adoption.

On a practical and empirical point of view, large corporations' security infrastructure may be strengthened with the help of the IOT and blockchain, as well as for data extraction and analysis. Open ledgers can enable the fault-proof integration of connected devices in smart networks with blockchain IOT solutions, removing problems such as data transparency and end-to-end process tracking, transaction automation and verification, real-time data exchange across the network, limitations of cloud-based IOT platforms (such as stress-free scalability), IOT data analytics, and network issues [69].

On the theoretical side, this model and the study's findings add to the literature already in existence [70,71] by developing a framework of IOT prolongation in public services and by effectively explaining the mediating effect of blockchain leading citizens' continuous usage behavior of the IOT in smart cities making them smarter.

It is essential to keep in mind that while many of the same security and privacy vulnerabilities still exist in today's smart cities, they do not happen as frequently as they do when these technologies are completely networked.

Stakeholders must work together to find solutions to the security and privacy problems smart cities confront to stop some issues from affecting the rest of the intelligent network. To help foster the development of the necessary smart technologies, ambitious security experts and smart city planners must take advantage of existing sustainable cities and initiatives. The current concerns and efforts to address these security difficulties and issues will determine the secure construction of the smart sustainable communities of the future. The usage of blockchain has a significant part in adding solutions to all these problems, and as seen in the research findings, the population perceived all blockchain technology to be advantageous.

According to the United Nations (UN), the rate of urbanization will surpass 60% in 2030. This development is the outcome of a change in living habits that makes it possible for many people to be more connected and knowledgeable. The perception of the space that enables people to appropriate the premises, particularly from a visual and auditory point of view, is a major factor in this phenomenon, which is where architects and urban planners come into play [71].

The area cannot be separated from its surroundings and can be impacted by them. This idea is true on a regional, national, and even worldwide level.

According to Galichet F. [72], the idea of security and trust is not only a concept that ensures both peace and the absence of crime, but it is also a condition of equilibrium in which a person may truly feel at peace with himself. In every aspect of a person's everyday existence, security is considered. Almost every element of life is impacted [73].

Axworthy L. [74] claimed that there are seven main components that make up human security: social security, individual security, national security, political security, environmental security, food security, and economic security. Layers of security are utilized to safeguard citizens and their possessions, which define human security.

Threats to security change with time and geography. New approaches to design, especially in the area of security, stimulate the designer to think differently. In addition

to being regarded in terms of their security, incorporating new security technologies into daily life has altered how the world perceives trust and security [75].

Moreover, the power of AI has been extended into government services and city experiences to improve citizens' lives. Real-time data from connected devices, such as vehicles, for instance, in terms of position, speed, and acceleration, can reflect driving behavior and be useful in identifying aggressive driving.

Therefore, the increased advantages of the IOT through blockchain can be considered on different levels and have several implications in diverse sectors.

5. Conclusions

The challenges that the IOT faces in smart cities were covered in this paper, along with some possible blockchain-based solutions. Future IOT public services will need to be implemented more successfully and sustainably; hence, a framework for combining blockchain with the IOT was created based on the mediating role of blockchain in the conceptual model tested on Chinese citizens.

By strengthening the overlap between government and technology, an advancement and a new way of life will occur. Using IOT networks and sensors is a new approach to govern the physical world. Technology is a crucial instrument for improving the lives of individuals, and adding trust to its implementation and continuous usage through blockchain can add more advancement in the usage and application of e-services.

The smart city sector is transforming because of the convergence of blockchain and AI. Companies, governments, and even entire nations come together because of it. Due to its decentralized structure and peer-to-peer features, blockchain-AI technology is well known and highly regarded. By examining the numerous difficulties in various facets of sustainable smart cities, we explored the various security concerns and obstacles preventing blockchain-AI technology adoption in this study. Finally, we addressed some potential future paths for the technology, and we covered blockchain security solutions for smart cities.

The extraordinary rise of the Internet of Things (IOT) has created new opportunities for the community, including methods for accessing and exchanging information. However, a lack of confidence is one of these programs' most significant weaknesses. Due to flaws in the security and integrity of data transfers, businesses have encountered several difficulties adopting the IOT. This subject is unique because of all the characteristics mentioned above, making it innovative and worthy of this research. In addition, a return will be provided on the existing literature. Advancing co-design and systems engineering practices in smart cities in order to improve a prototype intelligent service system will not only be smarter but also kinder and more citizen-trust-centered.

The investigation of the advancing co-design and systems engineering practices in smart cities allowed us to:

- Evaluate the effectiveness of the new strategies aiming to ensure security in smart sustainable cities;
- Improve the safety of the individuals and their goods;
- Study the effect of environmental and lifestyle factors of the IOT and blockchain adoption;
- Determine the effects of the IOT in the society;
- Design and advocate for a more trusted Internet of Things to make cities and human settlements inclusive, safe, resilient, and sustainable.

6. Limitation and Future Work

This study suffers some limitations which can open the gate for a new stream of research. First, data and service security worries are becoming more prevalent. A person can suffer significant harm from even a small item that is lost, stolen, hacked, misplaced, or exposed. In future work, the authors will consider proposing a system based on the findings of [76] that successfully raises the cybersecurity of images against a variety of attacks in terms of robustness and efficacy in order to face and deactivate these issues when

transmitting data in wireless broadcasting circumstances; this system will increase citizens' trust in the continuous usage of the IoT.

In addition, the Edge-Cloud architecture is made with dynamic properties and real-time reaction requirements in mind to achieve smart manufacturing by efficiently acquiring, processing, analyzing, and storing factory-generated data [77]. So, in order to increase smartness and efficiency, the authors aim to conduct another future study related to deep learning-based algorithm.

In line with the current study, it will be interesting to see how the introduction of certain disruptive changes, such as financial innovations, can change the traditional usage of public services or banking services in several countries [78]. It will also be interesting to increase the sample and include other less-developed countries to replicate the results and check whether differences exist. This study was conducted in the context of an emerging economy and was based on one country; this limits the capability to generalize the results to other countries, as the explanatory variables may vary across countries.

Moreover, this study adopted a quantitative approach. It would be interesting to add a qualitative approach to evaluate the real effect of the various factors included in the model on blockchain adoption in increasing the usage of the IOT.

Author Contributions: Conceptualization, N.M.B. and Q.X.; methodology, N.M.B., Q.X. and Y.X.; software, Y.X.; validation, N.M.B., Y.X. and Q.X.; formal analysis, Y.X.; investigation, Q.X.; resources, Q.X. and N.M.B.; data curation, Q.X.; writing—original draft preparation, N.M.B., Q.X., and Y.X.; writing—review and editing, N.M.B. and Q.X.; visualization, N.M.B. and Q.X.; supervision, N.M.B., Q.X. and Y.X.; project administration, N.M.B. and Q.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This research was implemented taking care to ensure all ethical standards and followed the guidelines of the Declaration of Helsinki. The development of the study by questionnaire survey was approved by the ethics committee of Saint Joseph University of Beirut (Reference No.USJ-2022-230).

Data Availability Statement: Data are available from the corresponding author upon request.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

Exploring Key Aspects of an Integrated Sustainable Urban Development Strategy in Greece: The Case of Thessaloniki City

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Abstract: Even though efforts have been made in recent decades to revive urban areas in the European Union (EU), the contemporary challenges that mostly large cities face require continuous support and adjustments in urban policies. Under the EU Cohesion Policy for the 2014–2020 programming period, the integrated territorial development of various specific areas is pursued by the Integrated Territorial Investments (ITI). In Greece, many of these programs concern Integrated Sustainable Urban Development Strategies (ISUDSs). One of these is the ISUDS of Thessaloniki, which is perhaps the most complex in terms of management and implementation in Greece, mainly due to the chosen managerial approach and the size of Thessaloniki, the second largest city in the country. Thessaloniki's ISUDS is managed by the Urban Authority (UA), which has already evolved into a separate model of metropolitan governance administration. The aim of this paper is to identify the determinants in its design and implementation, as well as the effects of the strategy on urban development through the assessment of its strengths and weaknesses, as well as the opportunities and prospects of strategy through the Delphi approach.



Citation: Chatzitheodoridis, F.; Melfou, K.; Kontogeorgos, A.; Kalogiannidis, S. Exploring Key Aspects of an Integrated Sustainable Urban Development Strategy in Greece: The Case of Thessaloniki City. *Smart Cities* **2023**, *6*, 19–39. <https://doi.org/10.3390/smartcities6010002>

Academic Editors: Véronique Flambard, Sadia Benamrouz-Vanneste and Abir Karami

Received: 18 November 2022

Revised: 10 December 2022

Accepted: 19 December 2022

Published: 21 December 2022



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Keywords: integrated territorial investment (ITI); integrated sustainable urban development strategy (ISUDS); urban authority (UA); metropolitan unit of Thessaloniki (MUTH); Delphi analysis; SWOT Analysis

1. Introduction

The first strategies with a territorial, spatial dimension were launched in the early 1990s as Community Initiatives. The Community Initiatives, Leader (I, II and +), Urban (I and II), and Urbact (I, II and III), referred to integrated rural and urban development, respectively. Apart from their territorial dimension, these programs could also be classified according to their design and implementation. Hence, there have been integrated local development strategies following the bottom-up approach and programs (such as PRODER and Integrated Rural Development Programs IRDP) from the top-down. Integrated urban development programs, such as the Integrated Interventions and the Urban Development Plans 2007–2013, were designed and implemented mainly through local authorities. The concept of ‘localness’ in all these programs was mainly concerned with interventions in homogeneous rural micro-regions or residential areas or neighborhoods. Although integrated spatial strategies and development plans did not command significant financial resources in any programming period [1–3], they were characterized by their innovation and the high demonstrability of their interventions [4]. Their success has led them either to be integrated into European policies or to become development ‘models’ of spatial approach [5]. In the 2014–2020 programming period, the EU moved towards broader implementation of integrated territorial development policies and adopted tools such as

the bottom-up approach and multi-budgetary funding [6], while this approach continues in the new programming period 2021–2027.

In the context of the 2014–2020 Cohesion Policy, interventions are implemented under the term Integrated territorial investments (ITIs), which aim to enhance the sustainable development of larger areas to ensure synergies in investments supported by European structural and investment funds [7]. ITIs is an integrated spatial development instrument, for implementing development strategies in particular areas (sub-regional or inter-regional, rural or urban) that face specific problems or have significant development potential that needs to be addressed as a whole within a development plan. Improving the economic situation and employment, improving the daily life of citizens, and preserving the natural and built environment are key objectives [8,9]. They are characterized as multi-budgetary in their funding, multi-sectoral in their objectives, and with a local socio-economic foundation in their design. Specifically, in Greece, the framework of the ITIs includes Integrated Sustainable Urban Development Strategies (ISUDS) in cities with more than 10,000 inhabitants and those for non-urban areas with a clear spatial and developmental direction [10,11].

The city of Thessaloniki is the second most populous city in Greece [12], located in the northern part of the country, and belongs to the region of Central Macedonia. The city's problems are significant and have been accumulating [13], while urban interventions in the last decades could be considered limited and have been mainly funded by EU resources. For the first time, an integrated approach to the urban development of the city has been pursued through the Thessaloniki ITI-SUD Plan, designed and implemented by the Urban Authority (an intermediate management body with a metropolitan character), and funded by the Regional Operational Program (ROP) of Central Macedonia [14].

The aim of this paper is to identify the critical factors of the Thessaloniki SUD strategy through the Delphi approach, to analyze them in the framework of swot analysis, and at the same time, to describe the implementation process of the strategy. The attempted evaluation is expected to help similar strategies address potential cooperation and management problems, as well as to identify important and common factors in their implementation. The originality of the study relies not only on the data concerning the specific city and its integrated strategy, but also on the innovative management of the SUD and its metropolitan character, in a city where until recently the metropolitan unit of Thessaloniki did not have a distinct institutional role [15]. The paper is structured by presenting the literature review after the Introduction, followed by the Methods and Techniques section, the results of the research, and finally, the Discussion and Conclusions where a critical evaluation is attempted.

2. Background

2.1. Community Initiatives and Policies for Urban Regeneration

In some Southern European countries, such as Spain, Portugal, Italy and Greece, the need to support and regenerate urban areas was already vital before the 1980s. Post-war, in some of them, urbanization has enlarged and changed cities [16], usually where urban development has been pursued in an unregulated, ad hoc manner to meet the increased demand for housing. In some cases, this has changed the character and form of cities, while the lack of national urban policies is still evident today [17]. As around 72% of the EU population lives in urban, semi-urban, and peri-urban environments [18,19], since 1980, urban issues and problems have received political attention from the EU, and since 1998, through European Spatial Development Perspective (ESDP), EU policies have been continuously focused on the urban, urban-rural, and rural questions [18]. The cohesion policy in the frame of EU regional development has been helping in parallel with urban development [5,20–23]. Specifically, today, the investments that absorb 40% of the total financial resources available from the European Regional Development Fund (ERDF) are taking place in cities, while contemporary challenges continuously reinforce the focus on ISUDSs and on more effective support for cities [24,25].

In the 1980s, issues such as urban decline and the fair demands of EU cities to address them began to emerge [22,26,27]. Acting in urban areas through the establishment of specific instruments [28] started with the Urban Pilot Programs (UPP) in 1989, which was the first attempt at urban regeneration. These programs were a forerunner to the first URBAN Community Initiative (CI) (1994–1999), which was continued in the next programming period 2000–2006 with the Community Initiative URBAN II and URBACT I program. This was the first time that cohesion policy, and the EU in general, had allocated financial resources exclusively to confronting urban decline through urban regeneration programs. The results and impact of these programs have been positively assessed by both Member States and the stakeholders and institutions [15]. The URBAN became an instrument in designing and implementing urban regeneration programs, had a substantial impact on related cohesion policy programs that followed, and was particularly appreciated by countries that did not have an urban policy [29,30]. The importance of the URBAN ‘method’ or ‘approach’ [19,21], lies in the components and structure of an urban regeneration vision that includes the urban area of intervention, the strategy, the integrated approach, the partnership vision, the collaborative approach of local authority and government, the added value of the measures proposed and the competitiveness of the call [13,22].

The URBAN I was an integrated and territorial approach that combined urban regeneration actions, as well as actions related to the support of human resources [31,32]. The 118 programs funded, totaling 900 million euros, concerned the urban neighborhoods of cities with more than 100,000 inhabitants in crisis, with a high unemployment rate, the infrastructure of poor quality, inadequate housing conditions, and a lack of social amenities. URBAN II followed in the footsteps of the previous CI by seeking to create added value through urban sustainability and through the exchange of knowledge and experience actively pursued by the URBACT program. It has funded a total of 70 programs with a budget of 730 million euros, mainly targeting small, severely disadvantaged areas, and has innovated by seeking to network and implement programs through strong partnerships at the local level.

During the 2007–2013 programming period, the URBAN was discontinued, but it prompted the Cohesion Policy to adopt ‘urban integration and the principles of the initiative in Member States’ operational programs [33]. Although the Member States were given the opportunity to fund the development of urban regeneration actions, both the principles of the initiative and the possibility to further support urban development faded [21] within the national strategies with some exceptions (Urban Priority Axis in Romania and Iniciativa Urbana in Spain). Thus, in most countries, the urban dimension of EU policy at the national level was lost mainly due to the inclusion of urban development actions in the regional programs [22].

In Greece, Community Initiatives (URBAN) implementation was considered successful, while their management was carried out at a central level. A total of six programs were implemented from the first URBAN (Volos—Nea Ionia, West Thessaloniki, Ermoupoli, Keratsini—Drapetsona, Patras, and Peristeri) and in URBAN II, three programs (Heraklion, Komotini, Perama). Although the experience of implementing programs within the framework of the URBAN Community Initiative in Greece was considered positive, their implementation encountered many obstacles and difficulties. The most important was a lack of cooperation between implementing bodies, coordination between the involved ministries, immaturity of many proposed projects, and fragmentation of actions [13,29]. In the framework of the Regional Operational Programs, during the programming period 2000–2006, actions were implemented for “Integrated urban development interventions in small-scale local zones”, and in the programming period 2007–2013, “Integrated plans for urban and rural regeneration” with the participation of intermediate management agencies. There were problems with fragmentation of areas and projects, management inadequacy by local government organizations (OTAs), and delays in the implementation of projects remained to a significant extent [34]. However, these programs covered basic needs in urban projects, even if their actions could be characterized as piecemeal. More

generally, Greece is among those countries of the European south where there is no national urban policy, but it is also associated with a tradition of “non-planning”, especially at the local level.

2.2. *Integrated Sustainable Urban Development Strategies*

In the 2014–2020 programming period, the objective of integrated territorial and urban development has been given a new impetus within the framework of a cohesion policy. The URBAN approach and the URBACT program returned afresh in the context of a cohesion policy, where the trend seemed to be to reinforce the development role of cities in relation to other territorial administrative units [35]. In this programming period, they have become the main vehicle to support urban and territorial strategies, while for urban development, more local urban-based solutions are pursued through ISUDSs, specifically designed to address local challenges and perspectives [36]. The experiences that have been gained relate to supporting urban investments in cities that manage the investments themselves, and their funding can come from different sources. The ISUD strategies at the city or metropolitan area level seek to address economic, social, demographic, environmental, and climate change challenges in a coordinated manner.

Alongside the new instruments to strengthen the urban dimension introduced by the 2014–2020 cohesion policy, a common vision for urban development was formed at the intergovernmental level, with a more active role of stakeholders in urban policymaking. The European Commission and the European Parliament 2014 launched initiatives on the urban dimension of EU policies that led to the signing of the Treaty of Amsterdam on 30 May 2016, a clear political commitment to the implementation of an Urban Agenda [37]. Based on the pact, urban partnerships were created that have important urban issues as their object. In this context, 14 partnerships were created with corresponding action plans; these were implemented and contribute to the design of relevant EU legislation in 14 vital themes. Urban Agenda in the period 2016–2019 helped to better coordinate urban issues and the European Commission, after 2020, seeks to further support the initiative [38].

The “integrated character” as a concept and content of the integrated urban strategies, remains the main question for the policymakers and stakeholders. It may be that the integrated approach has been primarily linked to the sustainable and qualitative development of the dimensions of urban life (economic, environmental, social, and cultural) according to the international literature [9,22,36,39,40], but equally important is the aspect of sustainable planning and management, i.e., its link to the concept of urban governance [41] and the democratic participation of cities stakeholders.

The integrated approach to urban areas should be implemented through strong multi-level governance systems, not top-down, resulting from the voluntary participation of a variety of actors, based on new organizational and operational approaches; these aim at to design and deliver solutions through the combination of urban regeneration interventions [24,42–44]. The bottom-up approach is essential in most cases applied at all stages of integrated programs, and concerns both the managing body, their design and management, and their implementation.

In fact, under the 2014–2020 programming period and for the forthcoming period 2021–2027, territorial development is based on the ITIs and on the programs of the Community-Led Local Development (CLLD). The ITIs refers to the ITIs of integrated sustainable urban development strategies and to the ITIs of other territorial strategies [11]. For the period 2013–2020, they are financed by the European Social Fund (ESF), the European Regional Development Fund (ERDF), and the Cohesion Fund, and it is foreseen (ERDF Regulation Article 7) that at least 6% of the ERDF resources allocated at the national level shall be allocated to ISUDSs. In the new programming period 2021–2027, urban development is included in the new specific policy objective 5 (a Europe closer to its citizens) of the Cohesion Policy; meanwhile, ISUDSs are financed with the contribution of all European Funds, including the European Agricultural Fund for Rural Development (EAFRD), where it is foreseen that 8% of all ERDF resources will be allocated to these strategies. [45]. In

addition, in the new programming period, the ISUDs will be financed exclusively by the Regional Operational Programs (ROPs), which are included as a priority axis, with the possibility of continuing the approved ISUDs in the new programming period after updating. In Greece, they are implemented through the Regional Operational Programs of the Partnership Agreement for the Development Framework (ESPA) 2014–2020 and 2021–2027.

2.3. The Integrated Sustainable Urban Development Strategy of Thessaloniki

Thessaloniki is in the northern part of Greece (Macedonia) and is the second-largest urban center in the country, after Athens (Figure 1). The urban complex of Thessaloniki belongs administratively to the Metropolitan Unit of Thessaloniki of the Region of Central Macedonia (MUTH). The MUTH is an administrative sub-unit of the Region of Central Macedonia that belongs to the second tier of local government [15]. The administrative responsibilities of the ICU are relatively limited despite the great importance of the spatial and developmental role it could have [46,47]. Geographically, the metropolitan unit of Thessaloniki includes a total of 13 municipalities, of which seven are urban municipalities and form the urban complex of Thessaloniki. The total population of the MUTH is 1,019,191 inhabitants in an area of 111,703 km², while the population of the Municipality of Thessaloniki is 789,191 inhabitants, according to the 2011 census [48].

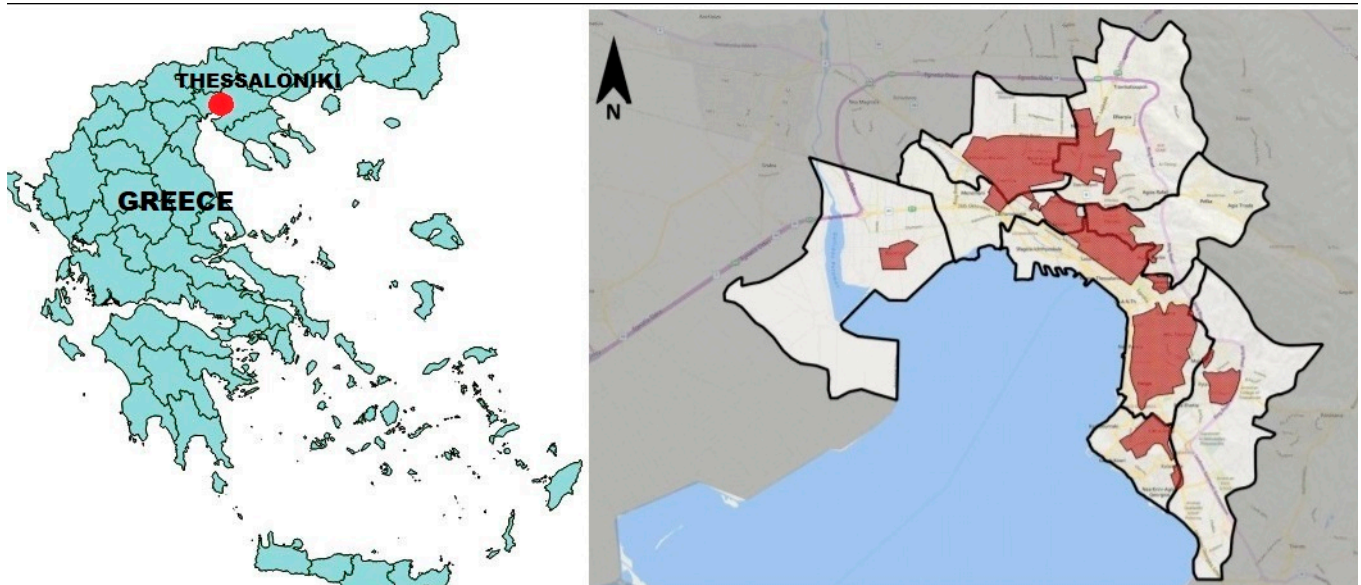


Figure 1. The Map of Greece and the intervention area of the Integrated Sustainable Urban Development Strategy of Thessaloniki; the focus areas are also included (in brown color).

In the past and in the framework of the URBAN I, a program was implemented in the city of Thessaloniki; this concerned the western districts of the city (sub-program West Thessaloniki) in an area of 1447 Ha and a population of 14,700 inhabitants. The actions implemented included the regeneration of public spaces and the site of a former army camp (Papakiriazi), and the construction of buildings (by the Municipality of Polihni and the Ithaca Rehabilitation Centre). Under URBAN II, no projects were included, but the participation of the municipalities of Thessaloniki in the URBACT networks was promoted. In addition, during the 2007–2013 programming period, limited urban development projects were implemented in the framework of integrated urban development projects, funded by the Regional Operational Programs of Central Macedonia and involving municipalities of Thessaloniki.

Nowadays, the city of Thessaloniki is facing several problems regarding its urban environment [14], but also on an economic and social level. Traffic, lack of redevelopment, deficiencies in the promotion of its cultural resources, and areas with land use conflicts are some of the problems [13]; these, combined with the country's decade-long economic

crisis, the consequences of the COVID-19 virus pandemic, as well as the Russian invasion of Ukraine, have led to economic and social underdevelopment. The significant potential and prospects of the city, due to its strategic location in Northern Greece and the Balkans, remain little or partially exploited.

To address these problems and challenges, the Metropolitan Unit of Thessaloniki, in cooperation with eight Municipalities, the city's stakeholders, and citizens, established the Urban Authority (intermediate management body), which designed, promoted, and implements the ISUDS for Thessaloniki. The aim of the strategy is to put in place an integrated action plan with the cooperation of all stakeholders, which will improve the infrastructure and the natural environment, and, at the same time, strengthen urban entrepreneurship and the social fabric of Thessaloniki. The intervention area of the strategy covers the entire area of the Municipalities of Ampelokipon—Menemenis, Thessaloniki, Kalamaria, Kordelio–Evosmos, Neapolis–Sikeon, Pavlou Mela, the municipal unit of Pylaia of the Municipality of Pylaia–Hortiatis and the municipal district of Kalochori of the Municipality of Delta. At the same time, some areas were identified where the challenges were more pronounced, and, therefore, it was planned to prioritize these areas and direct investments there to specific projects.

The Thessaloniki ISUD strategy is funded by the Regional Operational Program 2014–2020 of Central Macedonia; it has a total budget of 84.3 million euros, of which 68.3 million from the European Regional Development Fund (ERDF) and 16 million from the European Social Fund (ESF), while the total private contribution amounts to €11.2 million. The Thessaloniki ITI-ISUD Strategy is developed around four priority axes, as follows:

- Axis 1: “Thessaloniki competitive and innovative”
- Through its specific objectives, it seeks to support local entrepreneurship, and attract investment, business, research, and innovation (1.1). It seeks to promote the education and skills acquisition of its human resources (1.2), promote the city as a tourist destination based on culture (1.3), and redefine the city's identity.
- Axis 2: “Cohesive Thessaloniki”
- Through its specific objectives, it seeks to address the immediate consequences of the crisis and integrate disadvantaged groups (2.1), strengthen the social economy and social services (2.2), and provide equal access to schooling (2.3).
- Axis 3: “Green and resilient Thessaloniki”
- Through its specific objectives, it seeks to enhance adaptability to the impacts of Climate Change (3.1), improve the urban environment and microclimate (3.2), and enhance sustainable urban mobility (3.3).
- Axis 4: “Effective Thessaloniki”
- Through its specific objectives, it seeks to ensure administrative efficiency and modernization of the organization of local functions (4.1), and the strengthen public administration and services (4.2).

Figure 2 presents the Axes of the Thessaloniki ISUDS and the percentage of participation of each Axis in the total public expenditure in euros. Table 1 shows in detail the distribution of funding by Priority Axis, special objective, and intervention of the ISUD Thessaloniki Strategy.

The operation of the Urban Authority (UA) in managing the strategy and in relation to the other stakeholders is shown in Figure 3; here, the various phases of planning, implementation, evaluation, and monitoring of the strategy, a series of processes are required that functionally involve, in addition to the Urban Authority (UA), the Special Management Authority (SMA), the Planning and Evaluation Team (PET) as well as the Monitoring Committee (MC) (in which they participate all municipalities and organizations involved). At the same time, at the implementation level of the included projects, there is the involvement of various regional and municipal technicians and other services. The need for communication, cooperation, and coordination between them is evident so that the strategy is implemented without delays and with consistency in terms of options and results.

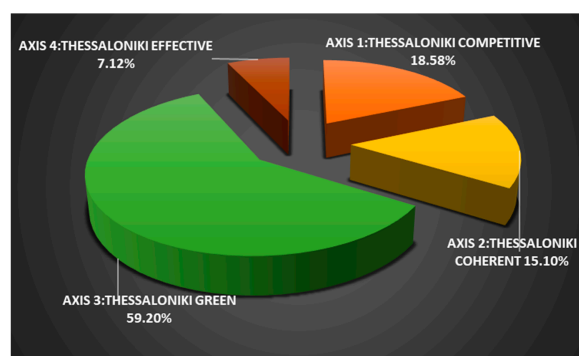


Figure 2. Budget Percentage of Public Expenditure per Priority Axis of the Thessaloniki Integrated Sustainable Urban Development Strategy (ISUDS).

Table 1. Distribution of funding per Priority Axis, Specific Objective, and Intervention of the ISUD Strategy of Thessaloniki.

Specific Objectives	Interventions	Public Expenditure in €	Private Participation in €	Total Budget in €
PRIORITY AXIS 1. THESSALONIKI COMPETITIVE AND INNOVATIVE				
1.1. Entrepreneurship support, attracting investment & promoting innovation	1. Entrepreneurship support structures 2. Business clusters and urban excellence 3. Entrepreneurship in central areas	8.350.000,00	6.831.818,17	15.181.818,20
1.2. Development and the skills certification	1. Investor attraction and Innovation promotion 2. Urban human resource improvement via skills certification	4.700.000,00	2.203.413,54	6.903.413,54
1.3. City's promotion as a tourism destination based on culture	1. Tourist and cultural resources promotion 2. Strengthening of tourism corporations 3. Tourism human resource skills improvement 4. Support self-employment in tourism sectors	2.706.939,00	1.396.586,46	4.103.525,46
		15.756.939,00	10.431.818,18	26.188.757,18
PRIORITY AXIS 2. THESSALONIKI COHERENT				
2.1. Relief from the direct consequences of economic crisis and embodiment of the less favored groups	1. Training and Vocational embodied 2. Support actions for target groups	4.973.685,00	0,00	4.973.685,00
2.2. Social economy strengthening and supply of high-quality social services	1. Support of social economy 2. Access to social and health services	5.931.316,00	783.517,09	6.714.833,09
2.3. Equal access to school	1. Actions for volunteering activities raising 2. Small-scale improvements in schools	1.900.000,00	0,00	1.900.000,00
		12.805.001,00	783.517,09	13.588.518,1
PRIORITY AXIS 3. THESSALONIKI GREEN AND RESILIENCE				
3.1. Adaptability Improvement to the impacts of the Climate Change	1. Flood protection 2. Protection and management of the coastal front 3. Prevention and response to natural disasters	7.000.000,00	0,00	7.000.000,00
3.2. Improvement of the microclimate and the urban environment	1. Urban greenery reinforcement 2. Creation of green cores/ green routes 3. Upgrading local urban green cores 4. Projects for Green Rooms/Vertical Gardens 5. Promotion of environmental volunteering	36.800.000,00	0,00	36.800.000,00
3.3. Improvement of sustainable urban mobility	1. Actions for multimodal urban transport 2. Development of bike-path systems 3. Intelligent mobility management systems	6.415.000,00	0,00	6.415.000,00
		50.215.000,00	0,00	50.215.000,00

Table 1. Cont.

Specific Objectives	Interventions	Public Expenditure in €	Private Participation in €	Total Budget in €
PRIORITY AXIS 4. THESSALONIKI EFFECTIVE				
4.1. Ensuring the Administration effectiveness and functions modernization of local organizations	1. Interoperability of Municipal Information Systems 2. Digitization of historical, cultural, and tourist footprint	1.550.000,00	0,00	1.550.000,00
4.2. Public Administration Strengthening and public services improvement	1. Strengthening public governance 2. Strengthening monitoring networks and observatories for urban challenges	4.500.000,00	0,00	4.500.000,00
		6.050.000,00	0,00	6.050.000,00
TOTAL BUDGET ISUD STRATEGY		84.326.940,00	11.215.335,27	95.542.275,30
FUNDING BY ERDF	68.320.000,00			
FUNDING BY ESF	16.006.939,00			

Source: Authors' own work based on ITI—SUD of Thessaloniki, MUTH, 2020.

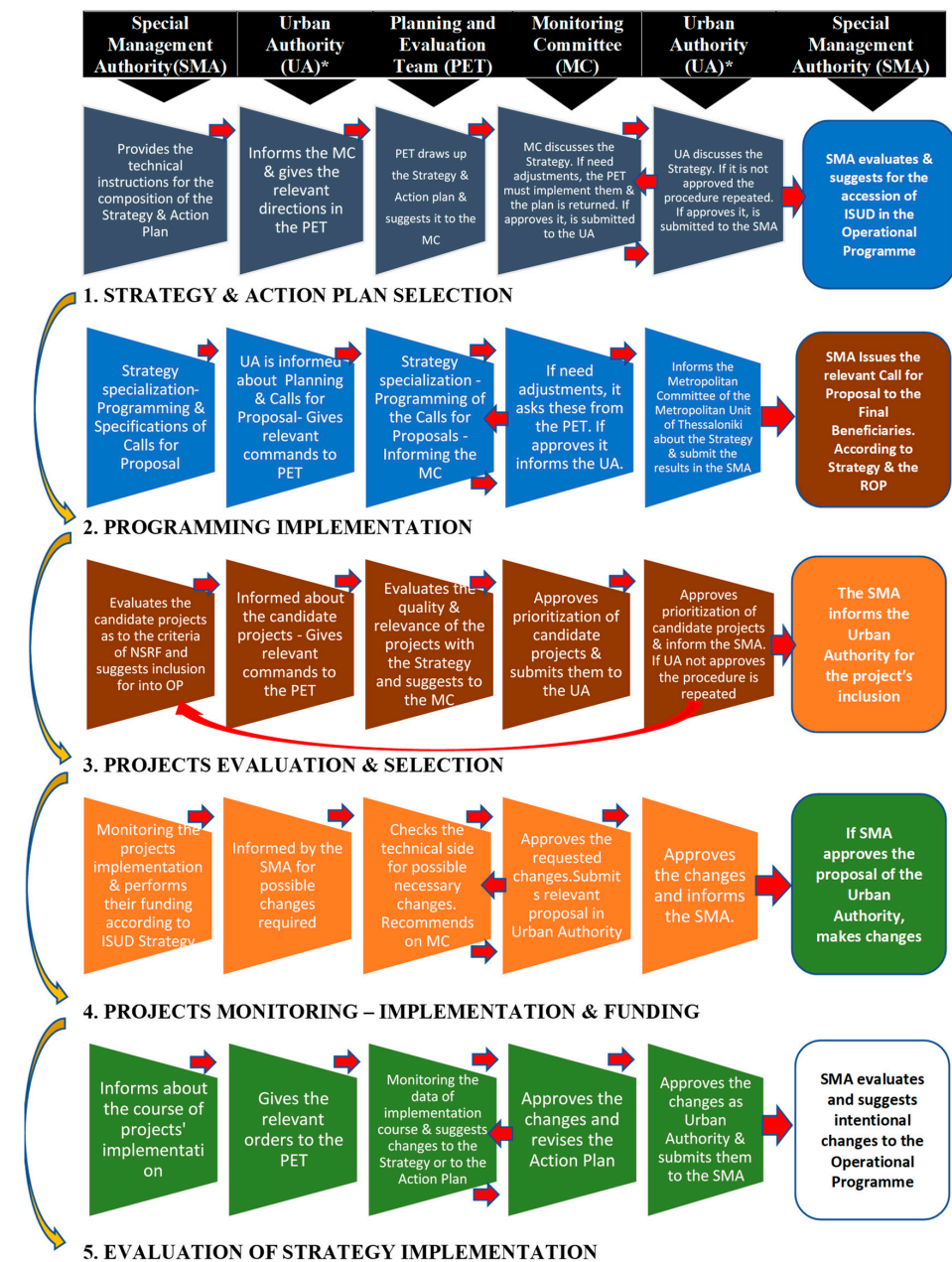


Figure 3. Presentation and Flowchart of the administrative system of the Integrated Sustainable Urban Development Strategy of Thessaloniki. Source: Authors' own work.

3. Methods and Techniques

3.1. Research Design

The research was carried out in three stages. The first and second stages are characterized by the “qualitative” element, while in the third stage the research was continued using the Delphi method with the output of the second stage (interviews with experts) as the main input (stage 1), as shown in Figure 4.

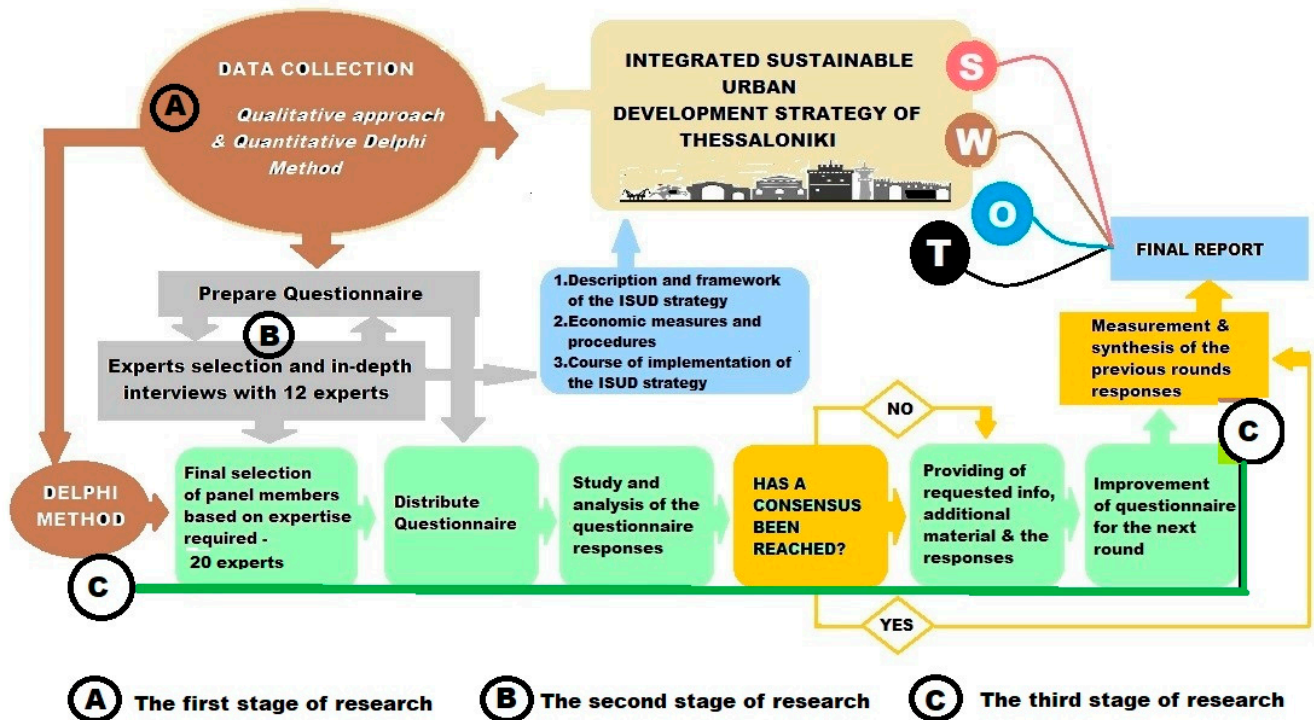


Figure 4. Chart flow of the research stages. Source: Authors' own work.

The first stage aimed to explore the ISUDS in terms of its design and implementation [49] through a qualitative approach, as new management processes and partnerships are implemented. The aim was to identify the different dimensions of the topic under study through its content, dynamics, associations, and depth [50,51]. It started with the collection and study of secondary sources related to the strategy, its key financial figures (budgets, calls, approved projects, legal commitments, absorption), and the processes of planning, management, and implementation. This information was collected mainly from stakeholders, but also from strategic documents and ITI-ISUDS archives. The operational progress of the strategy was captured through the management processes and responsibilities of the stakeholders (Figure 3), and through the evolution of the key financial indicators of the priority axes from the start of the program implementation until mid-2020.

After the collection of secondary data related to the SUD strategy, the second stage was followed by interviews with experts using a semi-structured questionnaire in order to record their views on the design, the critical points in the implementation of the strategy, and its impact on the urban space of Thessaloniki. In addition to providing important empirical data from a relatively small number of participants, these interviews in some cases lead to specific observations and recommendations [52], whose value is high [53]. Twelve experts were selected, and the interview stage lasted one month and was completed at the end of February 2020.

The COVID-19 pandemic, and the quarantine imposed in March 2020 in Greece, led to the need to modify and continue the research with the Delphi approach; in particular, a variant of the method preferred at the time was collecting data via email [54,55]. In this third stage, the results of the interviews from the previous stage were used, and a general ranking was carried out in relation to the strengths and weaknesses of the strategy, as

well as the opportunities and threats it faces. The number of experts increased from 12 to 20 in total, after the selection of those who met the requirements and characteristics of a representative Delphi group [54,56,57]. Closed-ended questionnaires were sent by email during the months of April and May 2020 to the 20 experts who formed the final sample for the evaluation of the strategy characteristics.

3.2. Delphi Method

The Delphi technique was originally introduced in the 1940s by Helmer and Dalkey, who produced what became the classical approach in the 1960s, on pages 458–467 of their paper entitled ‘An experimental application of the Delphi method to the use of experts’ [58]. It is a research technique aimed at reaching a consensus among members of a group of experts in the context of investigating and finding reliable predictions on specific issues. Turoff defined the Delphi approach as “an organized method for correlating views and information concerning a particular strategic policy area and allowing the participants representing them to evaluate and react to differing perceptions” [59]. Given its changes and evolution, the approach has established itself over time as an expert-based forecasting approach that uses multiple iterative questionnaires that approach the research topic in depth [54,60–62]. The Delphi consensus technique has been used by the research community as a tool to solve a wide range of problems and has been encountered more frequently in recent decades in the investigation of natural and environmental resource management issues [63].

In the international literature, there are various and diverse variants and modifications of the Delphi technique, but due to their use and their reference density, three types are distinguished: The “Classical or Conventional Delphi Technique”, the “Policy Delphi Technique—PD” and the “Decision Delphi Technique—DD”. In the classical approach, the first round of data collection is usually “qualitative”, as it aims to identify as wide a range of opinions and experiences as possible. The nature of subsequent rounds in many cases ends up being ‘quantitative’, as the data is analyzed and grouped into a second questionnaire and the process is repeated until maximum consensus is reached.

As Okoli and Pawlowski suggest, the quantitative Delphi technique is characterized as a flexible method that is suitable for investigating complex research questions that require in-depth knowledge from experts with practical experience [64]. At the same time, it does not require a large number of experts, nor the need for them to physically meet each other. In our case, this technique is considered appropriate for identifying and quantifying the critical points regarding the implementation of the sustainable urban development strategy, as well as for identifying the impact it may have on urban development; for these reasons, this method was adopted for our research.

3.3. Selection of the Team of Experts

From the second stage of the research, the selection of the 12 experts was based on the procedure proposed by the literature and presented in Figure 5. In particular, the identification and inventory of experts [65], closely related to the design, implementation, management, and administration of Thessaloniki’s ISUDS, was carried out. At the same time, those who were willing and ‘committed’ to participate and report on the subject matter of the research were identified; they possessed heterogeneity and representativeness, as defined by the relevant literature [54,66,67]. Specifically, of the initial 12 experts, six were elected local government officials (three from the participating municipalities and three from the Region of Central Macedonia) and six were high-level executives involved in the implementation of the program (three executives from the Region of Central Macedonia and three from the Special Managing Authority (SMA) of the Regional Operational Program (ROP) of Central Macedonia 2014–2020).

In March 2020, eight more experts were added to the 12 experts for reasons of representation (two executives from Urban Planning, three from academia, and three engineers from municipalities participating and supervising ISUD projects), and the research team in the third stage of the Delphi method comprised a total of 20 selected experts.



Figure 5. Experts' selection procedure. Source: Authors' own work.

The expert interviews in the second stage of the research produced initial results, observations, and descriptions of the Thessaloniki ISUDS, which were captured in sections on the implementation, the impacts, and the problems of the strategy. In the third stage, which continued with the Delphi approach through questionnaires circulated by email among the 20 experts, this list of initial results was resourcefully grouped into a SWOT analysis of the program [68], i.e., into sections on the strengths and weaknesses of the ISUDS, as well as the opportunities and threats it faces [69]. The SWOT analysis captures the context to help identify priorities, operational objectives, and prospects for further successful achievement of the strategy.

In the third stage of the research, the list was sent to a heterogeneous group of more than 20 experts to validate the appropriateness of clustering of responses from the interviews in the SWOT analysis sections. Each expert was then asked to rank, hierarchically, the elements of the strategy contained in the strengths, weaknesses, opportunities, and threats [70]. In a subsequent step, the experts quantified, in terms of their significance (on a scale from 0—completely disagree to 7—completely agree), the most important of the strengths, weaknesses, opportunities, and threats of the strategy that emerged from the previous step. In this context, the experts were able to change their choices if they so wished (now knowing the mean and standard deviation of the others per section) to reduce the standard deviation and achieve as much consensus as possible. This final step was repeated twice until the consensus condition (standard deviation of all <25% of the mean of the items contained in each section of the analysis) was reached.

4. Results

4.1. Course of the ISUD Strategy

As shown in Figure 6, the Regional Operational Program (ROP) of Central Macedonia issued a Call for Proposals to the Metropolitan Unit of Thessaloniki (MUTH) for the submission of an ISUD strategy for Thessaloniki in September 2016. The design of both the strategy and the action plan on behalf of the MUTH followed a bottom-up approach, through a participatory process of spatially involved municipalities and stakeholders

and open consultation. The strategy was submitted by the MUTH in February 2017 and approved on 26 June 2017 [14]. The Thessaloniki ITI-ISUDS is part of the broader strategy of the ROP of Central Macedonia, and 10% of the total public expenditure of the ROP Central Macedonia was allocated for its implementation. The Urban Authority was appointed as an intermediate body in July 2017, headed by the Vice-Regional Head of MUTH for the governance and management of the strategy.

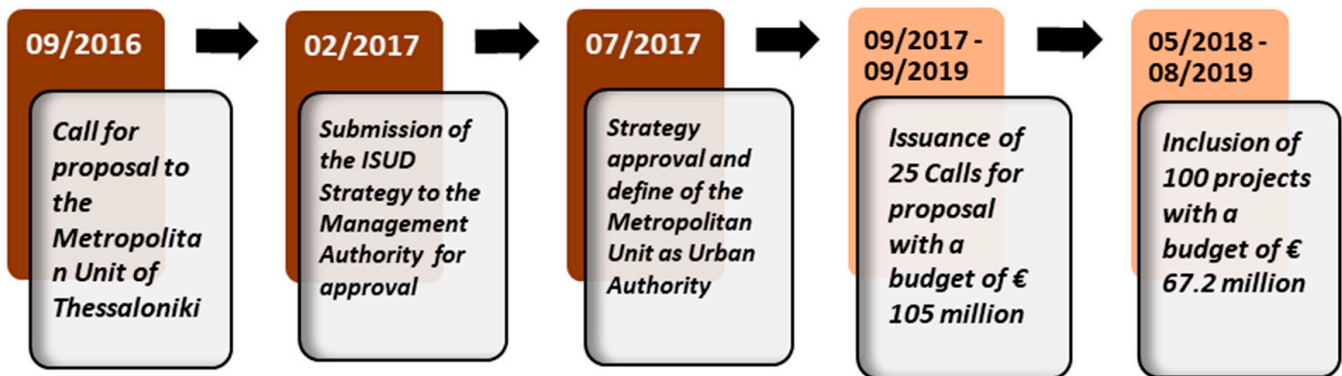


Figure 6. Schedule of implementation of Thessaloniki SUD Strategy. Source: Authors' own work based on ITI—SUD of Thessaloniki, MUTH, 2020.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

From September 2017 to mid-2020, the Urban Authority activated all the Axes of the Operational Plan for the ISUDS of Thessaloniki, with 25 Calls for Proposals addressed to the beneficiaries (Figure 6), with a total budget of more than 105 million euros (>110% of the total budget). It included, in the same period, 100 projects worth 67 million (Table 2), while it signed project contracts worth approximately 5.5 million euros (Figure 7). In the first quarter of 2020, the strategy's progress was halted due to the COVID-19 response measures, mainly in terms of contracting and project implementation.

Table 2. Projects inclusion in the ISUDS of Thessaloniki per Beneficiary (2020).

Municipality or Other Beneficiaries	Number of Projects	Budget (€)
Thessaloniki	19	8.509.131,00
Ambelokipoi–Menemeni	12	4.775.416,00
Neapoli–Sykeon	8	4.904.480,00
Kalamaria	14	3.645.003,00
Kordelio–Evosmos	4	766.023,00
Pavlou Mela	9	24.303.590,00
Pylea–Chortiatis	7	4.199.362,00
Delta	2	244.214,00
Others	25	15.900.768,00
TOTAL	100	67.247.987,00

Source: ITI—SUD of Thessaloniki, MUTH, April 2020.

Among the important projects that are included in the ISUDS of Thessaloniki, are the environmental upgrade and performance in the common use of the Pavlos Melas Metropolitan Park, the sanitation and restoration of the subsoil and underground water in the wider area of the Municipalities of Thessaloniki, Ampelokipi—Menemeni and Delta, the creation of green spaces and the construction of parks in all Municipalities, the regeneration of the area of the Hippocrates Hospital, the restoration of Byzantine Walls, the pocket parks of the Municipality of Thessaloniki, the planted roofs and the green schoolyards, the Civil Protection equipment of Municipalities, and the expansion of the National Air Pollution Monitoring Network in the urban planning complex of Thessaloniki,

etc. Many of these projects already have been implemented in 2022 and they are used by the Thessaloniki citizens.

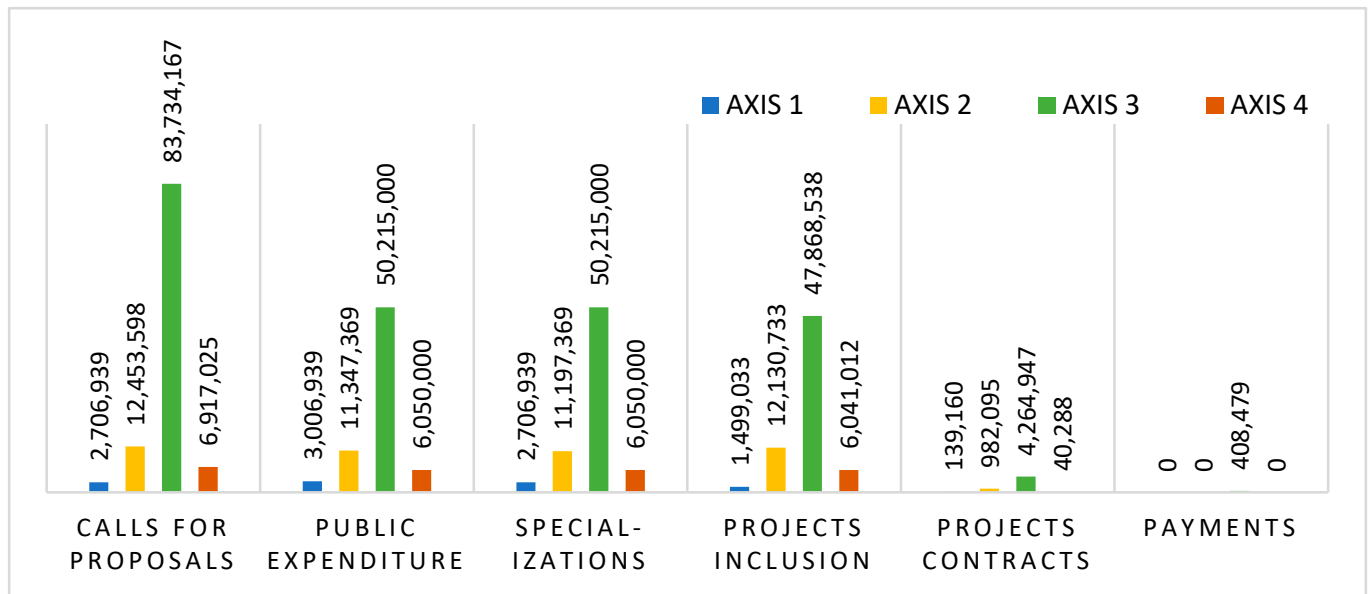


Figure 7. The course of economic measures of the ISUDS Thessaloniki Axes until 2020. Source: Authors' own work based on data from UA, ISUDS of Thessaloniki, April 2020.

One might observe, from the structure of the strategy (Table 1), that it is missing the axis of the Thessaloniki smart city and the relevant projects. The city, after a long period with a lack of critical projects, through the ISUDS, has the chance to improve the needed infrastructures and to implement projects that will improve citizens' ways of life. That was the main reason, according to the experts' opinion, why many projects regarding a smart city were not included (or a separate relative axis in the strategy). However, among the projects that have been included in the strategy of the ISUD Thessaloniki, are the intelligent integrated traffic management system, the integration of the traffic control centers, and the electric vehicles, but their participation in the whole strategy is limited.

Despite the repeated lockdowns in 2020 due to the pandemic, the good progress of the program continued and as a result, at the beginning of 2021, the total budget of the ISUD strategy from the Operational Program 2014–2020 of the region of Central Macedonia was increased by 15 million euros, reaching a total of 100 million euros of public expenditure.

4.2. SWOT Analysis

All experts consider that the course of the Thessaloniki ISUDS until early 2020 has been very successful, while all experts expressed concern about the continuation of the program due to the delays that the COVID-19 pandemic may cause in the near future. The two-year period since the activation of the program was fully utilized by the Planning Authority, the beneficiaries, and those involved in its implementation. Subsequently, the quarantine imposed in March 2020 halted this momentum due to the suspension of work, both in the implementation of projects and in their management by the executives of the Municipalities, the Urban Authority, and the Special Management Authority of the ROP of Central Macedonia.

From the analysis of the questionnaires in the context of the Delphi approach, the SWOT analysis of the main strengths, weaknesses, needs, opportunities, and threats to the Sustainable Urban Development Strategy of Thessaloniki emerged.

4.2.1. Strengths and Weaknesses

From the initial in-depth interviews, and subsequent consensus circles that took place among the experts, there was absolute agreement on the strength of the Thessaloniki ISUDS, which was the program management model. Meanwhile, a high level of agreement was also reached on the expertise of the human resources involved in the implementation of the technical and development programs. The integrated nature of the strategy, as well as the “green” projects included, were also highlighted as strengths. The purely urban and socio-economic projects included in the strategy were ranked among the strengths of the strategy, but with less weight by the experts.

As shown in Figure 8, the most important weakness highlighted was the low budget of the Thessaloniki SUD strategy, given the very high project needs of the region, followed by the implementation time and bureaucracy. Among the weaknesses, also to a lesser extent but equally important, the institutional/legislative framework and the fragmentation of responsibilities in implementation (many stakeholders and departments involved in the implementation of projects) were identified by the experts.

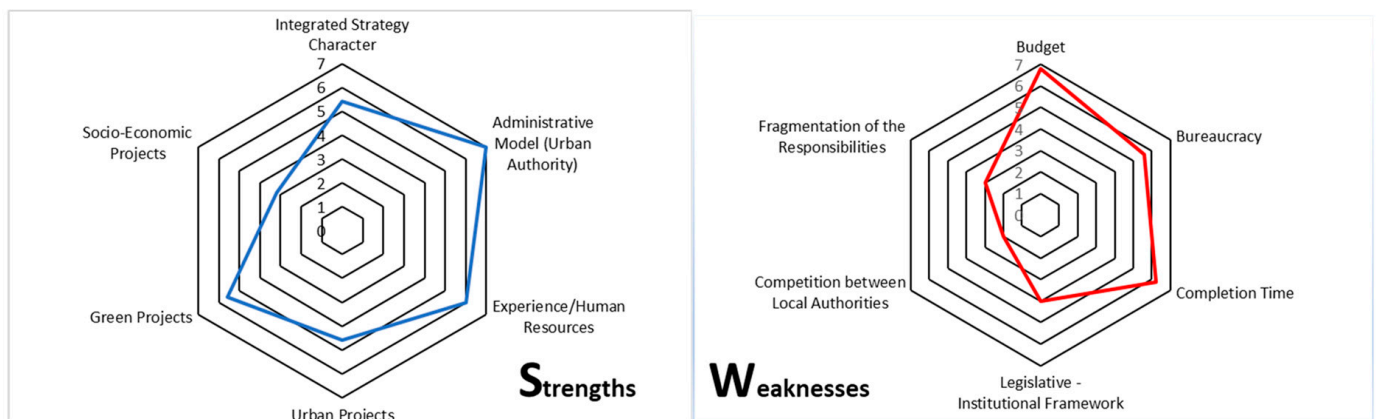


Figure 8. Strengths, and Weaknesses of Thessaloniki ISUD strategy.

4.2.2. Opportunities and Threats

From the results of the survey, and as shown in Figure 9, the most important opportunities recorded in relation to the Thessaloniki SDS are the trends presented internationally for the empowerment of cities in the direction of green and ‘human’ conditions, as well as the institutional and economic empowerment of local authorities (a continuous effort in the Greek territory during the last decades). The research also highlighted, as important opportunities, the continuation of co-funded programs and the flow of Community and national resources, the strategic geographical location of the city of Thessaloniki in the Balkans, especially as a transit and trading center, and, finally, the tourism development that the country has been experiencing in the last decade and the willingness to recover its economy after the financial crisis that preceded it in the period 2008–2019.

The experts identified the COVID-19 pandemic as the most important threat in relation to the strategy, followed by the economic crisis and climate change, which appear to be equally important threats to the sustainable urban development of the city. The continuous increase in problems in the city (traffic etc.), the unstable institutional framework in Greece, and finally the dependence on private developers for the implementation of public works (mainly national or local contractors’ companies who are few in number and, for this reason, indirectly impose their terms), were also identified as important threats to the strategy of Thessaloniki’s urban development.

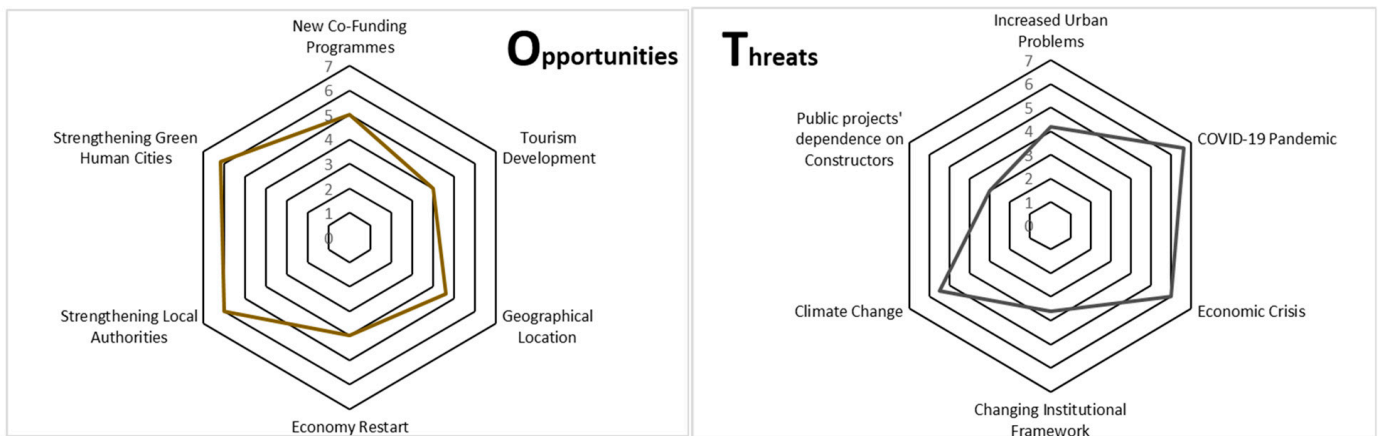


Figure 9. Opportunities and Threats of Thessaloniki ISUD strategy.

5. Discussion and Conclusions

The Thessaloniki ISUDS is a comprehensive plan that fills an important gap, as there has been no institutionalized development strategy for the Thessaloniki region (either as an urban complex or as a set of urban municipalities) that addresses the economic, social, demographic, and environmental challenges in an integrated way. The ISUDS has filled an important gap concerning the existence of a holistic all-inclusive plan for the development of the city of Thessaloniki. Whatever approaches have been taken so far through, for example, regulatory plans, master urban plans, or operational plans of municipalities, have not met the requirements of an integrated strategy due to their focused nature, limited spatial scope, and lack of synergies.

The beginning of the implementation of this strategy could be described as being dynamic, although the available financial resources are very limited compared to the economic, environmental, and social needs of the city, which is in line with the findings of similar studies [1,9,27]. The design of the strategy followed organizational rules and approaches that yielded its integrated character, unlike similar programs of previous programming periods that were described by informants (mostly officials) as fragmented and confusing. The successful and rapid activation of the program is mainly due to the efficient operation of the Urban Authority and the considerable experience of the departments involved in the implementation of co-financed projects in the Region of Central Macedonia (SMA, technical and programming departments).

The design and implementation of the ITI-ISUD strategy required the consensus and cooperation of different local and regional government agencies, which was successfully achieved under the metropolitan umbrella [71]. In the words of the Deputy Mayor of the Metropolitan Unit of Thessaloniki and President of the Urban Authority during the interview: *“all mayors from the beginning were impeccable and fully cooperative and, in all processes, and meetings they showed willingness and consensus”*, and those of the Technical Services Director General of the Region of Central Macedonia, who added that this was unprecedented and that he does not remember anything similar in his long professional career. The mayors involved in recent years have possibly been facing more intense pressure from the pressing problems of their municipalities; pressure may also come from their citizens, who are urging for solutions and the improvement of urban conditions, which leads to a consensual attitude on their part and a willingness to use every available financial resource for urban regeneration.

There is a widespread agreement that the most important aspect of the strategy appears to be the cooperation (regardless of the motives for achieving it) within the Urban Authority and the creation of a model of metropolitan management of the program, and possibly a model of independent metropolitan administration in the future [46,47,72]. Through the strategy implementation, and the creation of an innovative and effective urban authority that relies on the cooperation between urban municipalities and the metropolitan unit of

Thessaloniki, there seems to be a substantial gain for the urban area [73,74]. Moreover, the recognition of the innovative character of the Thessaloniki Urban Authority as a model of metropolitan management/governance has already taken place; it has already won international awards, praised as a model of good practice and administration in the framework of European programs and projects (Bravo Governance Award, INTERREG EUROPE REFORM program, European Platform (Eltis) for Sustainable Urban Mobility Plans) [75,76]. In effect, this new “metropolitan” management administration respects Article 4 of the ‘Kallikrates’ reform plan [17]; at the same time, it gives coordination and development content to the Metropolitan Unit of Thessaloniki, while introducing new management practices and standards for future use. During the implementation of Thessaloniki’s integrated urban development strategy, the management model, despite its complicated structure, has worked effectively and efficiently as an Urban Authority. The Thessaloniki metropolitan unit, although by law has restricted powers, coordinated the municipalities involved and gave the Urban Authority an entity for its work. The SWOT analysis that has been based on the opinions and experience of experts, and has shown that, in addition to the innovative model of governance and the integrated character of the operational program, this was an equally important positive aspect of Thessaloniki’s ISUD strategy. The integrated character was based on the four axes of the business plan, which were called to face the city’s economic, social and environmental direct needs in the context of the limited economic resources of the strategy. Although, according to experts, the absence of an extra axis for a smart city was obvious and could contain important projects which would be aimed at upgrading and modernizing Thessaloniki city, a limited number of projects for the smart city were in fact implemented in the context of the 4th axis, mainly concerning the effectiveness of public administration. Among the axes, the axis of the environment (Green Thessaloniki) was highlighted as the most important axis by the experts, and this shows that unlike other strategies [34], it has been given particular importance to urban green during design. Climate change, but also extreme weather events that have hit the city over the last decade, combined with the great need for green spaces apparently, has led to the reinforcement of the Green Axis with a significant proportion of the overall ISUDS budget; however, they have also given special importance to this axis in the context of strategy. Positive aspects of the strategy also included the axes related to the construction of infrastructures for Thessaloniki, as well as socio-economic support for vulnerable groups and citizens. The lack of important infrastructures and entrepreneurship support in the city has been evident in the recent decades, either through the operational problems that arose, or from the constant degradation of the city’s productive base. The 12 -year financial crisis has led to business closures, inadequate staffing, and unemployment, particularly high for the city of Thessaloniki. According to experts, the strategy was a first step in the integrated treatment of urban problems and against the threats of the Thessaloniki urban complex.

In order to implement the strategy, according to the experts, chronic problems plaguing the Greek public administration and self-government had to be overcome. Bureaucracy, inconsistency in meeting timetables, an unstable institutional environment, and the division of responsibilities between different levels of government and agencies were identified by the research as the main problems, combined with the small budget of the strategy and the lack of cooperation between the stakeholders. In reality, none of these weaknesses have managed to stop the good progress of the implementation of the strategy, not even the threat of the COVID-19 virus pandemic; despite initially creating reasonable delays, the pandemic did not seem to prevent the ISUDS project’s completion within the stipulated time limits.

At the same time, the city’s growing problems continued to exist as the pandemic was followed by the effects of the Russian invasion of Ukraine, the energy crisis, and the spike in inflation, that resulted in a rapid increase in construction costs; this was at a time when a large part of the strategy’s projects had already been implemented. From the external environment, the most significant threats to the strategy were also assessed by the experts to be climate change and the extreme phenomena with which it is related,

the constantly changing institutional framework, and the attitude of local and national construction companies toward public works, which usually exert pressure due to their limited number and the power they have in the construction sector.

Despite the weaknesses of the strategy and the threats from the external environment, the opportunities from the external environment related to the strengthening of the levels of local government during the last decade in Greece worked positively; this was also thanks to the continuous inflow of financial resources for co-financed programs from the EU. The international trend in favor of green cities also influenced the project and worked positively in shaping Thessaloniki's urban development strategy. At the same time, at the national level, there was optimism for the restart of the economy after the economic crisis, but also from the positive results recorded by the tourism activity in the country. Thessaloniki and the city's port are in a strategic geographical position in relation to the Balkan countries. It has prospects to develop into both an important transit center and trade center; in this case, it is necessary to upgrade the city both in infrastructure and in projects that will make it attractive and sustainable. According to the experts, the ISUD Thessaloniki strategy seems to be an 'example' and a 'model', and it is estimated that it will continue with a second phase in the programming period 2021–2027, enriched with an appropriate budget and a new operational program that will cover more urban needs.

5.1. Policies Suggestions

In the context of proposals for urban development policies, the role of the metropolitan units in the two major cities of Greece must be upgraded, both at the level of legislation and the level of responsibilities. Metropolitan units should act as an umbrella for inter-municipal projects and programs to ensure their broader character.

Generally, in EU countries, cities should seek the existence and functioning of a metropolitan level of governance, to formulate a metropolitan "vision" for their region and create a strategic and coordinating body that will promote projects of inter-municipal scope.

The signing of development cooperation pacts between different levels of government and civil society can solve a host of urban problems between authorities, save resources through economies of scale, and promote collaborations that will benefit all cooperating administrative, social agencies, NGOs, and groups of citizens.

The planning of urban development strategies should follow the bottom-up approach and be the result of a consensus, but also an integrated approach. The cases of integrated sustainable urban development strategies, based on the present research findings, show that it can be a 'model' for the implementation of 'complex' and demanding integrated urban business plans.

5.2. Limitations and Future Research Perspectives

The research was launched at a time when the COVID-19 pandemic was showing its first results worldwide, while Greece was entering its first lockdown after a short period of time. This fact was the major limitation that compelled the research to change methodologically and adopt the Delphi approach, remotely. Regarding the implementation of the integrated urban development strategy of Thessaloniki, the research was carried out at a stage where its positive course had already been charted and traced, but had not been completed, in order to make a first assessment of its impact on the urban space. Future research will seek to capture the impact of the strategy on the city and its residents through a survey of residents using a questionnaire and an ex-post evaluation. Future research will also try to explore the management framework and implementation of a typical integrated spatial investment in another territory (outside the urban area) in Greece, in order to capture both the differences in relation to the implementation of the ISUD strategy and the specific conditions outside the urban area.

Author Contributions: Conceptualization, F.C. and A.K.; methodology, F.C.; software, A.K.; validation, A.K., K.M. and S.K.; formal analysis, F.C. and S.K.; investigation, F.C. and S.K.; data curation, A.K., S.K. and F.C.; writing—original draft preparation, K.M. and F.C.; writing—review and editing, A.K.; visualization, K.M.; supervision, F.C.; project administration, F.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

Sociotechnical Characteristics of Conceptually Related Smart Cities' Services from an International Perspective

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Abstract: Sustainable smart cities (SSCs) have developed various services and technologies with multi-stakeholderism under multiple names. The characteristics of SSCs are specified by implementing conceptually related smart cities (CRSCs), which are ICT-based transformative cities. Many scholars point out that in-depth empirical studies of CRSCs are necessary to clarify the nature of the sociotechnical transition of SSCs while avoiding the oversimplified narratives of techno-utopia. Utilizing a periodic matrix taxonomy, this study aims to examine empirical characteristics of CRSCs services' socio-technical transformation from international perspectives. The target cities were sampled using cluster sampling through three screening steps based on four representative documents reflecting the critical aspects of the operational definition of SSCs. The city-level data were collected using Preferred Reporting Items for Systematic Review and Meta-Analysis Protocol and preprocessed with coding and weighting to create a periodic matrix taxonomy. The outcomes are the commonalities and different services' sociotechnical transitions of sampled European cities from perspectives of multi-stakeholderism. The outcomes have managerial implications demonstrating empirically the sequences of service transformation of European megacities. Theoretical implications for the existing theories also arise through empirical analysis of historical real-city data and specification of stakeholders' partnerships in conceptually related smart cities.

Keywords: conceptually related smart cities; smart cities; smart services; sociotechnical transition; sustainability; sustainable smart cities



Citation: Kim, N.; Yang, S. Sociotechnical Characteristics of Conceptually Related Smart Cities' Services from an International Perspective. *Smart Cities* **2023**, *6*, 196–242. <https://doi.org/10.3390/smartcities6010011>

Academic Editors: Véronique Flambard, Sadia Benamrouz-Vanneste and Abir Karami

Received: 2 December 2022

Revised: 27 December 2022

Accepted: 28 December 2022

Published: 7 January 2023



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1. Introduction

Sustainable smart cities have developed through technologies and services in a paradigm of a socio-technology transition, which is the co-development nature of society, technologies, and human innovation, under various names to achieve urban sustainability [1–7]. The sustainable smart cities' transformations have been influenced by miscellaneous stakeholders' participation and partnerships [3]. According to Komninos et al. (2019), the governance and investment from international public and global private sectors in the first circuit transform the first circuit of establishing core technologies such as backbone internet, virtual communities, and cyberspaces using Advanced Research Project Agency Network to a second circuit, which is also transformed by citizen behavior based on urban awareness of efficiently using urban infrastructure into third one that emphasizes the improved local government systems based on strong participation of local entities [3]. Subsequently, conceptually related smart cities are developed as an innovative platform to gather diverse stakeholders to transform society into sustainable smart cities.

The two concepts of sustainability and smart cities have distinctive characteristics that compensate for their counterparts' shortcomings [8]. Sustainability has distinct indicators of citizen participation, social inclusion, future diversity, and GDP, which are more related to the Sustainable Development Goals (SDGs). At the same time, smart cities are more oriented toward ICT to improve the efficiency of urban management and services, citizens'

quality of life, and urban competitiveness so as to satisfy the needs of present and future generations [9–13].

Conceptually related smart cities are subordinate to sustainable smart cities. Related studies have synthesized the two concepts to contribute to sustainable development in smart cities [14–19]. The definitions of sustainable smart cities have arisen from five academic disciplines as follows: (1) a combination of sustainability and smart cities, (2) a compound word emphasizing urban resource management, (3) a unified, innovative index, (4) a transformative process of urban services based on ICT, and (5) places of transformative sociotechnical innovative transitions to satisfy current and future local needs and improve urban ecosystems. The latter supports a multilevel perspective framework and the middle range of sustainable smart cities [5]. Diversely named smart cities are largely understood in the last concept of Sustainable smart cities when analyzed in the existing literature [8,20–23]. They emphasize the need for urban planning, data, and infrastructure to appropriately guide the direction of ICT and data analytic technologies for developing sustainable smart cities [8]. By following the last concept [5,8,24], this study conceives conceptually related smart cities as ICT-based transformative communities and cities, including cyber cities, virtual cities, Internet cities, wireless broadband cities, intelligent cities, digital cities, ubiquitous cities, and smart cities [8]. They have been introduced, advanced, and expired in the history of sustainable smart cities. Subsequently, conceptually related smart cities have been developed and implemented in the transformative sociotechnical framework of sustainable smart cities in cooperation with diverse players, based on the advancement history of ICT and applied urban services.

The qualitative literature review method was utilized to identify the characteristics of studies on smart cities in relation to other topics and unresearched fields within smart city studies. The related study adopts a scoping review [25] to extract the relevant data from each piece of literature as possible, including the methods, findings, and variables, because the method aims to provide an overview of what has been done [26]. A systematic literature review is largely utilized in the field of sustainable smart cities to provide the standards for applying the term “smart city” in the view of knowledge management since 2010 [27]. A systematic literature review has been utilized to identify key services or elements to understand the key notion of smart cities in relation to sustainability [14,28–31]. The Preferred Reporting Items for Systematic Review and Meta-Analysis Protocol (PRISMA) is utilized based on a systematic literature review to identify how disruptive technologies transform cities in relation to the fields of environment, health, and social services [32–38]. The data for conducting PRISMA are not limited to white literature, but they utilize data extracted from social network services, blogs, news, and other informal online written documents to analyze public opinion [39]. Theoretical research has been conducted on smart cities using meta-reviews to identify a holistic view of smart city development, which creates advanced ICT to promote sustainability and participatory urban governance [40,41]. Some studies have used bibliographic analysis to identify the effect of smart infrastructure on e-governance and e-participation [42]. This study adopts PRISMA to collect related data on three conceptually related smart cities based on white literature, grey literature, and unofficial written documents in line with existing literature on smart cities.

A lack of in-depth empirical studies of sociotechnical transitions in conceptually related smart cities affects the oversimplified narratives [43]. Since the new technologies have been emphasized in the development of conceptually related smart cities, it has resulted in the absence of in-depth empirical studies of the sociotechnical transition and oversimplified the narratives of techno-utopia by ignoring the urban sustainability, diverse urban systems, and stakeholders’ capabilities [43]. The challenges of the recent development of conceptually related smart cities give rise to the necessity of empirical studies to identify the different characteristics of real cities’ cases of sustainable smart cities in sociotechnical transformation. Based on the comprehensive research question “what are the sociotechnical characteristics of Conceptually Related Smart Cities services from an international perspective”, this study aims to identify the empirical characteristics of conceptually related smart

cities services' socio-technical transformation led by different stakeholders' cooperation for service implementation from international perspectives.

Considering the study's aim illustrated in Figure 1, this paper is structured as follows. Section 2 reviews the concept of sustainable smart cities and establishes a theoretical background based on a literature review. Section 3 describes the framework of the proposed method. Section 4 describes the study process and explains its three outcomes. Section 5 discusses and expands our findings using existing theories, and the last section presents concluding remarks.



Figure 1. Schematic Section Framework.

2. Literature Review

2.1. Background of Conceptually Related Smart Cities

Empirical characteristics of conceptually related smart cities have yet to be thoroughly studied from a holistic perspective using several real-city cases. Scholars have conceptually typified names to identify the classified heterogeneities and features, as shown in Table 1. The term of conceptually related smart cities was first suggested by Kim and Yang (2021) to analyze the different names of smart cities in holistic manners [8]. It encompasses all the names of smart cities developed by the public, private, and public sectors, as illustrated in Table 1. Meanwhile, Research by Anthopoulos [23] has shortcomings in describing cities' characteristics as it unifies the concepts related to conceptually related smart cities based on the real cities' projects even if the research ushered in new approaches to smart city research based on real cities' transformation. Therefore, it is necessary to clarify the meaning of various terminologies using real-city cases by focusing on the local distinctiveness and sustainable implementation of ICT to deal with smart city challenges of developing local sustainability.

Table 1. The names of Conceptually Related Smart Cites in the existing literature.

Citation	Author (Year)	Title	Conceptually Related Smart Cites
[20]	Nam et al. (2011)	Conceptualizing smart city with dimensions of technology, people, and institutions	a technological dimension (the digital city, intelligent city, ubiquitous city, wired city, hybrid city, and information city), a people dimension (a creative city, learning city, a human city, and knowledge city), and a community dimension (smart community)
[21]	Guo et al. (2019)	A Bibliometric Diagnosis and Analysis of Smart Cities	smart city, digital city, information city, intelligent city, knowledge-based city, and ubiquitous city
[22]	D’Auria et al. (2018)	Modern Conceptions of Cities as Smart and Sustainable and Their Commonalities	technology-led digital city, human capital emphasized smart cities, cyber cities, and virtual cities
[8]	Kim&Yang (2021)	Characteristics of Conceptually Related Smart Cities (CRSCs) Services from the Perspective of Sustainability	cyber city, virtual city, internet city, wireless broadband city, intelligent city, digital city, ubiquitous city, and smart city
[23]	Anthopoulos et al. (2017)	The rise of the smart city	A cyber-based city, a web city, a virtual city, a knowledge base, a broadband city, a wireless/mobile city, a smart city, a digital city, a ubiquitous city, and an eco-city.

Conceptually related smart cities are regarded as innovative platforms in cooperation with diverse stakeholders’ partnerships. Technology and society have developed through the formulation of correlated relationships. The technologies are influenced by economic, social, environmental, and political urban resources to satisfy different needs in each period while untethering a flood of social changes in modern society [44]. Those sociotechnical communities are the conceptually related smart cities developed in the five stages of IT transformative history, beginning from pre-telecommunications, telegraph, telephony, computing, and ICT [45–47]. In the history of transitions, ICTs have influenced better decisions and policymaking at the city level. It has empowered citizens’ participation by opening up the data and training them to become intelligent citizens, encouraged multi-stakeholder partnerships by breaking down traditional silos, and enhanced city sustainability by managing social, economic, and environmental resources, even though the technologies seem to be emphasized in the initial implementation stages. Sociotechnical advancement based on different stakeholders’ partnerships diversifies and evolves conceptually related smart cities in innovative trajectories. Their endogenous elements emphasize the role of stakeholders, geographical characteristics, and dynamic urban services [5,48–50]. The ICT-based transformative communities and cities are, aforementioned, cyber cities, virtual cities, Internet cities, wireless broadband cities, intelligent cities, digital cities, ubiquitous cities, and smart cities [8]. Through the interaction of these three factors, cities become innovative laboratories to develop place-based technologies [47,48] through exploration and exploitation activities immersed in the urban services’ interaction, especially in cooperation with the public, private, people, academia, and NGO sectors [51].

Overall, the related literature insists on the importance of multi-stakeholder partnerships and place-based urban services to make conceptually related smart cities sustainable. However, few studies have examined the empirical development of sustainable smart cities according to different stakeholder partnerships [43]. This study typified sociotechnical service developments of conceptually related smart cities according to different stakeholders’ cooperation by adopting the comprehensive concept of multi-stakeholderism. Meanwhile, this study differs from previous sustainable smart cities studies with respect to empirically clarifying three types of service sustainability by focusing on different stakeholders’ partnerships.

2.2. Concept of Sustainable Smart Cities

The concept of sustainable smart cities is neither a general nor fixed term. It has been discussed disparately by combining two terms: smart cities and sustainability. The concept of sustainable smart cities is based on (1) the concept of sustainability or sustainable development goals (SDGs) as a vision in a government plan [52–55] which the United Nations’ SDGs influence, 2030 Agenda, the New Urban Agenda to improve indiscreet urbanization,

and the rapid growth of urban populations [56–58]. (2) Some studies define it as a compound term for managing urban resources by mobilizing ICT [21,59,60]. (3) It is regarded as a complex and innovative index for achieving urban sustainability [53,61–64]. (4) Other studies consider sustainability as a transformative process of urban services sustainability based on the transformative concept of ICT and multi-stakeholder partnership [51,65–67]. (5) Established from the transformative concept of sustainable smart city services, others conceive it in transformative sociotechnical innovative transitions to improve urban ecosystems and meet local needs [3,11]. In particular, Mora et al. (2021) adopt a middle-range of sustainable smart city transitions, which bridge the theoretical proposition with subsequent empirical testing based on the multilevel perspective framework to bring new theoretical insights beyond techno-utopianism [5]. Kim and Yang (2021) defined sustainable smart cities as complex initiatives aiming to develop and implement sustainably and integratively diverse urban services from social, technological, governancial, environmental, and managemental aspects [8]. Tcholtchev and Schieferdecker (2021) describe sustainable smart cities as those that fulfill SDGs in a sustainable process based on ICT, including IT, to boast various fields sustainably based on their development history [24].

In this study, sustainable smart cities are defined as transformative initiatives for developing and implementing integrative social, technological, governance, economic, environmental, and management urban services sustainably by extending the ideas of Tcholtchev and Schieferdecker (2021) [24], Kim and Yang's (2021) concepts [28], and Mora et al.'s (2021) framework [5].

2.3. Literature Review of Socio-Technical Transition

The theory of a multilevel perspective of sociotechnical transitions was first framed by Geels [68] and influenced by various multilevel transition concepts. The field began its study by understanding technological changes and shifts by scholars in evolutionary economics. Nelson-Winter's model is a representative study for identifying technological transitions using technological regimes and organizational and cognitive routines [69]. The technological regime focuses on the attention of engineers to provide strong guidance on the tactics for probing in that direction [70]. The regime results from the organizational and cognitive routines that engineers and firms share. It results in technological trajectories through innovative activities and R&D towards incremental improvements based on the stability of the technological regime [68,69]. Rip and Kemp widened the concept of the technological regime by conceiving sociological and economic perspectives [71]. Having the foundation of these two concepts, Geels combines various concepts by adopting Hughes' large technological systems and the relationship between sociology, institutions, and rules [72]. This notion is supported by multilevel perspectives [73]. Malerga's sectoral systems of innovation [74] and Carlsson's technological systems [75] frame the sociotechnical transition from multilevel perspectives [68,76]. Rotmans et al. (2001) collaborated with Geels on different research levels of aggregation, including sociotechnical landscapes, regimes, and niches [77]. Geels was influenced by existing sociotechnical transition theories, including transformative economic, institutional economic, and middle-range frameworks, to conceptualize overall dynamic patterns in sociotechnical transitions [78].

The multilevel perspectives on sociotechnical transitions include three levels: niche innovations, sociotechnical regimes, and sociotechnical landscapes. Niche innovations are developed by small networks of various social groups and actors to build internal momentum based on visions, expectations, and the learning process. It is an expanded concept that embeds the concept of Dosi's (1982) technological trajectories [79] with social groups and engineering communities, such as a knowledge base, engineering practice, corporate governance structures, manufacturing processes, and product characteristics [68,79]. As an extended version of the technological regime in Nelson and Winter's theory, the sociotechnical regime acts as a window of opportunity for niche innovation by stabilizing the uncertainty of dominant design, which results in technological trajectories and cognitive routines. The socio-technical

landscape, which is an exogenous context, places pressure on the existing regime and opens up opportunities for novelty.

Multilevel perspectives become robust when more empirical studies with diverse cases in varied time-periods and sectors [68]. The perspectives have been supported by historical case studies and typological studies [68]. The real society has different phases from adopting emerging technologies. As there is a lack of research on conceptually related smart cities from a holistic multilevel perspective that considers technological trajectories, technological regimes, local contexts, and different stakeholders' characteristics and participation, it is not easy to conceptualize smart cities visions and definitions, and develop conceptually related smart cities sustainably [80,81]. Empirical research has been conducted in specific fields or areas, such as the Metaverse, which has recently been researched as socially constructed, politically driven, economically conditioned, and historically situated to overcome its problematic nature [82]. As the technologies have consistently been considered in the local context and the distinct characteristics of stakeholders, in-depth empirical studies of the sociotechnical transition are necessary to clarify diverse urban systems and stakeholders' capabilities to make cities sustainable by avoiding the oversimplified narratives of techno-utopia [2,43]. This study has a gap in terms of identifying the holistic development of technological trajectories, regimes, and participants from multilevel perspectives. Sophisticatedly, this study is different from other sociotechnical transition researchers adopting multilevel perspectives in terms of clarifying "which services are developed mainly by whom in which cities" by reflecting the different conditions of local context and historical trends in each period.

3. Materials and Methods

A periodic matrix taxonomy was utilized based on the literature-reviewed data after cluster sampling, as illustrated in Figure 2. The cluster sampling method is helpful when the frame of the study population is not fully available [83], especially in the case of ongoing projects in smart cities. Multi-stage cluster sampling is a probability sampling method in which researchers list the study population as Table 2, divide them into clusters, and randomly select data from among them. The selected clusters were listed to conduct stratified sampling to determine the final samples randomly [84]. This method is usually utilized to select cities or people in social sciences, medical research, and agricultural studies for interviews or surveys [85–90]. Some systematic literature review researches use adaptive cluster sampling by clustering sources into three overarching steps of sample selection [91,92]. In this study, sampled European cities were selected using cluster sampling from all lists of smart cities (population), combined with lists of sustainable smart cities (study population), while considering the concept's sectoral keywords, including social, technological, governance, economic, environmental, and management elements. The second step was to compile relevant conceptually related smart cities data through longitudinal PRISMA and sort them by criteria to create a dataset for further analysis. The next step was data preprocessing by coding the projects and providing weights to the services depending on the number of stakeholders. The fourth step was to create a periodic matrix taxonomy using coded services and years. It comprises the year category on the top of the x -axis and the category of services on the left side of the y -axis. The vision and names of cities are positioned below the y -axis services and are marked as identical to the services. The cells are shaded if there is a service in a corresponding year, even if identically categorized services are developed within a year. Periodic matrix taxonomy provides two results from an international perspective within the framework of sociotechnical transitions. The following paragraphs elaborate on methodologies and outcomes in a detailed manner.

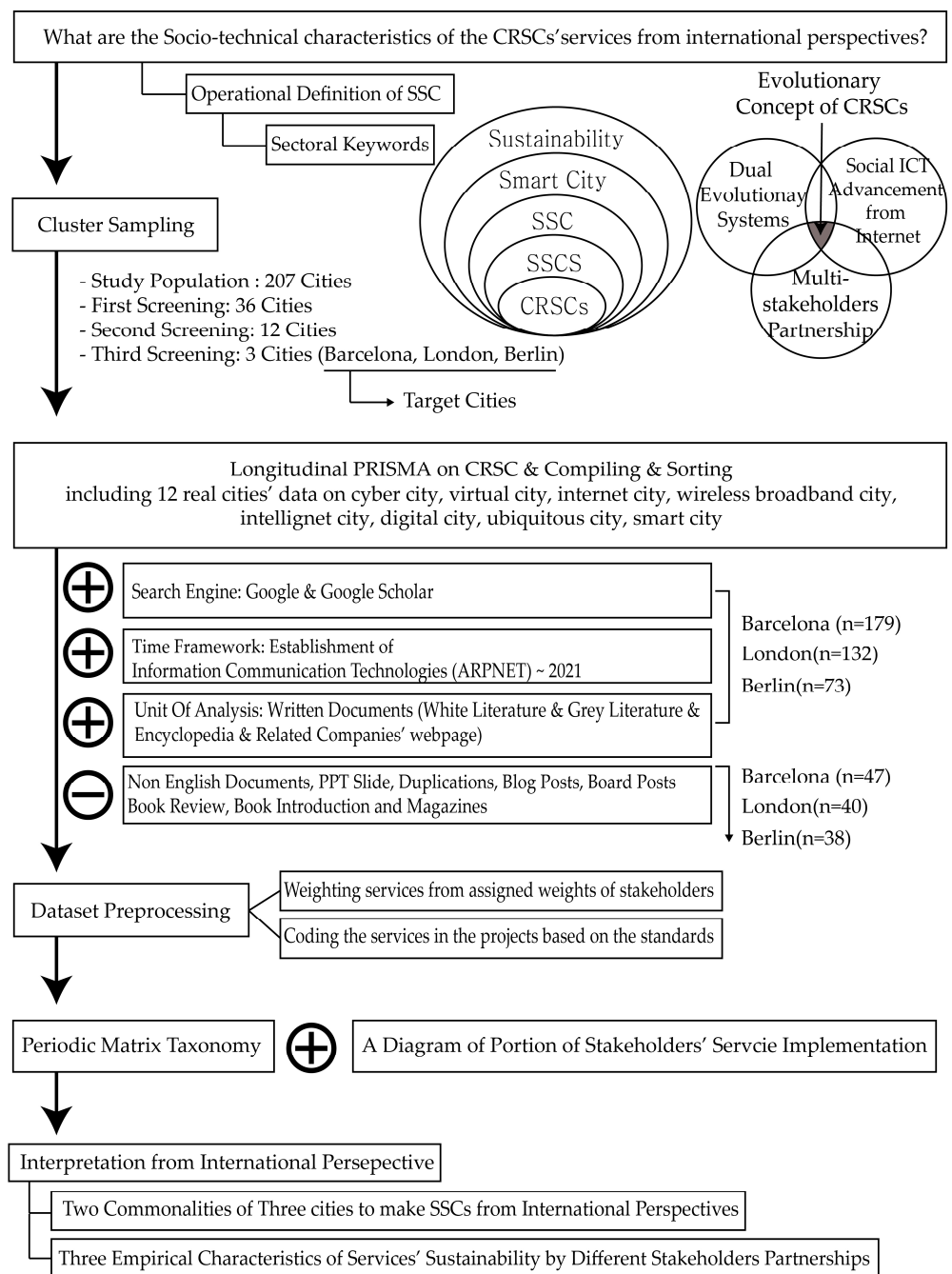


Figure 2. Study Framework.

The first step in framing the methods was started by casting the research question. The question is correlated with the study aim and concept of conceptually related smart cities in the concept of sustainable smart cities, which contain measurable indicators to establish the study frame, as illustrated in Figure 2. As mentioned above, in the concept of sustainable smart cities, the factors of six aspects and one keyword are narrowed down by adopting suitable research materials to sample sustainable smart cities to reflect the concept. The key concept in this study is the sustainability of urban services, and the six aspects are social, technological, governancial, economic, environmental, and managerial elements.

Table 2. A process of sampling cities.

Study Population	First Screening Result	Second Screening Result	European Cities
Singapore, Tokyo, New York, London, San Francisco (Oakland), Paris, Hong Kong, Osaka, Los Angeles-Long Beach-Santa Ana, Chicago, Barcelona, Moscow, Stockholm, Seoul, Munich, Stuttgart, Boston, Madrid, Shenzhen, Frankfurt am Main, Philadelphia, Toronto, Taipei, Houston, Miami, Berlin, Melbourne, Rome, Shanghai, Seattle, Manchester, Atlanta, San Jose, Cleveland, Sydney, Hiroshima, Birmingham, Beijing, Milan, Montreal, Dallas-Fort Worth, Buenos Aires, Vienna, Tel Aviv-Yafo, Denver-Aurora, Hamburg, Zurich, Nagoya, Baltimore, Kitakyushu-Fukuoka, Copenhagen, Hannover, Salt Lake City, San Diego, Perth, Washington D.C., Incheon, Suzhou, Raleigh, Kuala Lumpur, Vancouver, Amsterdam, Astana, Geneva, Brussels, Detroit, Guangzhou, Austin, Orlando, West Yorkshire, Cologne, Helsinki, Daejeon, Istanbul, Ulsan, Richmond, Valencia, Jerusalem, Columbus, Sao Paulo, Bridgeport Stamford, Phoenix-Mesa, Nanjing, Doha, Haifa, Antwerp, Hartford, Riyadh, Sapporo, Gwangju, Busan, Naples, Xiamen, Milwaukee, Glasgow, Adelaide, Dubai, Daegu, Santiago de Chile, Malaga, Athens, Wuxi, Dortmund, Louisville, Pretoria, Essen, Tianjin, Foshan, Taichung, Brisbane, Auckland, Dresden, Saint Petersburg, Virginia Beach, Calgary, Las Vegas, Bogota, Medina, Dongguan, Wuhan, Lima, Kaohsiung, Dusseldorf, Tampa-St., Petersburg, Belfast, Jeddah, Worcester, Hangzhou, Lyon, New Haven, Leipzig, Dublin, Hamilton, Hague, Buffalo, Charlette, Liege, Zaragoza, Torino, Colorado Springs, Chengdu, Qingdao, Nashville-Davidson, Macao, Rio de Janeiro, San Antonio, Zhongshan, Minneapolis-Saint Paul, Sendai, Lisbon, Silo, Ningbo, Lille, Liverpool, Provo-Orem, Changzhou, Zhengzhou, Amman, Venice, Dammam, Rotterdam, Tainan, Changsha, Leicester, Tehran, San Juan, Providence, Shizuoka-Hamamatsu M.M.A., Verona, Johannesburg, Baton Rouge, Bangkok, New Orleans, Gold Coast, Ottawa-Gatineau, Bologna, Leon, Solfa, Indianapolis, Shenyang, Pittsburgh, Ogden, Florence, Kansas City, Budapest, Montevideo, Zhuhai, Honolulu, Barcelona-Puerto La Cruz, Oklahoma City, Dallin, Minsk, Porto, Mecca, Xi'an, Ahvaz, Hefei, Marseille-Aix-en Provence, San Francisco, Tallinn, Roma, São Paulo, Mexico City, Warsaw, Prague, Almaty	Singapore, New York, Stockholm, Seoul, Shanghai, Amsterdam, Helsinki, San Francisco, Chicago, Copenhagen, Barcelona, Melbourne, London, Tokyo, Paris, Moscow, Madrid, Toronto, Berlin, Bogota, Buenos Aires, Istanbul, Brussels, Dubai, Mexico City, Sydney, Johannesburg, Lisbon, Athens, Kuala Lumpur, Seattle, Austin, Vienna, Beijing, Shenzhen	Singapore, New York, San Francisco, Chicago, Barcelona, Melbourne, London, Tokyo, Berlin, Dubai, Mexico City, Seoul	Barcelona, London, Berlin
207 cities	36 cities	12 cities	3 cities

The cluster sampling in this study proceeded through three filtering steps. The cluster sampling needs to list the population to cluster them, and the population for this study is 221 cities, according to Smart City Tracker 1Q18 [93]. The study population combines three rankings representing the sectoral aspects of the sustainable smart cities concept: the United Nations-Habitat Global Urban Competitiveness Report, McKinsey Company's Smart Cities: Digital Solutions for a More Livable Future, and the United Nations E-Government Survey 2020 [94–96]. The first report represents the social, economic, environmental, and management aspects. The second report indicates the aspect of technology, while the third one represents the aspects of governance. The first screening results came from the combination of three sustainable smart cities rankings, mentioned more than twice in the three groups of selected cities based on the Sustainable Smart Cities concept, which resulted in 36 cities. The second sampling is conducted to select high-performing sustainable smart cities by integrating the first screen result and the top 20 smart cities from the rank of smart cities performance published by Juniper Research, which included 12 cities. Among the result of the second screening, European cities were selected, and Berlin, London, and Barcelona are the sampled cities representing European samples of the operational concepts' keywords.

Longitudinal PRISMA is conducted to compile the year of occurrence, related events, stakeholders on duty, and related government plans from the written documents that describe events starting from 1968 to 2021, considering the emergence of social ICT from the Advanced Research Project Agency, a pioneer of the Internet. As illustrated in Table 3, the search keywords refer to the existing literature in Section 2 and Kim and Yang's study because they typify the elements of conceptually related smart cities by combining the indicator of sustainable smart cities and conceptually related smart cities based on

transformative concepts using a systematic literature review [8]. The search keywords were used to collect related data from Google and Google Scholars for each city.

Table 3. Search Keywords of Conceptually Related Smart Cities.

Conceptually Related Smart Cities	Search Keywords
Cyber City and Virtual City	Advanced Research Project Agency, file transfer protocol, packet switching, ethernet, telnet, e-mail, backbone networking, web-based community, video chat, audio chat, Bulletin Boards Systems, list server, news lists, Usenet, Bitnet, Computer Mediated Community, Internet Relay Chat, and Multiuser Dungeons.
Internet City	Transmission Control Program/Internet Protocol, modem, and World Wide Web.
Broadband City	digital subscriber, and fiber optic data communication.
Wireless Broadband City	packet radio, local area network, Packet Radio Network, Wave LAN, Wi-Fi, 1G, 2G, 3G, 4G, LTE, and 5G.
Intelligent City	Intelligent Cities are related with keywords of intelligent city, intelligent transport systems, artificial intelligence, intelligent government and intelligent building system.
Digital City	digital city, Geographic Information System, cloud computing, one-stop services, digital inclusion, digital education, digital economy, digital participation, crowd funding, crowdsourcing, digital plan, and data network.
Ubiquitous City	3A(anywhere, anyone, anytime), and manage city resources using ubiquitous, computing, sensors and microchips such as ubiquitous computing, operation center, clouding computer, Radio-Frequency Identification, Near Field Communication, Quick Response code, CCTV, ubiquitous city, ubiquitous plan and u-services.
Smart City	smart city, smart citizens, smart services, Internet of Things, Internet of Everything, robotics, 3D printing, neuro-technologies, quantum computing, solar desalination, zero-carbon natural gas, nanotechnology-cloud computing, energy storage, predicting future and proacting to the disasters and climate changes, cyber-physical system, digital twin, microdata, super connectivity, 5G, Big Data, data security, blockchain, Vehicle To Grid, autonomous vehicle, health passport, DNA computing and storage, carbon based transistors, and other emerging technologies.

Collecting relevant government, company, NGO, academic, and international organization publications is a fundamental step in constructing a dataset for further work. The data features for analysis are shown in Table 4. After searching for the documents with keywords in Table 3, it resulted in 182 documents concerning Barcelona, 110 documents regarding London, and 64 documents regarding Berlin. Non-English documents, PPT slides, duplications, blog posts, board posts, book reviews, book introductions, and magazines were excluded. As organized in Appendix A, the final data sources for analyzing three cities were 47 documents for Barcelona [97–143], 40 sources for London [65,106,144–181], and 38 sources for Berlin [161,182–218]. As Table 4, the 179 Barcelona projects were implemented with 182 participants over 34 years continuously and in an ad hoc manner. The 132 London projects are implemented with 110 players in London under the five names of the conceptually related smart cities for 44 years, mostly continuous plans. Berlin has implemented 73 projects with 64 participants under three names of conceptually related smart cities in 25 years in an ad hoc manner.

Table 4. Compiled Data Features.

Name of Cities	The Number of Participators	The Number of Conceptually Related Smart Cities	The Number of Implemented Years	Implemented Projects
Barcelona	182	3	34	179
London	110	5	44	132
Berlin	64	3	25	73

The compiled data were organized into the categories of the year of occurrence, related projects, stakeholders on duty, and related government plans. Since the compiled data are usually long sentences or paragraphs that are difficult to analyze systematically, it is challenging to identify the flow of conceptually related smart city services' sustainable

development. The data were divided into service, vision, naming, and reference categories by extracting relevant data from long sentences following the progress shown in Figure 3.

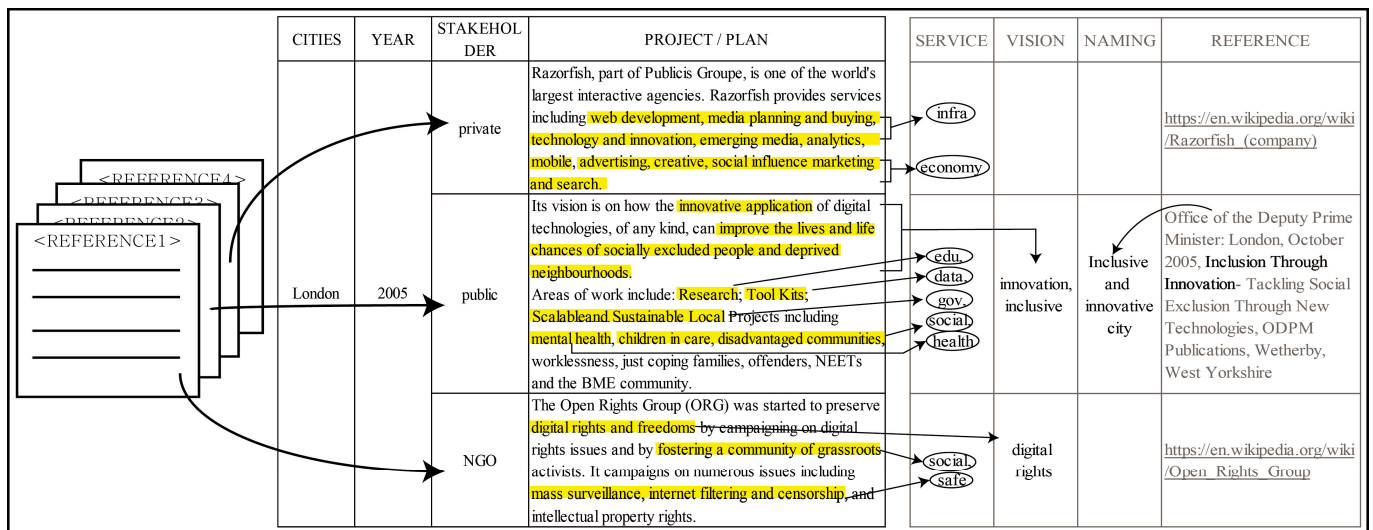


Figure 3. Compiling and Sorting Data.

The compiled text data were transformed into numeric data for the analysis as Appendix A. The first step for data preprocessing is to code them using sustainable smart cities service categories in Figure 4 by referring to Kim and Yang’s study because of their similar study aims and concepts [8]. This study adopts 17 service indicators, including social, tour, safety, environment, economy, health, transport, government, waste, architecture, energy, education, history, media and art, standardization, data, and infrastructure, while excluding urban planning vision and including three subordinate elements of hard infrastructure from Kim and Yang’s study [8]. The coding index of vision consists of extracting frequently mentioned words from the data documents of the three cities. Following the progress illustrated in Figure 5, the services are codified to create a periodic matrix taxonomy. The codes are marked on the top of the x-axis, referring to the year categories, and service categories are marked on the left side of the y-axis. The vision and names of the cities are marked below the y-axis services based on the government plan.

The second step for data preprocessing is to give weights to each service and stakeholder to count them equally if they correspond in the same years. The weighting process is a crucial step to identify which services are more developed by whom in individual cities. Some projects, which describe only the vision and absent action plans or activities, were excluded from making a weighted service table as this study purposed to identify the characteristics of implemented or planned activities. The services involved in each stakeholder are divided by services’ number from the assigned weights of the individual stakeholders. As each year weights “1” equally, the weight is divided by the number of participating stakeholders in that year to distribute the weight to the participated stakeholders equally. The services get weights individually through dividing the assigned weights for stakeholders by the number of implemented services. The point is that the total weight of services in the same year needs to be “1”, as shown in Appendix A. Each service is included in some stakeholders each year because this is counted equally, and stakeholders are vice versa in the same year.

The key players are illustrated distinctively in Table 5 and Figure 6. The number of individual stakeholders’ driven services is deducted by adding weights corresponding to each city’s stakeholders’ services. The portion of services results from dividing the number of stakeholder services by the entire year of service implementation in individual cities. When the result is interpreted with the major service-leading stakeholders, the public and private sectors, separate from the others, it reveals that the private and people partnership

has developed in Berlin. By contrast, Barcelona’s smart cities have comparatively more weight in the public and people sectors, and London’s smart cities are relatively strong in public, academic, and NGO partnerships.

Sustainable Smart Cities (SSCs) Coding Standards			
Service Categories		Vision Categories	
IFR	Infrastructure	IC	Inclusive
Social	Social	Sus	Sustainability
E	Economy	opn	Open
GOV	Government	eff	Efficiency
EDU	Education	ptc	Participatory
SF	Safety	con	Convenient
Tour	Tour	col	Collaborative
DATA	Data	self	Self-sufficient
ENV	Environment	QoL	Quality of Life
H	Health	mea	Measurable
STD	Standardization	mng	Manageable
EG	Energy	DR	Digital Right
TSP	Transportation	IN	Innovation
WST	Waste		
ARC	Architecture		
MA	Media & Art		
HST	History		

Figure 4. The Sustainable Smart Cities Coding Standards.

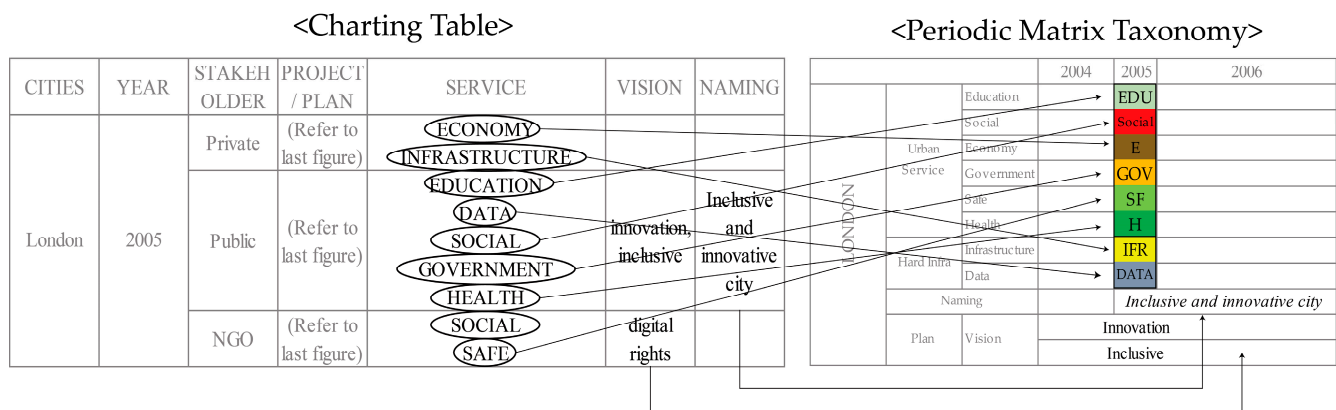


Figure 5. Coding Data.

Table 5. Three types of services’ sustainability by different stakeholders’ partnerships.

	Barcelona	London	Berlin
The weights of publicly driven services	26.82	23.64	9.58
The weights of privately driven services	4.3	12.99	13.47
The weights of people-driven services	1.92	0.33	1.95
The weights of academic-driven services	0.89	4.87	0
The weights of NGO-driven services	0.08	2.17	1
Total year of service implementation	34	44	25

Table 5. Cont.

	Barcelona	London	Berlin
The portion of public-driven services	0.79	0.54	0.34
The portion of private-driven services	0.13	0.3	0.54
The portion of people-driven services	0.06	0.01	0.08
The portion of academic-driven services	0.03	0.11	0
The portion of NGO-driven services	0	0.05	0.04
Total	1	1	1

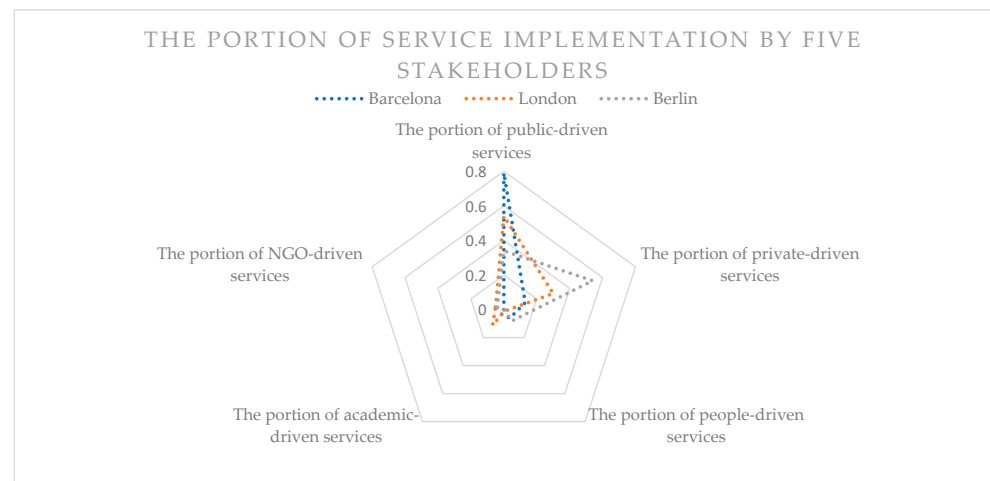


Figure 6. The portion of service implementation by five stakeholders.

4. Results

The periodic matrix taxonomy provided two important commonalities and three different empirical characteristics from an international perspective through cluster sampling, PRISMA, and data preprocessing of coding and weighting. The first commonality among the three cities is the comparatively higher weights for publicly and privately driven services. The two stakeholders have led the projects since the smart cities and their essential technologies were developed. After the public and international private sectors develop built environments, core technologies, and infrastructure with their large funds in the initial stage, the frontier and emerging technologies are publicized by national companies in support of small and medium companies. After spreading across nations and cities, innovation has emerged in cooperation with multiple stakeholders, such as public-academics-NGO, private-people, or public-people partnerships. In other words, the major players in the development of smart cities are the public and private sectors. The other commonality is sustaining the development and implementation of services after approximately 2015. This phase is influenced by the public sector's leadership at the national level and the launch of SDGs at the international level. Specifically, London launched a London Infrastructure in 2015 to advance supportive technologies after planning the Smart London Plan in 2013. Barcelona planned municipal action plans after the smart city project was launched after Mayor Trias' decided to enhance citizens' quality of life and reduce the cost of government operations in 2012 [101]. The Berlin government launched a "Smart city makes the people and citizens smarter" plan with ten goals. The plans correlate with the SDGs to make smart and existing cities sustainable. It deals with current challenges based on active participation in innovative ideas, advanced, resilient infrastructure to reduce resource consumption, and interactive, diverse urban services to encourage smart networks. Consequently, the three cities have commonalities in stakeholder cooperation and service sustainability.

The period matrix taxonomy discovers three different characteristics of service development in socio-technical transitions concerning different stakeholder partnerships, as illustrated in Figure 7. The primary focus of the public-people-driven city in Barcelona was used to

develop infrastructure, government, economic, and social services for the preparation of the Olympics by implementing the @BCN Plan beginning in 1985 with 500 km of communication infrastructure of fiber optic cables [98]. As an Internet city, they have mobilized Internet networks in cooperation with academia and citizens, such as the Guifi.net platform [105], to educate citizens to allow anyone to make anything. Additionally, it implemented transportation and environmental services in 2000 when the government launched programs such as electric motorcycle charging stations, water management facilities, and hybrid bus prototypes and regulated new buildings to install solar energy sources [100]. In 2013, Barcelona provided health and well-being services and ensured the availability and sustainable management of water and sanitation [102,105,107,112,219]. Other current services and related projects are sustainably developed and posted in the municipality website (e.g., 5G-related projects, eight Barcelona Open Data Challenge projects, the makers' fair Barcelona, innovative solutions for dependent senior citizens project led by I. Lab, the mobile youth festival, remote surgeons, and other public-people partnership projects). They generally focus on participatory urban planning led by public-people partnerships in developing conceptually related smart cities.

Berlin is a private-people-driven smart city. Its first computer networking was implemented in 1981 by networking with the Stanford Research Institute to produce the German Ministry for Research and Technology status report on computer networking in the intended federal project "German Research Network" [182]. The Internet network was publicized in cooperation with the government and private sectors until Deutsche Telekom was established in 1995. Although Deutsche Telekom became a government corporation, the required services for operating companies were still developed in an ad hoc manner until 2011, including transportation (e.g., Door2door and on-demand air taxi), health (e.g., farming tech and Plantix), and social (e.g., Internet café and Internet Relay Chat) services. However, cooperation between the public and private sectors began when Silicon Allee was implemented through urban planning in 2011 to build a start-up community using meetups, events, and an English-language blog [189]. The government and companies branded Silicon Allee in Berlin as a creative city through urban planning, which implied a vision of the future with urban planners. The plan aimed to instill an ideal future in the city by attracting new creative classes, ideas, investments, businesses, and money [220]. Public plans (e.g., "Smart City makes the people and citizens smarter," and "Digital Strategy 2025") led to other types of services, including social, public, energy, safety, and education services, which have been sustained with previously developed services.

Public-academic-NGO-driven services are provided in London. It has a long history of developing data transmission infrastructure in cooperation with governments and researchers since Donald Davies conceived the idea of packet switching for data communications chosen by the Advanced Research Project Agency Network to serve as an interface message processor [44]. The government and private companies have provided social services since the public view data service was opened by Prestel [175]. Health services were provided for research purposes in 1986 (e.g., NYSERNet) and were served within the government project by creating a set of locally sustainable and nationally scalable digital inclusion initiatives in 2005 [221]. As broadband technology was implemented, more people used the Internet [175], and commercial ISPs (e.g., Pipex) and nonprofit ISPs (e.g., GreenNet) were introduced. As an inclusive and innovative city, the government launched free services (e.g., Mapping service, Tool kits, and other Scalable and Sustainable Local Projects) and private sectors (e.g., TalkTalk and Sky TV) while NGOs raised their voices to secure digital rights (e.g., Open Rights Group). The digital city emphasizes the digital economy, cyberspace security, and digital content [156]. Other services, including energy, the environment, and transportation, have been implemented through the London Infrastructure 2050 Plan by supplying energy to homes and businesses and unlocking housing growth through transport infrastructure [148].

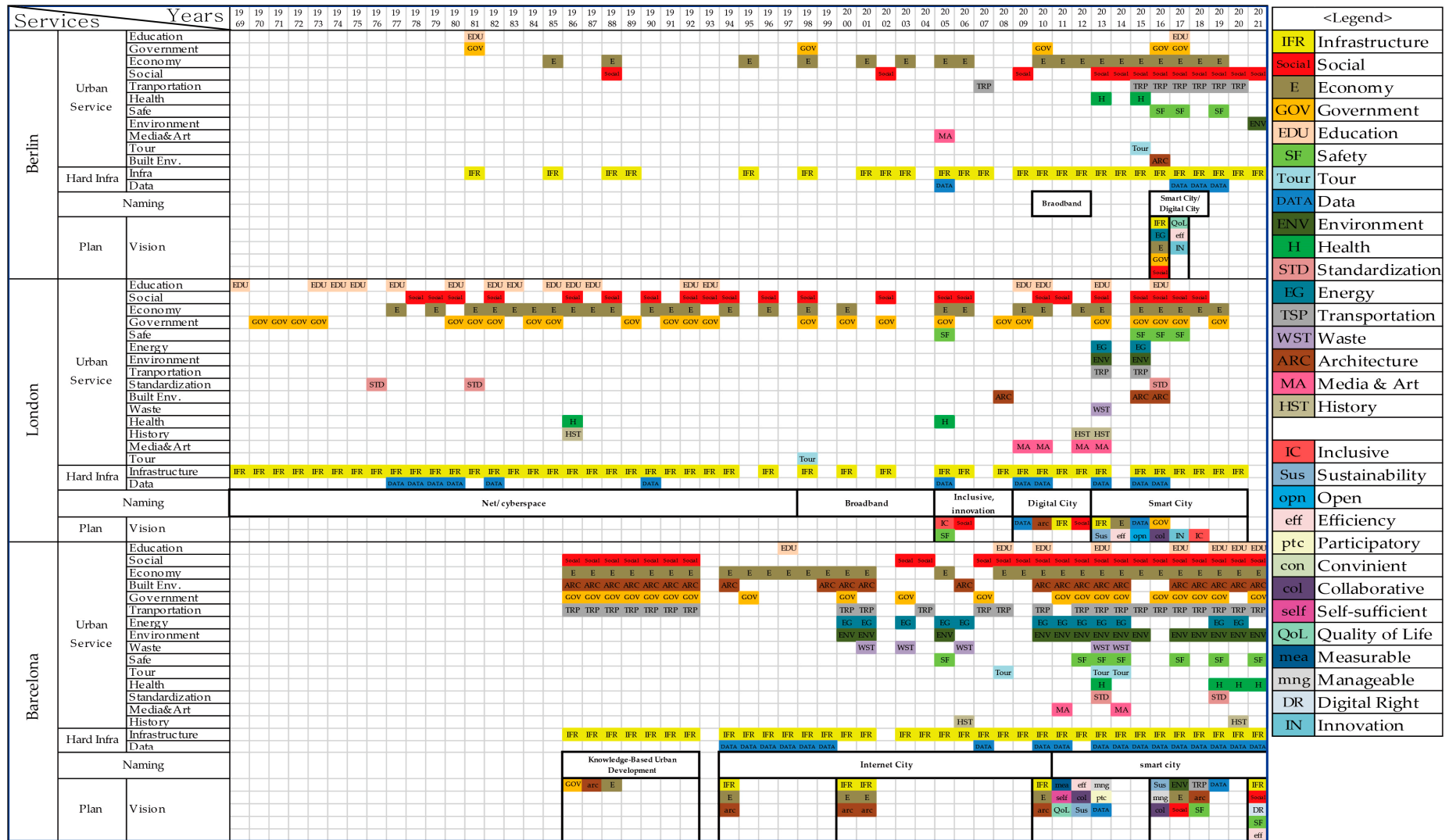


Figure 7. Periodic Matrix Taxonomy of Three European Smart Cities.

5. Discussion

Conceptually related smart cities have evolved in the history of sociotechnical transitions to realize SDGs for urban sustainability in cooperation with diverse stakeholders' partnerships. Some scholars point out that some service implementation standards are far from real-cities, because they lack a holistic strategic framework of service development and are drawn from related research, mostly on the conceptual characteristics of smart cities or the empirical characteristics of technological fields [81,222,223]. In this regard, this study identified the sociotechnical characteristics of conceptually related smart cities services from international perspectives by using the periodic matrix taxonomy under the research question of "What are the sociotechnical characteristics of conceptually related smart cities services from international perspectives?". The empirical characteristics are based on three sampled European sustainable smart cities using a periodic matrix taxonomy. This section elaborates on the findings and implications of their relations with the existing literature.

The first outcome concerns two commonalities of European conceptually related smart cities development in the history of sociotechnical transitions from an international perspective. The development process, from a macro perspective, analyzes the European empirical cases in correlation to the existing study, which uses city data from Manchester (UK) and Boston, Massachusetts, and San Diego (US) [224]. Subsequently, this study has implications in terms of providing a headstone for making a global consensus reflecting on the local sustainable smart cities context regarding Schiavo and Magalhães' research [81] for establishing the global sustainable smart cities' urban service standardization. Specifically, this study clarifies that initial services, including infrastructure, economy, government, society, and education, are fundamental to develop smart cities. The services are either shifted or diversified to meet needs in the current period, including safety, health, and transportation services. These transitions are based on an Extended Metabolism Model by Newman, demonstrating how livability is integrated with the flow of resources [225] and supports smart metabolism, which assesses cities with three critical approaches to increase livability involving the use of sensors, real-time data, and informing different stakeholders through the use of pervasive technologies [80,226]. The transitions of magnified services in each period have shifted smart metabolism to increase livability. Using the internal combustion engine automobile for e-mobility is an example of the smart metabolism of sustainable smart cities service development. The smart metabolism can be empirically identified, given that the sensor and big data analytic device analyze the related spatial-temporal and longitudinal data. The second commonality is that public or private stakeholders initialize and sustain them with various local services, in line with the SDG plan after 2015. It compensates for the issues raised by Parra-Domínguez et al. [18], who demonstrate the necessity of smart city development by incorporating the SDGs set by the 2030 Agenda with technology implementation. However, it would be challenging for the local indicators and themes to be used or reflected in conjunction with global smart city indicators and local context, and vice versa in a holistic and systemic view [81].

The other outcome is the development of three empirical characteristics of sustainable smart cities according to different stakeholder partnerships, which are divided into public-academic-NGO, public-people, and private-people partnerships. This study empirically demonstrates the multi-level perspectives in socio-technical transitions raised by Geel and expands the technological transitions by Nelson-Winter's model. It contributes to the discourse on multi-stakeholderism in conceptually related smart cities by specifying partnerships based on the development of services and local physical characteristics. The multi-stakeholderism for developing sustainable smart cities has been discussed in several previous studies empirically from the perspective of sociotechnical transitions by mobilizing ICT, which serves as a gluing component to interact with different services and engage stakeholders' partnerships by responding resiliently to upcoming challenges through technological advancement [24]. The quadruple-helix framework helps to understand the different characteristics of service implementation based on the local context in sociotechnical history and multi-stakeholderism [227]. It has been researched in several

models, such as strategic niche management [71], technological innovation system [228], and multilevel perspective models [2,68]. The middle range theory, based on multilevel perspective frameworks, provides a scientific foundation by empirically examining the patterns, regularities, and stylized mechanisms of diverse sustainable smart city transition processes and using general conceptual schemes [5]. However, related empirical studies have not yet been conducted using transformative city-level data. Therefore, this study expands the existing literature based on the middle-range theory framework to identify the empirical characteristics of sustainable smart cities development from the perspective of stakeholder roles, innovation, and sustainable smart city planning.

6. Conclusions

Sustainable smart cities have evolved through sociotechnical transitions in cooperation with diverse stakeholders to achieve future sustainability. In-depth empirical studies of the sociotechnical transition based on conceptual studies would prevent one-size-fits-all narratives [43] and provide a fundamental node for planning sustainable smart cities. This study aims to identify the empirical characteristics of the service developments of conceptually related smart cities services' socio-technical transitions from an international perspective. The empirical characteristics were identified based on the real-city data sources of three sampled cities, which are selected by cluster sampling using the representative ranks of keywords in the concept of sustainable smart cities. The outcomes were measured using periodic matrix taxonomy. It results in two outcomes: two commonalities from international perspectives and three empirical characteristics of the development of sustainable smart cities. The two commonalities of the conceptually related smart cities service development of the three cities resulted in the identification of leading stakeholders and the starting year of cooperation between the local level of sustainable smart cities implementation and the international level of sustainable smart cities development. The other outcome is the three empirical characteristics of sociotechnical transitions in sustainable smart cities development according to different stakeholders' partnerships, resulting in conceptually related smart cities services development in cooperation with public-academic-NGOs, public people, and private-people partnerships.

These results provide managerial contributions. The first outcome provides the entire sequence of developing smart cities services for achieving sustainability in correlation to existing studies. Specifically, the initial services such as infrastructure, economy, government, society, and education are fundamental to develop smart cities. At the same time, the services diversify other services satisfying the local context and the needs in the era including safety, health, and transportation services. This transformation in the history of developing smart city services could be considered as one of the socio-economic development processes [229] but also intelligent metaphoric approaches for upcoming challenges. In the current transformation, the local authorities and citizens' active participation would be the determinant factors in adjusting cities to the new environment mobilizing new technologies, digitalization, data, information, and vision. Meanwhile, cities could develop contextualized or advanced services based on geographical, cultural, political, economic, and environmental data drawn from measuring cities' status using sensors, data analytic technologies, and alerting devices. The second result empirically clarifies that smart cities' development emphasizes place-based development rather than the disappearance of time and space by extending Sassen [229]. The place-based traits, which are intrinsically inherited in the history of developing cities mobilizing ICTs, influence smart city services' development and stakeholders' cooperation characteristics.

Moreover, the outcome has theoretical contributions to smart metabolism that empirically clarify how urban resources and services have been transformed or evolved in the history of sustainable smart cities with the advancement of ICTs. It would be empirically identified given that the sensor and big data analytic device analyze the related spatial-temporal and longitudinal data. It could contribute to the conceptualization of establishing smart cities' history by analyzing the commonalities of several mega smart city

services' transformation so as to provide a fundamental principle to newly participated sectors and to deal with the development from the perspectives of the technological utopia. The second outcome contributes to the discourse on multi-stakeholderism in conceptually related smart cities by specifying partnerships based on the development of services and local characteristics. Empirical models of sustainable smart cities have been discussed from the middle-range theory based on multilevel perspective frameworks [2,68]. It thoroughly examines the sustainable smart city transition process and the general conceptual scheme using diverse empirical smart city-related concepts and models [5]. However, this field has not used data from transformative cities. Therefore, this study expands the middle-range theory framework to identify the empirical transformative characteristics of sustainable smart cities through the lens of stakeholders' roles, innovation, and smart city planning.

This study had some limitations. First, the unit of analysis, which is entirely related to documents describing conceptually related smart cities, could have the possibility to omit some relevant documents, even though the research result provides managerial and theoretical implications by explaining the priorities of developing conceptually related smart cities' services according to different stakeholders' partnerships and local contexts. Second, a lack of background knowledge makes it difficult to explain the development of different services based on multi-stakeholderism in a sophisticated manner. To deal with these issues, it updates and applies the theory and related research on multiple stakeholders to further studies.

Nevertheless, the outcomes have managerial implications of empirically demonstrating the different sequences of service transformation for European megacities depending on diverse stakeholders' partnerships, and theoretical implications to the existing theories, such as smart metabolism, multilevel perspectives, and the middle range theory, through the empirical analysis of historical real-city data and the specification of stakeholders' partnerships in conceptually related smart cities to identify the successful element of establishing sustainable smart cities from the urban sustainability perspective.

Author Contributions: Conceptualization, S.Y. and N.K.; methodology, N.K.; software, N.K.; validation, S.Y. and N.K.; formal analysis, N.K.; investigation, N.K.; resources, N.K.; data curation, N.K.; writing—original draft preparation, N.K.; writing—review and editing, S.Y.; visualization, N.K.; supervision, S.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Year	Data Source	Stakeholder	Service	Barcelona					Sum of CNS	Converted Weight of Services
				Converted Number of Stakeholders						
				Public	Private	People	Academia	NGO		
1986		public	architecture	1	0	0	0	0	1	0.166666
		public	social						0	0.166666
		public	gov						0	0.166666
		public	economy						0	0.166666
		public	infra						0	0.166666
		public	transport						0	0.166666

Barcelona										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
1987		public	architecture	1	0	0	0	0	1	0.166666
		public	social						0	0.166666
		public	gov						0	0.166666
		public	economy						0	0.166666
		public	infra						0	0.166666
		public	transport						0	0.166666
1988		public	architecture	1	0	0	0	0	1	0.166666
		public	social						0	0.166666
		public	gov						0	0.166666
		public	economy						0	0.166666
		public	infra						0	0.166666
		public	transport						0	0.166666
1989	[97,98,230]	public	architecture	1	0	0	0	0	1	0.166666
		public	social						0	0.166666
		public	gov						0	0.166666
		public	economy						0	0.166666
		public	infra						0	0.166666
		public	transport						0	0.166666
1990		public	architecture	1	0	0	0	0	1	0.166666
		public	social						0	0.166666
		public	gov						0	0.166666
		public	economy						0	0.166666
		public	infra						0	0.166666
		public	transport						0	0.166666
1991		public	architecture	1	0	0	0	0	1	0.166666
		public	social						0	0.166666
		public	gov						0	0.166666
		public	economy						0	0.166666
		public	infra						0	0.166666
		public	transport						0	0.166666
1992		public	architecture	1	0	0	0	0	1	0.166666
		public	social						0	0.166666
		public	gov						0	0.166666
		public	economy						0	0.166666
		public	infra						0	0.166666
		public	transport						0	0.166666
1994	[99]	public	infra	0.5	0	0	0	0	0.5	0.25
		public	architecture						0	0.25
		public	economy	0.5	0	0	0	0	0.5	0.1
	[98]	public	infra						0	0.1
		public	architecture						0	0.1
		public	economy						0	0.1
1995		public	data						0	0.1
		public	economy	0.5	0	0	0	0	0.5	0.166666
		public	infra						0	0.166666
	[231]	public	data						0	0.166666
		public	infra	0.5	0	0	0	0	0.5	0.25
		public	gov						0	0.25

Barcelona										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
1996	[98]	public	economy	1	0	0	0	0	1	0.333333
		public	infra						0	0.333333
		public	data						0	0.333333
public		economy	0.5	0	0	0	0	0.5	0.166666	
public		infra						0	0.166666	
public		data						0	0.166666	
1997	[100]	academia	infra	0	0	0	0.5	0	0.5	0.5
		academia	Edu						0	0
1998	[98]	public	economy	1	0	0	0	0	1	0.333333
		public	infra						0	0.333333
		public	data						0	0.333333
public		economy	0.3333	0	0	0	0	0.3333	0.111111	
public		infra						0	0.111111	
public		data						0	0.111111	
1999	[98]	public	infra	0.3333	0	0	0	0	0.3333	0.111111
		public	economy						0	0.111111
		public	architecture						0	0.111111
public		infra	0.3333	0	0	0	0	0.3333	0.333333	
public		gov	0.25	0	0	0	0	0.25	0.0625	
public		economy						0	0.0625	
2000	[100]	public	architecture						0	0.111111
		public	env						0	0.0625
		public	economy	0.25	0	0	0	0	0.25	0.25
		public	gov	0.25	0	0	0	0	0.25	0.05
		public	energy						0	0.05
		public	infra						0	0.05
		public	transport						0	0.05
		public	transport						0	0.05
		public	energy	0.25	0	0	0	0	0.25	0.25
		public	energy	0.5	0	0	0	0	0.5	0.166666
2001	[100]	public	infra						0	0.166666
		public	waste						0	0.166666
		public	infra	0.5	0	0	0	0	0.5	0.07142857
		public	transport						0	0.07142857
		public	env						0	0.07142857
		public	waste						0	0.07142857
		public	energy						0	0.07142857
		public	economy						0	0.07142857
		public	architecture						0	0.07142857
		2003	[101]	private	infra	0	0.3333	0	0	0
private	social								0	0.166666
private	infra			0	0.3333	0	0	0	0.3333	0.08333333
private	waste								0	0.08333333
private	energy								0	0.08333333
private	gov								0	0.08333333
public	infra			0.3333	0	0	0	0	0.3333	0.08333333
public	waste								0	0.08333333
public	energy								0	0.08333333
public	gov								0	0.08333333

Barcelona										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
2004	[100]	public	transport	0.5	0	0	0	0	0.5	0.5
	[105]	people	infra	0	0	0.5	0	0	0.5	0.25
2005	[101]	people	social						0	0.25
		private	infra	0	1	0	0	0	1	0.2
		private	energy						0	0.2
		private	env						0	0.2
		private	economy						0	0.2
2006	[100]	public	energy	0.3333	0	0	0	0	0.3333	0.333333
		public	architecture						0	0
	[101]	public	waste	0.3333	0	0	0	0	0.3333	0.333333
	[100]	public	infra						0	0
2007	[102]	public	history	0.3333	0	0	0	0	0.3333	0.333333
		public	infra	0.25	0	0	0	0	0.25	0.08333333
		public	gov						0	0.08333333
	[101]	public	social						0	0.08333333
		public	infra	0.25	0	0	0	0	0.25	0.08333333
		public	gov						0	0.08333333
		public	transport						0	0.08333333
	[103]	public	gov	0.25	0	0	0	0	0.25	0.08333333
		public	infra						0	0.08333333
		public	social						0	0.08333333
2008	[104]	public	data	0.25	0	0	0	0	0.25	0.125
		public	transport						0	0.125
		private	infra	0	0.25	0	0	0	0.25	0.0625
		private	transport						0	0.0625
	[105]	private	economy						0	0.0625
		private	tour						0	0.0625
		public	infra	0.25	0	0	0	0	0.25	0.0625
		public	transport						0	0.0625
		public	economy						0	0.0625
		public	tour						0	0.0625
2009	[104]	people	infra	0	0	0.25	0	0	0.25	0.125
		people	social						0	0.125
		people	social	0	0	0.25	0	0	0.25	0.0625
	[106]	people	infra						0	0.0625
		people	Edu						0	0.0625
		people	economy						0	0.0625
		public	infra	0.5	0	0	0	0	0.5	0.166666
[106]	public	social						0	0.166666	
	public	economy						0	0.166666	
[106]	private	infra	0	0.5	0	0	0	0.5	0.166666	
	private	social						0	0.166666	
[106]	private	economy						0	0.166666	
	private	architecture	0	0.142857	0	0	0	0.14286	0.07142857	
		private	infra					0	0.07142857	

Barcelona										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
2010	[101]	private	infra	0	0.142857	0	0	0	0.14286	0.03571429
		private	transport						0	0.03571429
		private	data						0	0.03571429
		private	economy						0	0.03571429
		public	infra	0.142857	0	0	0	0	0.14286	0.03571429
		public	transport						0	0.03571429
		public	data						0	0.03571429
		public	economy						0	0.03571429
	[107]	public	data	0.142857	0	0	0	0	0.14286	0.07142857
		public	social						0	0.07142857
	[108]	public	architecture	0.142857	0	0	0	0	0.14286	0.04761905
		public	env						0	0.04761905
		public	economy						0	0.04761905
	[101]	private	infra	0	0.142857	0	0	0	0.14286	0.02380952
		private	architecture						0	0.02380952
		private	economy						0	0.02380952
		private	Edu						0	0.02380952
		private	media and art						0	0.02380952
		private	env						0	0.02380952
	[109]	public	energy	0.142857	0	0	0	0	0.14286	0.04761905
public		env						0	0.04761905	
public		transport						0	0.04761905	
2011	[110]	people	social	0	0	0.076923	0	0	0.07692	0.02564103
		people	infra						0	0.02564103
		people	media and art						0	0.02564103
	[101]	public	infra	0.076923	0	0	0	0	0.07692	0.01923077
		public	energy						0	0.01923077
		public	env						0	0.01923077
		public	data						0	0.01923077
		NGO	infra	0	0	0	0	0.076923	0.07692	0.01923077
		NGO	energy						0	0.01923077
		NGO	env						0	0.01923077
NGO		data						0	0.01923077	
[110]	public	gov	0.076923	0	0	0	0	0.07692	0.02564103	
	public	infra						0	0.02564103	
	public	social						0	0.02564103	
	public	gov	0.076923	0	0	0	0	0.07692	0.01923077	
	public	social						0	0.01923077	
	public	economy						0	0.01923077	
	public	infra						0	0.01923077	
	public	infra	0.076923	0	0	0	0	0.07692	0.01538462	
	public	gov						0	0.01538462	
	public	data						0	0.01538462	
	public	social						0	0.01538462	
	public	standardization						0	0.01538462	

Barcelona										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
2012	[112]	private	infra	0	0.076923	0	0	0	0.07692	0.01538462
		private	gov						0	0.01538462
		private	data						0	0.01538462
		private	social						0	0.01538462
		private	standardization						0	0.01538462
		private	infra	0	0.076923	0	0	0	0.07692	0.02564103
		private	architecture						0	0.02564103
		private	env						0	0.02564103
		public	infra	0.076923	0	0	0	0	0.07692	0.07692308
		private	infra	0	0.076923	0	0	0	0.07692	0.07692308
		public	infra	0.076923	0	0	0	0	0.07692	0.03846154
		public	gov						0	0.03846154
		public	infra	0.076923	0	0	0	0	0.07692	0.03846154
		public	data						0	0.03846154
		public	env	0.076923	0	0	0	0	0.07692	0.01538462
	public	social						0	0.01538462	
	public	economy						0	0.01538462	
	public	infra						0	0.01538462	
	public	gov						0	0.01538462	
	public	infra	0.25	0	0	0	0	0.25	0.0625	
	public	energy						0	0.0625	
	public	safe						0	0.0625	
	public	architecture						0	0.0625	
	public	env	0.25	0	0	0	0	0.25	0.05	
	public	social						0	0.05	
	public	economy						0	0.05	
	public	infra						0	0.05	
public	gov						0	0.05		
public	gov	0.25	0	0	0	0	0.25	0.08333333		
public	economy						0	0.08333333		
public	architecture						0	0.08333333		
public	gov	0.25	0	0	0	0	0.25	0.03571429		
public	infra						0	0.03571429		
public	social						0	0.03571429		
public	architecture						0	0.03571429		
public	env						0	0.03571429		
public	energy						0	0.03571429		
public	transport						0	0.03571429		
2013	[113]	public	infra	0.041667	0	0	0	0	0.04167	0.02083333
		public	social						0	0.02083333
	public	env	0.041667	0	0	0	0	0.04167	0.00833333	
	public	social						0	0.00833333	
	public	economy						0	0.00833333	
	public	infra						0	0.00833333	
	public	gov						0	0.00833333	
	[102]	public	infra	0.041667	0	0	0	0	0.04167	0.04166667
	public	infra	0.041667	0	0	0	0	0.04167	0.01388889	
	[107]	public	gov						0	0.01388889
public	social							0	0.01388889	

Barcelona										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
2014	[102,105,219]	public	data	0.041667	0	0	0	0	0.04167	0.04166667
		public	social	0.041667	0	0	0	0	0.04167	0.04166667
		public	energy	0.041667	0	0	0	0	0.04167	0.04166667
		public	env	0.041667	0	0	0	0	0.04167	0.04166667
		public	env	0.041667	0	0	0	0	0.04167	0.04166667
		public	architecture	0.041667	0	0	0	0	0.04167	0.02083333
		public	infra						0	0.02083333
		public	safe	0.041667	0	0	0	0	0.04167	0.04166667
		people	social	0	0	0.041667	0	0	0.04167	0.01041667
		people	infra						0	0.01041667
		people	data						0	0.01041667
		people	env						0	0.01041667
		public	gov	0.041667	0	0	0	0	0.04167	0.04166667
		public	infra	0.041667	0	0	0	0	0.04167	0.04166667
		public	waste	0.041667	0	0	0	0	0.04167	0.04166667
		public	economy	0.041667	0	0	0	0	0.04167	0.04166667
		public	health	0.041667	0	0	0	0	0.04167	0.02083333
		public	social						0	0.02083333
		public	Edu	0.041667	0	0	0	0	0.04167	0.01388889
		public	economy						0	0.01388889
		public	env						0	0.01388889
		public	tour	0.041667	0	0	0	0	0.04167	0.04166667
		public	infra	0.041667	0	0	0	0	0.04167	0.04166667
		public	infra	0.041667	0	0	0	0	0.04167	0.01388889
		public	data						0	0.01388889
		public	economy						0	0.01388889
		public	transport	0.041667	0	0	0	0	0.04167	0.01388889
		public	infra						0	0.01388889
		public	social						0	0.01388889
		public	infra	0.041667	0	0	0	0	0.04167	0.00595238
		public	data						0	0.00595238
		public	standardization						0	0.00595238
public	social						0	0.00595238		
public	env						0	0.00595238		
public	energy						0	0.00595238		
public	gov						0	0.00595238		
public	transport	0.041667	0	0	0	0	0.04167	0.01388889		
public	infra						0	0.01388889		
public	data						0	0.01388889		
public	energy	0.076923	0	0	0	0	0.07692	0.01923077		
public	env						0	0.01923077		
public	social						0	0.01923077		
public	infra						0	0.01923077		
public	env	0.076923	0	0	0	0	0.07692	0.01538462		
public	social						0	0.01538462		
public	economy						0	0.01538462		
public	infra						0	0.01538462		
public	gov						0	0.01538462		
[102]	public	transport	0.076923	0	0	0	0	0.07692	0.07692308	
[115]	public	transport	0.076923	0	0	0	0	0.07692	0.07692308	

Year	Data Source	Stakeholder	Service	Barcelona					Sum of CNS	Converted Weight of Services
				Converted Number of Stakeholders						
				Public	Private	People	Academia	NGO		
2017	[100]	public	infra	0.03125	0	0	0	0	0.03125	0.015625
		public	gov						0	0.015625
		public	social	0.03125	0	0	0	0	0.03125	0.01041667
		public	infra						0	0.01041667
		public	data						0	0.01041667
		public	gov	0.03125	0	0	0	0	0.03125	0.01041667
		public	infra						0	0.01041667
		public	social						0	0.01041667
		people	gov	0	0	0.03125	0	0	0.03125	0.01041667
		people	infra						0	0.01041667
		people	social						0	0.01041667
		people	social	0	0	0.03125	0	0	0.03125	0.015625
		people	infra						0	0.015625
		public	social	0.03125	0	0	0	0	0.03125	0.015625
		public	infra						0	0.015625
		public	social	0.03125	0	0	0	0	0.03125	0.03125
		public	data	0.03125	0	0	0	0	0.03125	0.015625
		public	social						0	0.015625
		public	gov	0.03125	0	0	0	0	0.03125	0.01041667
		public	social						0	0.01041667
		public	infra						0	0.01041667
		public	data	0.03125	0	0	0	0	0.03125	0.015625
		public	social						0	0.015625
		private	gov	0	0.03125	0	0	0	0.03125	0.01041667
		private	data						0	0.01041667
		private	economy						0	0.01041667
		public	data	0.03125	0	0	0	0	0.03125	0.015625
		public	social						0	0.015625
		public	infra	0.03125	0	0	0	0	0.03125	0.03125
		public	infra	0.03125	0	0	0	0	0.03125	0.03125
		public	social	0.03125	0	0	0	0	0.03125	0.03125
		public	data	0.03125	0	0	0	0	0.03125	0.01041667
		public	gov						0	0.01041667
		public	social						0	0.01041667
		public	infra	0.03125	0	0	0	0	0.03125	0.015625
		public	data						0	0.015625
		public	data	0.03125	0	0	0	0	0.03125	0.01041667
		public	social						0	0.01041667
		public	architecture						0	0.01041667
		public	gov	0.03125	0	0	0	0	0.03125	0.0078125
public	social						0	0.0078125		
public	infra						0	0.0078125		
public	economy						0	0.0078125		
people	infra	0	0	0.03125	0	0	0.03125	0.00625		
people	gov						0	0.00625		
people	social						0	0.00625		
people	media and art						0	0.00625		
people	economy						0	0.00625		

Barcelona										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
2019	[119]	public	economy	0.090909	0	0	0	0	0.09091	0.01298701
		public	social						0	0.01298701
		public	gov						0	0.01298701
		public	data						0	0.01298701
		public	infra						0	0.01298701
		public	env						0	0.01298701
		public	standardization						0	0.01298701
	[120]	public	gov	0.090909	0	0	0	0	0.09091	0.01818182
		public	infra						0	0.01818182
		public	data						0	0.01818182
		public	economy						0	0.01818182
		public	social						0	0.01818182
	[121]	public	gov	0.090909	0	0	0	0	0.09091	0.02272727
		public	transport						0	0.02272727
		public	data						0	0.02272727
		public	infra						0	0.02272727
	[122]	public	architecture	0.090909	0	0	0	0	0.09091	0.01515152
		public	economy						0	0.01515152
		public	infra						0	0.01515152
		public	data						0	0.01515152
		public	social						0	0.01515152
		public	env						0	0.01515152
	[123]	public	env	0.090909	0	0	0	0	0.09091	0.03030303
		public	energy						0	0.03030303
public		gov						0	0.03030303	
[124]	public	architecture	0.090909	0	0	0	0	0.09091	0.01818182	
	public	transport						0	0.01818182	
	public	economy						0	0.01818182	
	public	social						0	0.01818182	
	public	gov						0	0.01818182	
[232]	public	infra	0.090909	0	0	0	0	0.09091	0.02272727	
	public	env						0	0.02272727	
	public	transport						0	0.02272727	
	public	gov						0	0.02272727	
[104]	public	architecture	0.090909	0	0	0	0	0.09091	0.04545455	
	public	infra						0	0.04545455	
[125]	public	infra	0.090909	0	0	0	0	0.09091	0.09090909	
	private	infra	0	0.071429	0	0	0	0.07143	0.02380952	
	private	transport						0	0.02380952	
[127]	private	safe						0	0.02380952	
	private	infra	0	0.071429	0	0	0	0.07143	0.03571429	
[126]	private	economy						0	0.03571429	
	private	infra	0	0.071429	0	0	0	0.07143	0.02380952	
	private	transport						0	0.02380952	
	private	health						0	0.02380952	
	public	infra	0.071429	0	0	0	0	0.07143	0.02380952	
	public	transport						0	0.02380952	
[128]	public	health						0	0.02380952	
	public	infra	0.071429	0	0	0	0	0.07143	0.03571429	
	public	Edu						0	0.03571429	

Barcelona										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
2020	[129]	public	architecture	0.071429	0	0	0	0	0.07143	0.01428571
		public	economy						0	0.01428571
		public	health						0	0.01428571
		public	env						0	0.01428571
		public	energy						0	0.01428571
	[130]	people	infra	0	0	0.071429	0	0	0.07143	0.01190476
		people	Edu						0	0.01190476
		people	social						0	0.01190476
		people	health						0	0.01190476
		people	data						0	0.01190476
	[131]	people	architecture						0	0.01190476
		people	infra	0	0	0.071429	0	0	0.07143	0.02380952
		people	economy						0	0.02380952
		people	Edu						0	0.02380952
		private	infra	0	0.071429	0	0	0	0.07143	0.02380952
		private	economy						0	0.02380952
		private	Edu						0	0.02380952
		private	infra	0	0.071429	0	0	0	0.07143	0.03571429
		private	economy						0	0.03571429
		private	infra	0	0.071429	0	0	0	0.07143	0.01785714
		private	social						0	0.01785714
	[132]	private	economy						0	0.01785714
		private	Edu						0	0.01785714
		private	transport	0	0.071429	0	0	0	0.07143	0.01785714
		private	infra						0	0.01785714
	[133]	private	data						0	0.01785714
		private	safe						0	0.01785714
	[104]	private	health	0	0.071429	0	0	0	0.07143	0.03571429
		private	infra						0	0.03571429
	[134]	private	Edu	0	0.071429	0	0	0	0.07143	0.02380952
private		social						0	0.02380952	
private		economy						0	0.02380952	
people		health	0	0	0.142857	0	0	0.14286	0.03571429	
[110]	people	Edu						0	0.03571429	
	people	infra						0	0.03571429	
	people	economy						0	0.03571429	
	public	data	0.142857	0	0	0	0	0.14286	0.03571429	
	public	infra						0	0.03571429	
	public	social						0	0.03571429	
	public	env						0	0.03571429	
	academia	data	0	0	0	0.142857	0	0.14286	0.03571429	
	academia	infra						0	0.03571429	
	academia	social						0	0.03571429	
[135]	academia	env						0	0.03571429	
	public	social	0.142857	0	0	0	0	0.14286	0.07142857	
	public	infra						0	0.07142857	
	private	social	0	0.142857	0	0	0	0.14286	0.07142857	
[136]	private	infra						0	0.07142857	
	public	economy	0.142857	0	0	0	0	0.14286	0.04761905	
	public	Edu						0	0.04761905	
		public	infra					0	0.04761905	

Barcelona										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
2021	[137]	public	economy	0.142857	0	0	0	0	0.14286	0.01428571
		public	Edu						0	0.01428571
		public	health						0	0.01428571
		public	history						0	0.01428571
		public	architecture						0	0.01428571
		public	energy						0	0.01428571
		public	env						0	0.01428571
		public	data						0	0.01428571
		public	health						0	0.01428571
		public	media and art						0	0.01428571
	[138]	public	economy	0.125	0	0	0	0	0.125	0.025
		public	env						0	0.025
		public	transport						0	0.025
		public	health						0	0.025
		public	tour						0	0.025
	[139]	private	data	0	0.125	0	0	0	0.125	0.0625
		private	economy						0	0.0625
	[140]	people	health	0	0	0.125	0	0	0.125	0.025
		people	infra						0	0.025
		people	data						0	0.025
		people	social						0	0.025
		people	env						0	0.025
	[137]	public	infra	0.125	0	0	0	0	0.125	0.025
		public	architecture						0	0.025
		public	social						0	0.025
		public	economy						0	0.025
		public	env						0	0.025
	[141]	public	infra	0.125	0	0	0	0	0.125	0.03125
		public	Edu						0	0.03125
		public	social						0	0.03125
		public	data						0	0.03125
[142]	public	social	0.125	0	0	0	0	0.125	0.02083333	
	public	gov						0	0.02083333	
	public	infra						0	0.02083333	
	public	safe						0	0.02083333	
	public	transport						0	0.02083333	
	public	data						0	0.02083333	
[143]	academia	infra	0	0	0	0.125	0	0.125	0.03125	
	academia	health						0	0.03125	
	academia	social						0	0.03125	
	academia	Edu						0	0.03125	
	private	infra	0	0.125	0	0	0	0.125	0.03125	
	private	health						0	0.03125	
	private	social						0	0.03125	
	private	Edu						0	0.03125	

London										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
1969	[177]	public	infra	0.3333	0	0	0	0	0.3333	0.166666
		public	Edu						0	0.166666
	[181]	academia	infra	0	0	0	0.3333	0	0.3333	0.166666
		academia	Edu						0	0.166666
	[233]	public	infra	0.3333	0	0	0	0	0.3333	0.166666
		public	Edu						0	0.166666
1970	[175]	public	infra	0.5	0	0	0	0	0.5	0.25
		public	gov						0	0.25
		public	infra	0.5	0	0	0	0	0.5	0.25
		public	gov						0	0.25
		public	infra	0.5	0	0	0	0	0.5	0.25
1971	[179]	public	gov						0	0.25
		public	infra	0.5	0	0	0	0	0.5	0.25
1972	[175]	public	gov						0	0.25
		public	infra	1	0	0	0	0	1	0.5
1973	[177]	public	infra	0.3333	0	0	0	0	0.3333	0.166666
		public	Edu						0	0.166666
		public	infra	0.3333	0	0	0	0	0.3333	0.166666
	[175]	public	gov						0	0.166666
		public	infra	0.3333	0	0	0	0	0.3333	0.166666
		public	gov						0	0.166666
1974	[177]	academia	infra	0	0	0	1	0	1	0.5
		academia	Edu						0	0.5
1975	[155]	academia	infra	0	0	0	0.5	0	0.5	0.25
		academia	Edu						0	0.25
	[178]	academia	infra	0	0	0	0.5	0	0.5	0.25
		academia	Edu						0	0.25
1976	[177]	academia	infra	0.5	0	0	0	0	0.5	0.5
	[176]	academia	infra	0	0	0	0.5	0	0.5	0.25
		academia	standardization						0	0.25
1977	[178]	public	infra	0.3333	0	0	0	0	0.3333	0.166666
		public	Edu						0	0.166666
		academia	infra	0	0	0	0.3333	0	0.3333	0.166666
	[178]	academia	Edu						0	0.166666
		private	data	0	0.3333	0	0	0	0.3333	0.111111
		private	economy						0	0.111111
1978	[175]	private	infra						0	0.111111
		public	infra	0.5	0	0	0	0	0.5	0.25
		public	social						0	0.25
		public	data	0.5	0	0	0	0	0.5	0.25
		public	infra						0	0.25
1979	[175]	private	data	0	0.5	0	0	0	0.5	0.166666
		private	infra						0	0.166666
		private	economy						0	0.166666
		private	data	0	0.5	0	0	0	0.5	0.166666
		private	infra						0	0.166666
		private	social						0	0.166666

London										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
1980	[171]	public	data	0.5	0	0	0	0	0.5	0.1
		public	infra						0	0.1
		public	gov						0	0.1
		public	social						0	0.1
		public	Edu						0	0.1
		public	data	0.5	0	0	0	0	0.5	0.166666
1981	[175]	public	infra						0	0.166666
		public	social						0	0.166666
		public	standardization	1	0	0	0	0	1	0.25
		public	economy						0	0.25
		public	gov						0	0.25
		public	infra						0	0.25
1982	[155]	academia	Edu	0	0	0	0.3333	0	0.3333	0.166666
		academia	infra						0	0.166666
		public	infra	0.3333	0	0	0	0	0.3333	0.111111
		public	gov						0	0.111111
		public	economy						0	0.111111
		private	infra	0	0.3333	0	0	0	0.3333	0.166666
1983	[175]	private	data						0	0.166666
		public	infra	1	0	0	0	0	1	0.333333
		public	Edu						0	0.333333
		public	economy						0	0.333333
		private	infra	0	0.5	0	0	0	0.5	0.166666
		private	gov						0	0.166666
1984	[175]	private	economy						0	0.166666
		public	infra	0.5	0	0	0	0	0.5	0.166666
		public	gov						0	0.166666
		public	economy						0	0.166666
		academia	infra	0	0	0	0.2	0	0.2	0.06666667
		academia	gov						0	0.06666667
1985	[155]	academia	Edu						0	0.06666667
		public	infra	0.2	0	0	0	0	0.2	0.06666667
		public	gov						0	0.06666667
		public	Edu						0	0.06666667
		public	infra	0.2	0	0	0	0	0.2	0.1
		public	economy						0	0.1
1985	[175]	private	infra	0	0.2	0	0	0	0.2	0.1
		private	economy						0	0.1
		private	infra	0	0.2	0	0	0	0.2	0.1
		private	economy						0	0.1
		NGO	social	0	0	0	0	0.5	0.5	0.1
		NGO	infra						0	0.1
1986	[174]	NGO	Edu						0	0.1
		NGO	history						0	0.1
		NGO	health						0	0.1
		public	social	0.5	0	0	0	0	0.5	0.25
		public	infra						0	0.25
		public	infra						0	0.25

Year	Data Source	Stakeholder	Service	London					Sum of CNS	Converted Weight of Services
				Converted Number of Stakeholders						
				Public	Private	People	Academia	NGO		
1987	[173]	private	Edu	0	0.5	0	0	0	0.5	0.166666
		private	infra						0	0.166666
		private	economy						0	0.166666
		academia	Edu	0	0	0	0.5	0	0.5	0.166666
		academia	infra						0	0.166666
		academia	economy						0	0.166666
1988	[172]	private	infra	0	0.5	0	0	0	0.5	0.166666
		private	social						0	0.166666
		private	economy						0	0.166666
	[175]	public	economy	0.5	0	0	0	0	0.5	0.5
1989	[171]	public	infra	1	0	0	0	0	1	0.5
		public	gov						0	0.5
1990	[170]	NGO	social	0	0	0	0	0.3333	0.3333	0.166666
		NGO	infra						0	0.166666
	[168]	academia	social	0	0	0	0.3333	0	0.3333	0.111111
		academia	data						0	0.111111
		academia	infra						0	0.111111
		private	infra	0	0.3333	0	0	0	0.3333	0.166666
		private	economy					0	0.166666	
1991	[171]	public	gov	0.3333	0	0	0	0	0.3333	0.166666
		public	infra						0	0.166666
		public	economy	0.3333	0	0	0	0	0.3333	0.166666
		public	infra						0	0.166666
		private	gov	0	0.3333	0	0	0	0.3333	0.166666
		private	infra						0	0.166666
1992	[167]	academia	social	0	0	0	0.3333	0	0.3333	0.08333333
		academia	Edu						0	0.08333333
		academia	infra						0	0.08333333
		academia	economy						0	0.08333333
		people	social	0	0	0.3333	0	0	0.3333	0.08333333
		people	Edu						0	0.08333333
		people	infra						0	0.08333333
		people	economy						0	0.08333333
1993	[171]	private	infra	0	0.3333	0	0	0	0.3333	0.111111
		private	gov						0	0.111111
		private	economy						0	0.111111
1993	[170]	NGO	gov	0	0	0	0	1	1	0.333333
		NGO	infra						0	0.333333
		NGO	social						0	0.333333
1994	[169]	Private	economy	0	0.3333	0	0	0	0.3333	0.111111
		Private	social						0	0.111111
		Private	infra						0	0.111111
	[168]	Private	infra	0	0.3333	0	0	0	0.3333	0.333333
		Private	infra	0	0.3333	0	0	0	0.3333	0.111111
		Private	social						0	0.111111
1996	[155]	Private	economy	0	1	0	0	0	1	0.333333
		Private	infra						0	0.333333
		Private	social						0	0.333333

Year	Data Source	Stakeholder	Service	London					Sum of CNS	Converted Weight of Services
				Converted Number of Stakeholders						
				Public	Private	People	Academia	NGO		
2010	[235]	public	economy	0.2	0	0	0	0	0.2	0.05
		public	infra						0	0.05
		public	media and art						0	0.05
		public	social						0	0.05
	[157]	public	infra	0.2	0	0	0	0	0.2	0.05
		public	social						0	0.05
		public	economy						0	0.05
		public	media and art						0	0.05
	[155]	private	infra	0	0.2	0	0	0	0.2	0.1
		private	economy						0	0.1
		public	social	0.2	0	0	0	0	0.2	0.1
	[221]	public	infra						0	0.1
		public	Edu	0.2	0	0	0	0	0.2	0.06666667
		public	social						0	0.06666667
		public	infra						0	0.06666667
private		infra	0	1	0	0	0	1	1	
2011	[155]	public	infra	1	0	0	0	0	1	0.2
2012	[154]	public	economy						0	0.2
		public	history						0	0.2
		public	media and art						0	0.2
		public	social						0	0.2
2013	[153]	private	infra	0	0.125	0	0	0	0.125	0.04166667
		private	social						0	0.04166667
		private	data						0	0.04166667
	[152]	private	infra	0	0.125	0	0	0	0.125	0.0625
		private	economy						0	0.0625
	[151]	public	infra	0.125	0	0	0	0	0.125	0.04166667
		public	social						0	0.04166667
		public	economy						0	0.04166667
	[150]	public	social	0.125	0	0	0	0	0.125	0.04166667
		public	infra						0	0.04166667
		public	economy						0	0.04166667
		public	data	0.125	0	0	0	0	0.125	0.025
		public	infra						0	0.025
		public	Edu						0	0.025
		public	economy						0	0.025
public		gov						0	0.025	
public		energy	0.125	0	0	0	0	0.125	0.01785714	
public		env						0	0.01785714	
public		waste						0	0.01785714	
public		infra						0	0.01785714	
public	transport						0	0.01785714		
public	data						0	0.01785714		
public	economy						0	0.01785714		

Berlin										
Year	Data Source	Stakeholder	Service	Converted Number of Stakeholders					Sum of CNS	Converted Weight of Services
				Public	Private	People	Academia	NGO		
2010	[189]	public	infra	0.3333	0	0	0	0	0.3333	0.166666
		public	gov						0	0.166666
	[185]	private	infra	0	0.3333	0	0	0	0.3333	0.166666
		private	economy						0	0.166666
	[238]	private	infra	0	0.3333	0	0	0	0.3333	0.333333
2011	[185]	private	infra	0	0.3333	0	0	0	0.3333	0.333333
	[204]	private	infra	0	0.3333	0	0	0	0.3333	0.166666
		private	economy						0	0.166666
	[198]	private	infra	0	0.3333	0	0	0	0.3333	0.166666
		private	economy						0	0.166666
2012	[185]	private	infra	0	0.3333	0	0	0	0.3333	0.166666
		private	economy						0	0.166666
	[192]	private	infra	0	0.3333	0	0	0	0.3333	0.166666
		private	economy						0	0.166666
	[239]	private	infra	0	0.3333	0	0	0	0.3333	0.111111
private		economy						0	0.111111	
2013	[169]	private	infra	0	0.25	0	0	0	0.25	0.08333333
		private	social						0	0.08333333
		private	economy						0	0.08333333
	[194]	private	infra	0	0.25	0	0	0	0.25	0.125
		private	economy						0	0.125
	[240]	private	infra	0	0.25	0	0	0	0.25	0.125
		private	economy						0	0.125
	[195]	private	infra	0	0.25	0	0	0	0.25	0.08333333
		private	economy						0	0.08333333
private		health						0	0.08333333	
2014	[185]	private	infra	0	0.3333	0	0	0	0.3333	0.166666
		private	economy						0	0.166666
	[196]	people	infra	0	0	0.3333	0	0	0.3333	0.166666
		people	social						0	0.166666
	[197]	people	infra	0	0	0.3333	0	0	0.3333	0.166666
people		social						0	0.166666	
2015	[202]	people	infra	0	0	0.111111	0	0	0.111111	0.05555556
		people	social						0	0.05555556
	[203]	people	infra	0	0	0.111111	0	0	0.111111	0.05555556
		people	social						0	0.05555556
	[198]	private	infra	0	0.111111	0	0	0	0.111111	0.05555556
		private	economy						0	0.05555556
	[199]	private	infra	0	0.111111	0	0	0	0.111111	0.05555556
		private	economy						0	0.05555556
	[200]	private	infra	0	0.111111	0	0	0	0.111111	0.03703704
		private	tour						0	0.03703704
private		economy						0	0.03703704	
[201]	private	infra	0	0.111111	0	0	0	0.111111	0.02777778	
	private	economy						0	0.02777778	
	private	health						0	0.02777778	
	private	social						0	0.02777778	

Year	Data Source	Stakeholder	Service	Berlin					Sum of CNS	Converted Weight of Services
				Converted Number of Stakeholders						
				Public	Private	People	Academia	NGO		
2016	[200]	private	infra	0	0.111111	0	0	0	0.111111	0.05555556
		private	economy						0	0.05555556
		private	infra	0	0.111111	0	0	0	0.111111	0.03703704
		private	economy						0	0.03703704
		private	transport						0	0.03703704
		private	infra	0	0.111111	0	0	0	0.111111	0.05555556
		private	social						0	0.05555556
	[198]	private	infra	0	0.166667	0	0	0	0.166667	0.08333333
		private	economy						0	0.08333333
	[205]	private	infra	0	0.166667	0	0	0	0.166667	0.08333333
		private	economy						0	0.08333333
	[204]	private	infra	0	0.166667	0	0	0	0.166667	0.05555556
		private	economy						0	0.05555556
		private	social						0	0.05555556
		public	gov	0.166667	0	0	0	0	0.166667	0.02777778
		public	economy						0	0.02777778
	[206]	public	social						0	0.02777778
		public	architecture						0	0.02777778
		public	infra						0	0.02777778
		public	safe						0	0.02777778
	[241]	people	infra	0	0	0.166667	0	0	0.166667	0.08333333
		people	social						0	0.08333333
	[207]	private	infra	0	0.166667	0	0	0	0.166667	0.05555556
		private	economy						0	0.05555556
		private	transport						0	0.05555556
	[204]	private	infra	0	0.25	0	0	0	0.25	0.125
		private	economy						0	0.125
	[208]	people	infra	0	0	0.25	0	0	0.25	0.08333333
		people	data						0	0.08333333
	people	social						0	0.08333333	
[209]	private	infra	0	0.25	0	0	0	0.25	0.08333333	
	private	economy						0	0.08333333	
	private	transport						0	0.08333333	
[191]	public	economy	0.25	0	0	0	0	0.25	0.04166667	
	public	infra						0	0.04166667	
	public	data						0	0.04166667	
	public	safe						0	0.04166667	
	public	Edu						0	0.04166667	
	public	gov						0	0.04166667	
[210]	public	social	0.3333	0	0	0	0	0.3333	0.111111	
	public	infra						0	0.111111	
	public	economy						0	0.111111	
[211]	private	data	0	0.3333	0	0	0	0.3333	0.111111	
	private	transport						0	0.111111	
	private	infra						0	0.111111	
[212]	private	infra	0	0.3333	0	0	0	0.3333	0.166666	
	private	people						0	0.166666	

Year	Data Source	Stakeholder	Service	Berlin					Sum of CNS	Converted Weight of Services
				Converted Number of Stakeholders						
				Public	Private	People	Academia	NGO		
2019	[213]	private	infra	0	0.142857	0	0	0	0.14286	0.03571429
		private	transport						0	0.03571429
		private	safe						0	0.03571429
		private	data						0	0.03571429
	[204]	private	economy	0	0.142857	0	0	0	0.14286	0.14285714
	[215]	people	infra	0	0	0.142857	0	0	0.14286	0.07142857
		people	social						0	0.07142857
	[194]	private	infra	0	0.142857	0	0	0	0.14286	0.07142857
		private	economy						0	0.07142857
	[214]	private	infra	0	0.142857	0	0	0	0.14286	0.07142857
		private	transport						0	0.07142857
	[200]	private	infra	0	0.142857	0	0	0	0.14286	0.07142857
		private	social						0	0.07142857
		private	infra	0	0.142857	0	0	0	0.14286	0.04761905
		private	social						0	0.04761905
private		economy						0	0.04761905	
2020	[216]	public	infra	1	0	0	0	0	1	0.333333
		public	economy						0	0.333333
		public	transport						0	0.333333
2021	[217]	public	infra	0.5	0	0	0	0	0.5	0.25
		public	env						0	0.25
	[197]	people	infra	0	0	0.5	0	0	0.5	0.25
		people	social						0	0.25

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Article

Guidelines for Renewal and Securitization of a Critical Infrastructure Based on IoT Networks

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Abstract: Global warming has increased uncertainty regarding managing traditional water supply systems. Unfortunately, there is a need for the smart management of water supply systems. This work aims to design a solution for renewing and securing critical infrastructure that supplies water and provides water purification inside the range of applications of Industry 4.0 for Smart Cities. Therefore, we analyze the renewal requirements and the applicable use cases and propose a solution based on IoT networks for critical infrastructure in the urban environment. We describe the architecture of the IoT network and the specific hardware for securing a water supply and wastewater treatment chain. In addition, the water level control process for the supply chain and the system that ensures the optimal level of chemicals for wastewater treatment are detailed. Finally, we present the guidelines for infrastructure operators to carry out this operation within Industry 4.0, constituting a development framework for future research on the design of Smart Cities.

Keywords: Industry 4.0; critical infrastructure; water management; IoT network



Citation: Villar Miguelez, C.; Monzon Baeza, V.; Parada, R.; Monzo, C. Guidelines for Renewal and Securitization of a Critical Infrastructure Based on IoT Networks. *Smart Cities* **2023**, *6*, 728–743. <https://doi.org/10.3390/smartcities6020035>

Academic Editors: Véronique Flambard, Sadia Benamrouz-Vanneste and Abir Karami

Received: 17 January 2023
Revised: 20 February 2023
Accepted: 24 February 2023
Published: 26 February 2023



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1. Introduction

Society is in a connected world in which technology and digitization are increasingly important. There is a more significant depletion of natural resources as the population increases. Quality and renewed water supply chains are essential for reducing drinking water consumption. Furthermore, global warming would increase uncertainty regarding managing traditional water supply systems according to [1]. Hence, water systems become critical infrastructure for a city, and it is essential to renew and make them compatible with future technologies such as artificial intelligence, as proposed in [1]. This helps to prevent possible leaks or failures of infrastructures. Digitally transforming the traditional city and making it a Smart City translates into making multiple advances in all internal processes.

Humans are causing a high negative impact on the environment with actions such as increased water consumption [2] and wastewater discharged into the sea without proper treatment [3]. Therefore, renewing the water supply chain and cities' wastewater treatment is necessary to help reduce the negative environmental impact. For this, we will apply the advantages of Industry 4.0. This is part of the general Smart City trend, in which automation and real-time monitoring are the protagonists. Specifically, in this study on the application of Industry 4.0 in the water and wastewater sector [4], it is proposed to integrate different systems to take advantage of data synchronization from various sources to reduce water consumption.

To fully apply digitization in the Industry, it is necessary to renew the environments related to scathing criticisms that provide society with an essential good, such as the case of water supply and wastewater control [5–7]. These infrastructures must ensure

the total availability of the service and very low latency. The article [8] explains NB-IoT technology's benefits for critical infrastructures. As cybersecurity plays a vital role in critical infrastructure, it is crucial to consider the security guidelines recommended in the study [9]. The study in [10] proposes to organize the different components of critical infrastructure networks on independent islands with high availability in such a way that a drop in one of these islands does not affect the rest.

With the advancement of Industry 4.0, processes increasingly essential for the population are being digitized and renewed. The water level control in a dam in India is described in the following paper [11]. It explains how the water level is measured using IoT technology, which sends the data to a central control platform. The use of IoT technology helps to renew the critical infrastructures of a Smart City. Kodali, Rajanarayanan and Yadavilli [12] show examples of an IoT project for critical infrastructure, which proposes control of chemical parameters in the water and sends an alert if these parameters are not within limits previously established by the specialized worker. Moreover, research from Chellaswamy et al. [13] shows actions identified to carry out a cloud platform that receives monitoring data of wastewater. It is an Indian experiment using Arduino One hardware. This is useful for developing applications for Smart Cities. Finally, the article in [14] experiments with the real-time response of IoT devices using the NB-IoT protocol, which would improve the supply chain control process.

1.1. Background

Nowadays, the Internet of Things (IoT) is a key technology for modern society. All communication systems are being renewed to include IoT to improve communication. For example, in [15], IoT is included in maritime communications. The literature shown in this section is focused on different areas supporting our research, such as the Industry 4.0 concept, IoT application in Industry 4.0 and the water sector. Industry 4.0 is a concept where the IoT shall be the leading technology to develop products with their own intelligence acquired during manufacturing. This new approach for industry includes intelligent transport and logistics (smart mobility and smart logistics), which contribute to energy efficiency to connect or create a Smart City. Lom et al. in [16] show the keys to integrating Industry 4.0 as a part of a Smart City.

Alcácer, V. et al. in [17] review the key within Industry 4.0 to lead the disruptive impact on manufacturing companies which will allow the smart manufacturing ecosystem paradigm. The enabling technologies and systems in the manufacturing environment are described. One of these technologies is cloud computing in conjunction with IoT, as proposed in [18]. Hence, recent studies report IoT-based productivity gains in manufacturing plants using sensors for data acquisition and supervisory control. However, bidirectional communication between these sensors is daunting because of the restrictions imposed by the variety and incompatibility of their interfaces and communication protocols. This problem increases the price of these solutions.

Within the group of IoT technologies, in this work, we have selected NB-IoT and the lower-power WAN (LPWAN) family of technologies and protocols. A comparative review of these protocols and their performance can be found in [19]. Leslie et al. argued for the potential of linking these technologies in [20]. The decision factors between technologies can be found in [21]. In this context, for Smart Cities, we have selected several works that help to contextualize the need for renovation already carried out in other city sectors. For the case of the agricultural sector A in [22], they present the trends and needs for its renovation towards Smart environments, while Monzon et. al in [23] present a satellite-based architecture with IoT to transport data from remote sites to the city. Another application for the renovation of the agricultural sector can be found in [24]. As for the energy sector, we have solutions in [25–27]. Technical guidelines have already been proposed for building a secure NB-IoT environment in [28]. However, they do not consider the regulatory and standardization topics. Perez et. al in [29] propose WPAN and LPWAN hybrid networks used for global

emergencies in Smart Cities. In the case of Smart water, [30] compares state-of-the-art methods to predict the water level in Catalan reservoirs.

To deal with the renewal of the infrastructures for industry, it is important to define the link between industrial designs and the effect that this renewal has on the sustainability that marks a smart city. Kuys, Koch and Renda in [31] perform a study of this performance for industrial design, conducted by 190 respondents from 53 countries, to establish the present state of industrial design practice globally and to better understand the priority of sustainability. The study performed by Cotrino, Sebastian and Gonzalez-Gaya in [32] uses a systematic literature review approach to determine the current research progress and future research potential of Industry 4.0 technologies to achieve manufacturing sustainability.

Within the industry, we find the water sector to be one of the most valuable because of the natural resource used for everyday living. Alabi, in [33], extends the concept of Industry 4.0 to Water 4.0 to include the water industry. In [33], an integrated business model for Water 4.0 is proposed. Different cloud platforms controlled through IoT are proposed to measure water quality in [34,35].

Jeurkar et al. in [36] focus on monitoring water use in a flat system. Other solutions, such as those shown in [37–39], are proposed to make the water manufacturing process smarter. However, these propose to require environmental awareness to distribute the sensors and high data processing from the sensors, which are not feasible for critical infrastructures.

For the development of the digitization of the industry, it is necessary to set some guidelines. There are many digitization solutions, so it is necessary to frame design guidelines at a high level. This article is to standardize the design criteria of a critical infrastructure environment. For this reason, a deep study of current ISO standards has been conducted.

1.2. Our Contribution

Before the previous background, this article proposes an architecture and the type of communications protocol selected to renew the infrastructure of a water supply chain and wastewater treatment, considered critical infrastructure. For this purpose, we include the following:

- Study, analysis and definition of requirements for critical infrastructures based on IoT environment.
- Solution for the renewal and securitization of the water supply and purification system based on IoT networks: it includes details of the architecture and the integration model of the techniques that are part of the monitoring and control solution set, as well the industrial supply chain and wastewater treatment.
- An intelligent water management framework for Smart Cities. We define the architecture, the bases and the necessary regulations to carry out technical projects.

The European directive 2008/114/CE on identifying and designation critical European infrastructures and evaluating the need to improve their protection is in force at the European Union level. This directive has been used to dictate the guidelines used in critical infrastructure such as the one proposed.

At the standards level, in 2018, the specific International Organization for Standardization (ISO) created indicators of city services and quality of life in its ISO 37120 [40]. In 2019, the ISO 37122 [41] incorporated two even more specific standards for Smart Cities based on the parent standard ISO 37120, which was on indicators for a Smart City. ISO 37123 [42] indicated resilient cities capable of maintaining their regular operation despite unknown disturbances. In a Smart City, certain specific operating parameters should be able to be measured.

At the level of cybersecurity regulations, we have UNE-EN ISO/IEC 27001: 2017 [43], which deals with the requirements requested in RDL 8/2011 on protecting critical infrastructures. Specifically, these common objectives are to protect: data confidentiality, data integrity and information availability.

The article is organized as follows. An introduction of this paper is made in Section 1. The requirements to define a critical infrastructure are shown in Section 2. The proposed IoT-based architecture is described in Section 3. In Section 4, KPIs to measure the proposal are shown, while Section 5 shows use cases. Finally, we conclude with some remarks in Section 6.

2. Requirements for Critical Infrastructure

All critical infrastructures, especially those related to the water supply chain, must meet, on the one hand, a series of technical or technological requirements to be renewed and, on the other hand, the criteria or conditions set in specifications and standards according to the regulation.

The requirements related directly to infrastructure are as follows:

- **High availability:** The availability of systems related to water supply and treatment must be at least 99%, which means that business activity should continue beyond 99% of the total activity time. Systems update: systems must be updated without affecting business availability. Upgrades before completion will have been tested on preproduction equipment to ensure a high probability of success in the production environment on the deployment day.
- **Grouping and analysis of the data obtained by the sensors:** A platform must be created to concentrate the data from all the sensors and homogenize them in the same format. Once the data have been grouped and standardized, they can be processed by the following system: the computer system, which will execute actions based on specifically configured alarms.
- **Daily maintenance of the solution in 24 × 7 mode:** A system maintenance plan should be included by operators with remote supervision and local on-site actions in case of high-level incidences. Operators should go to the water supply and water purification plant based on the detection of the incident that they have investigated with the remote monitoring platform.

On the other hand, security requirements for the proposed architecture are extracted from Standard ISO 27002 [44].

- **Documentation of operating procedures:** Any process related to the maintenance of the solution and operation, whether due to a configuration change or a task to update the firmware of equipment, must have its procedures documented. Specific plans must be established where the actions to be carried out and the authorizations to request the difference in the applicable network are planned.
- **Separation of environments:** This means having different and segmented infrastructures, whether physical or virtual, to deploy development environments, to develop new applications, to deploy test environments for using them, for example, to carry out bug update tests, and finally, there is the production environment that is in charge of running the product business. Any failure in the production environment supposes a stop in some of the services provided by the supply chain and water treatment.
- **Continuity of the security and infrastructure solution:** There will be an infrastructure with high availability with several firewalls in cluster mode, in such a way as to ensure the redundancy of the systems that support the solution for critical infrastructure. The details of the infrastructure to be deployed are detailed in Section 3 of this paper. In addition, network security policies for access control are included. Thus, segmentation mechanisms must be implemented for the different networks, avoiding traditional flat networks where users could access any infrastructure service.
- **Plans for monitoring SLAs:** The water supply and purification solution provider must comply with the service-level agreements (SLAs) according to the business parameters, and in case of noncompliance, the appropriate penalties will be shown. The transfer of information from a previous provider to a new provider would be done through secure protocols and encrypted data before the signing of confidentiality

contracts. The service provider must be requested to comply with the certification based on the ISO 27001 standard before any incident.

3. Computing Architecture

The architecture proposed for the solution comprises two subsystems: a computing core group and an action and measuring group.

3.1. Computing Core Group

The computing core group is the main architecture of the solution. This part of the proposed system will collect all the data from the IoT sensors and actuators of the architecture, named in this paper as the action and measuring group. The computing core group will receive data through 4G radio technology and store it in DDBB deployed in the data center servers. The extracted information will be studied through the data analytics processors, and the configurations at the software level of our system can be applied. The computing core group is based on a set of servers, switches, routers and firewalls to comply with current security standards for the industrial sector. This subsystem, as shown in Figure 1, is made up of the following platforms:

- **Centralized management IoT platform:** It is the central node for analyzing the data collected by the sensors and allows controlling the actuators' actions.
- **Monitoring, control and dashboard platform:** Policies are configured at a central level and fed by the data the IoT platform has analyzed. It can be accessed remotely through a secure connection. This platform will allow the visualization of the data in a control panel that will be accessed via the web.

Moreover, the *computing core group* will be developed in different IT environments:

- **Production environment:** It is the one in charge of the execution of the tasks of the solution, such as the control of the water level in the supply chain or the management of the level of chemicals for the sanitation of wastewater.
- **Test environment** (also called preproduction environment): It is the environment before the production environment in which the tests of new software updates of the critical infrastructure are carried out. Any changes to the software are tested in this environment before running in the production environment.
- **Development environment:** It is one in which pilots are run for new functionalities of the solution covered by R&D studies.

The production and preproduction environments will have similar computing capabilities, since the preproduction environment detects and prevents possible failures before deploying in the production environment by avoiding incidents and prolonged service downtime. The system operator could deploy both environments on private cloud provider infrastructure.

The development environment will be deployed in a public cloud provider and accessible through private networks; it will not be given access through a public Internet address. For this environment, public cloud infrastructure has been selected to lower the cost of the solution and speed up the time of creation, testing and configuration of pilots for R&D studies. Suppose these pilots were optimal and passed all the latency and resilience tests. In that case, they could be applied to the preproduction environment and later production, improving the general application of central computing. These drivers could range from enhancements to increasing the artificial intelligence of data analysis to improvements to the data visualization environment for the dashboard.

The *computing core group* architecture is shown in Figure 1. Next, this subsystem is described, starting from the operator's private network necessary for the remote connection of the operators and continuing with the layers of the solution infrastructure, which are the routing layer, security layer, LAN switching layer and processing layer for data control and analysis.

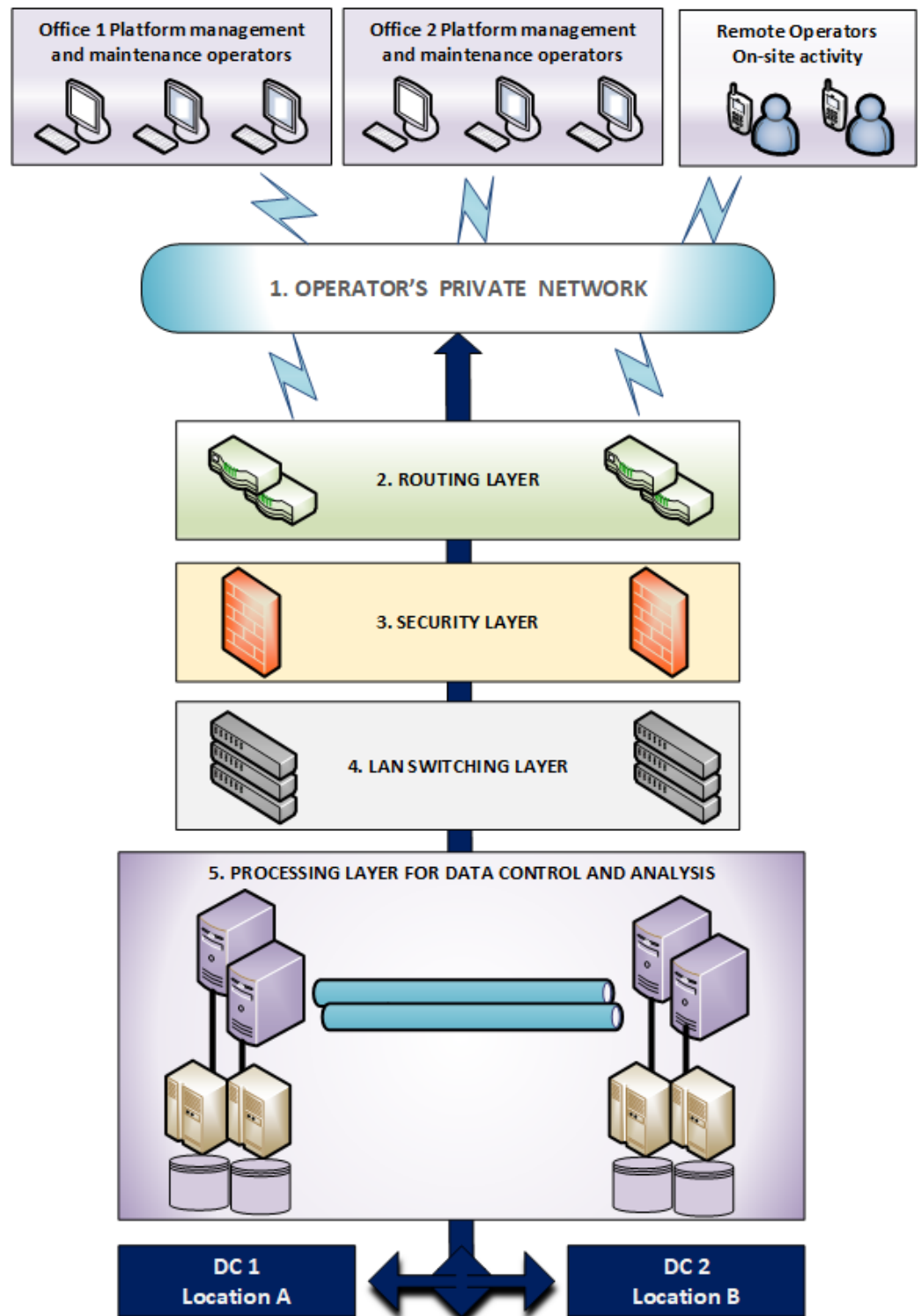


Figure 1. Computing core group architecture.

Core group—operator’s private network:

For the remote connection of the operators to the central computing group and the connection between the data collection and action group with the main computing group. In this solution, we need low-consumption sensor networks with a wide coverage range that are robust against interference. In addition, it implements a strong security protocol with low latency between the IoT devices and the central management platform. The cost of the sensors must be as low as possible to facilitate the investments for the adoption. For this

reason, the choice was made within the specific solutions within the LPWAN category. We specifically opted for those that reuse the existing cellular network structure to avoid investments in additional antennas. On the other hand, the most appropriate technologies for the design under the study of the water supply and purification of a Smart City will be those that use licensed spectrum to avoid interference. With the previous descriptions, it only remains to select the protocol between the NB-IoT or LTE-M options. Both use the security standards of the mobile network, essential for use in critical infrastructures. However, using NB-IoT was decided to have a lower cost in acquiring the devices. In addition, studies were found that use NB-IoT devices to monitor critical infrastructures, such as [14], in which actuators are monitored and controlled with a latency time of 8 seconds in indoor scenarios and 2 seconds in outdoor settings. For this reason, NB-IoT was also selected to implement the proposed solution.

A previous study in [45] has considered protocols and technologies for IoT. We collected the data concerning critical infrastructures in Table 1, from which the architecture based on NB-IoT was selected over other technologies in the IoT framework, based on priority on the security required by critical infrastructures. NB-IoT is not as sensitive to interference as LoRaWAN, and its encryption protocol is AES-256 versus LoRaWAN's AES-128 [45,46]. LPWANs can be vulnerable to security attacks, but NB-IoT offers sufficient security for certain applications if implemented with strong security policies and enforcement. Therefore, the lower interference level of NB-IoT due to the use of licensed radio frequency bands makes the proposed infrastructure more robust than LoRaWAN. The LoRaWAN and Sigfox options were discarded because they work in a spectrum without a license. Therefore, any user could use this spectrum, causing interference that would not allow a high level of availability of the intended service. Some simulations on the deployment and use of NB-IoT technology are summarized in [47], indicating latency in data transmission depending on whether they are indoors or outdoors. An NB-IoT traffic simulator in Smart City environments shows an average transmission delay value of 34.781 ms and 6.929 ms for indoor and outdoor environments, respectively. For average total delay, the values for Smart Cities shown in [47] are 239.876 ms for indoor and 85.676 ms for outdoor. These values are collected in Table 2. We can use them as a reference for latency in future deployments of the proposed architecture in this paper.

Table 1. Comparison of LPWAN technologies (Based on the study in [45]).

Parameter	NB-IoT	LoRa	SigFox	LTE-M
Standard	3GPP Rel. 13,14	LoRa Alliance	ETSI LTN	3GPP Release 14
Frequency	900 MHz	868 MHz	868 MHz	Cellular Band
Bandwidth	200 KHz	250 KHz	100 Hz	1.4–20 MHz
Security	NSA AES 256	AES 128b	Optional Encryption	AES 256
Topology	Star	Star of stars	Star	Star
Throughput (max data rate)	200 kbps	50 kbps	600 bps	4 Mbps
Range	1–5 km	2–5 km	3–10 km	1–5 km
Power Consumption	Medium–Low	Very Low	Low	Medium
Battery	10 years	10 years	12 years	2 years
Deployment Cost	Moderate	Moderate	Moderate	High

Table 2. Latency value for Critical Infrastructure in a Smart City as a reference.

	Average Transmission Delay (ms)	Average Total Delay (ms)
Indoor NB-IoT	34.781	239.876
Outdoor NB-IoT	6.929	85.676

On the other hand, according to [48], the latest 2021 statistics indicate the higher adoption of NB-IoT over LPWAN technologies for deploying critical infrastructure, as proposed here. For all these reasons presented so far, NB-IoT is chosen over other alternatives in IoT technologies.

The selected private network operator must ensure that 4G coverage is necessary to deploy the IoT solution based on the NB-IoT protocol.

Computing core group—routing layer:

It is made up of four router devices that allow communication at the IP level with the private network of the selected operator. These routers have activated IP filtering lists, allowing the solution's range of IPs to pass through, improving the solution's security level by preventing unauthorized IPs from passing through. Dedicated FTTH connects the routers to the operator's network with a fully diversified primary, and a backup connection with fiber runs at different locations to guarantee the operation of the solution in the event of a fall on one of the two roads.

Computing core group—security layer:

This subsystem will comprise a cluster of two firewall devices in an active–active high availability configuration, segmenting the network into different virtual routing and forwarding (VRF) traffic between said networks. VRF between the management and operation traffic of the solution, the sensorization data traffic and the actuator traffic will make the differentiation.

Computing core group—LAN switching layer:

Switches will be used to distribute traffic at Layer 2 to bring it to the processing layer for control and analysis.

Computing core group—processing layer for data control and analysis :

This element includes the "IoT platform" and "Monitoring, Control and Dashboard platform".

The requirements for the "IoT platforms" of the proposed architecture are divided into two large groups according to the functionalities that they will contribute:

- IoT platform for water supply control: Designed to control the sensors and actuators of the water supply system. They are all the policies that have been developed to analyze the data provided by the water supply sensors, such as the water level sensor. This platform also includes the actions programmed to execute the orders to the actuators based on guidelines drawn up by the operators in charge of maintenance and management of the infrastructure.
- IoT platform for water purification system: Designed to control the sensors and actuators dedicated to the water purification chain. It allows the creation of action policies on the actuators of the solution water purification chain.

Regarding the "Monitoring, Control and Dashboard platform", it will have the following functionalities:

- Visualization of the data of the different KPIs in web mode is designed for this solution. KPIs are detailed in Section 4 of this paper.
- Analysis of the data received from the sensors.
- Creation of reports to monitor the operation and possible incidents.

The *processing layer for data control and analysis* will be formed at a physical level by the following:

- Servers: Those in charge of displaying information from both the IoT platforms and the control platform and dashboard. These front servers will be a total of two clusters

in high availability. These servers will be contracted in virtualized mode, which will help the flexibility of the growth of the solution according to the needs of the business.

- Databases (DDBB) will be the store. They can be relational SQL databases or nonrelational databases such as MongoDB. The databases will also be two clusters in high availability and connected at level 2 to ensure their synchronism.
- Data copy system: A copy of the database data will be available in order to have them in case of incidence or corruption of the database data in production.

An example of commercially deploying the "Central Control and Analysis platform" is the FIWARE solution created by the European Program for the Development of the Internet of the Future (FI-PPP).

We recommend for the processing layer the use of data type XML. XML data support the exchange of information between computer systems and are easy to process. We also propose to use MongoDB as DDBB because NoSQL databases offer higher performance. In [49], a solution for data models for Internet applications is described with these XML data and MongoDB.

3.2. Action and Measuring Group

Sensors and actuators in this group communicate with several gateway devices, which talk to the *computing core group* of the solution. We can see the *action and measuring group* architecture in Figure 2.

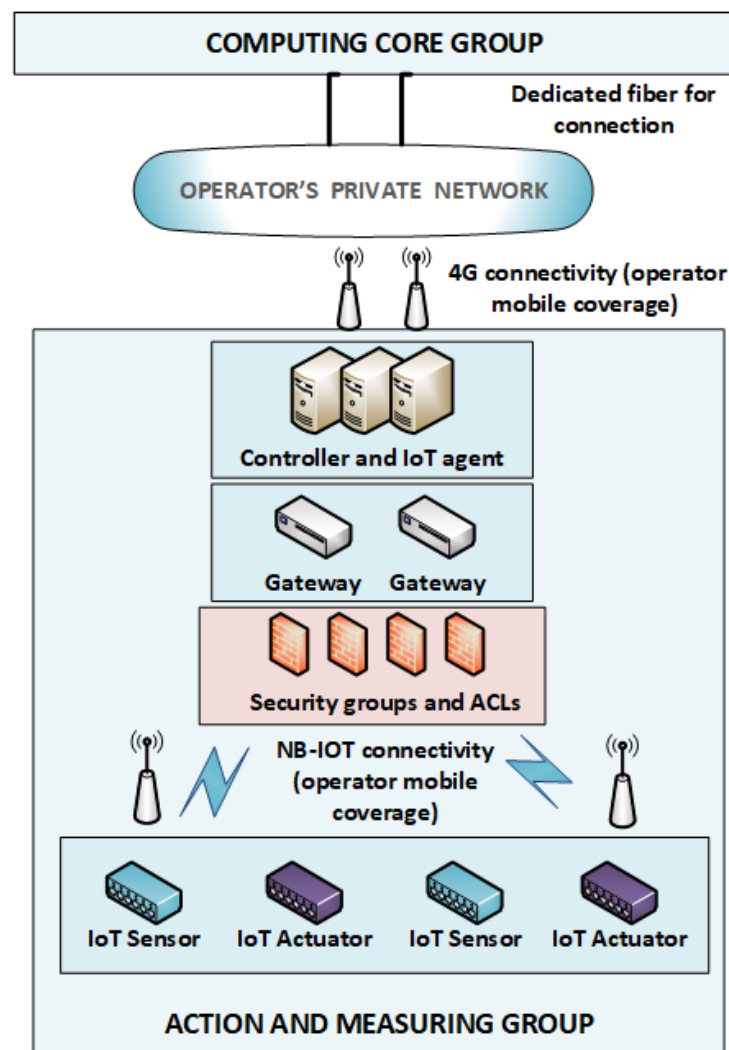


Figure 2. Action and measuring group architecture.

It comprises the levels of sensorization and action and is responsible for measuring any event that happens in the physical environment. It is the layer close to the physical elements of the supply chain and water treatment. More details about this system are as follows: action and measuring group

Sensorization level: It is the level related to the physical layer in which the NB-IoT devices of our solution are located. Some examples of NB-IoT sensors that could be used in our solution can be those from the manufacturer Sosteco, Movisat, or Kunak. In addition to the sensors, gateways communicate between the IoT network and the central computing group. IoT controllers would also be included for orderly data transmission to the central computing group.

Action level: It is the level related to the physical layer in which the NB-IoT devices of our solution are located. Unlike the class of sensorization, they are the devices in charge of making actions based on the configuration indicated in the central computing node. Some examples of actuators are door-opening regulation devices in the water supply chain, a device for controlling the number of chemicals to be included in the wastewater for proper treatment, or even devices that measure the noise level they make.

Elements of the group in Figure 2 are as follows:

Physical devices: Actuators and IoT sensors. They will connect wirelessly with the gateway and through the security groups and access control lists (ACL) configured on the network. Manufacturers of NB-IoT hardware devices are classified according to the type of market they are targeting; there are those specialized in Smart-Cities-related parameters such as water quality control, for example, Libelium and Kunak, or those specialized in electricity consumption control, such as Schneider. A price reference for an NB-IoT water chemical sensor device is about EUR 50 per unit for the Kunak K101 model [50].

Gateway devices: They communicate with the controller and IoT agent, and through them, the information is sent to the operator's private network through 4G connectivity. The availability of 4G coverage in the area must be ensured before proceeding with its deployment.

4. Key Performance Indicators (KPI)

To assess and accept the architecture of Smart Water infrastructure such as the one proposed in this work as an example of the Internet of Time-Critical Things, we use KPIs (key performance indicators) defined by a series of standards and norms in Section 1. The KPIs selected are summarized in Table 3.

Table 3. KPI.

	KPI	Description
PED	Protection of environmental diversity	To control that the water's purification is high enough to avoid altering the ecological environment.
PP	Pollution protection	To control the level of pollution generated by the water supply and purification solution.
CEE	Control of energy efficiency	To measure the amount of energy consumed by the population reached by the water supply solution.
SWL	Savings in water leaks	To measure the leaks that may exist in our supply chain.
ACP	Amount of water consumed by the population	To measure the amount of water consumed by the people (by a total number of inhabitants) based on the amount of water supplied by our solution.

Table 3. *Cont.*

KPI		Description
PR	Population reached	To measure the population reached by the wastewater collection facility.
LPT	Level of water purification treatment	To measure the level of water purification treatment according to the specialization of the treatment.
AIS	Average interruption of service	To measure the average annual hours of interruption of the water supply service.

These KPIs measure the protection of environmental diversity, the level of pollution generated by the water supply and purification solution, energy efficiency, the savings in water leaks in the supply chain and the amount of water consumed by the population, as well as the level of water purification treatment and the population reached by the wastewater collection facility. Finally, they measure the average annual hours of interruption of service.

5. Use Cases Results

Specific use cases using the aforementioned proposed architecture are described as an example below.

5.1. Water Level Management

The use case for water level management for the proposed architecture is shown in Figure 3. Sensors and actuators are located in the water supply pipe every 100 meters. The level sensor sends the data through the NB-IoT protocol to the central IoT platform. Whether the water level is at optimal levels or not, a signal will be sent to the actuator to open or close the pipeline gate. In the example of Figure 3, it can be seen that sensor 2 detects that the water level is much higher than sensor 1, which is why a signal is sent to actuator 2 to close the water damper and regulate the water flow. This allows for equalizing the water level at the different gates of the water supply chain.

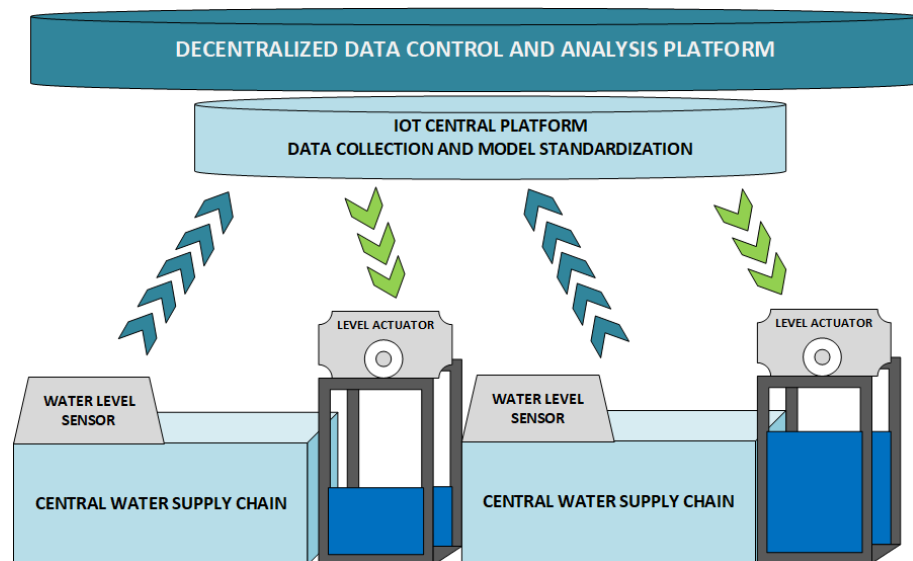


Figure 3. Water level management procedure.

5.2. Chemical Level Management in Water

According to the proposed solution, we can see in Figure 4 the use case for chemical level management in water.

This is an example of the sensor and actuator solution for wastewater treatment. Sensor number 1 of Figure 4 shows how it detects more microorganisms than desired in the wastewater. For this reason, from the central IoT platform, the flow of action data are sent so that the chemical that controls the number of organisms is introduced into the water. This process will be repeated many times until the level of microorganisms in the water is the desired one. Before repeating the process, it is necessary to wait a minimum time for the chemical to take effect and dilute in the water.

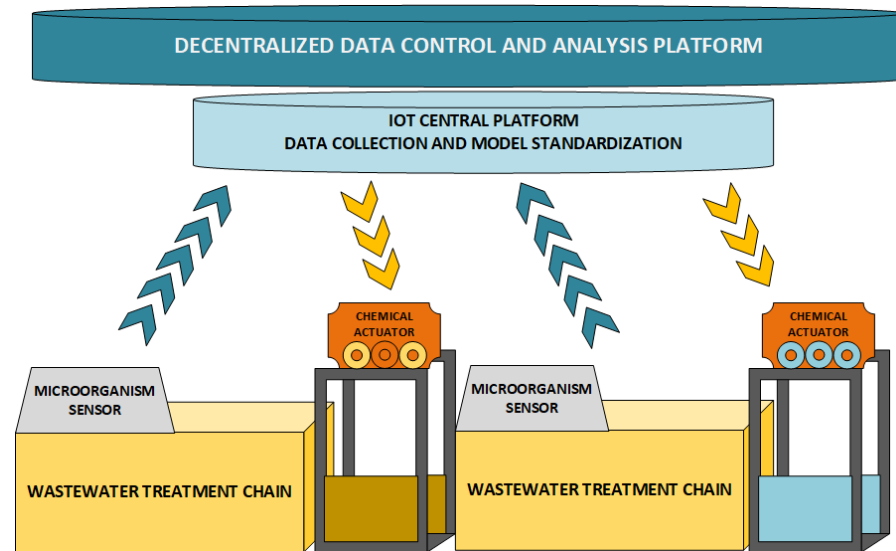


Figure 4. Chemical level management procedure.

The advantages obtained with the proposed infrastructure are shown next:

- Low power consumption: Using the NB-IoT communication protocol consumes little power for the IoT sensors.
- Wide range of sensors: Using an LPWAN solution achieves long ranges of communication with the sensors of the solution through the cellular network.
- Low cost in economic investment by reusing the infrastructure of existing 4G radio stations in the network of the selected operator.
- Lower cost due to NB-IoT sensors: Cost per NB-IoT sensor device is lower than Sigfox, LTE-M, or LoRa devices.
- Open-source flexibility of the management platform: Using an open-source platform improves the availability of applications for analyzing data received from IoT sensors.

The drawbacks are described next:

- Sparse standards: Further advances in standardization are needed to allow greater IoT network solutions.
- IoT sensors and actuators: There are few certified sensors on the market due to the lack of completeness of the standards, which means an increase in the price of all LPWAN devices.

6. Discussion

This article provides a common framework for designing a critical infrastructure that will comply with the standards established in Industry 4.0. It is intended to create a technical design guide to digitalize productive environments in the industrial sector. It is not about creating a unique and inflexible design but about laying the foundations for an Industry 4.0 environment. Below, we recommend guidelines to digitalize and renew a critical infrastructure within the industrial environment and some future improvements.

NB-IoT protocol and 4G mobile network coverage were chosen as the best technologies for the critical infrastructure renewal solution through IoT networks. NB-IoT uses

all the communication security protocols inherent in the mobile network, and the level of deployment of 4G coverage is high. The place where the solution is deployed will likely have sufficient 4G coverage. With the progress of standardization in 5G protocols, the natural evolution for IoT networks will be to use the advantages offered by the 5G network. Currently, the characteristics and needs of an IoT network are solved with the use of NB-IoT or LTE-M.

5G technology enables lower latency (uRLLC) and massive machine-type communications (mMTC), which would improve connectivity for the total number of IoT monitoring sensors required for critical infrastructure. However, as the number of sensor devices in our infrastructure grows, network design will need to be improved to meet the new lower latency requirements. This is where the use of 6G connectivity would come into play [51]. The improvements that 6G networks would bring and that would be applied to critical infrastructures that are usually located in areas with poor mobile coverage are, precisely, the improvement of coverage towards global coverage through the effective integration of satellite and submarine communication networks. Additionally, they provide a higher capacity than 5G networks, which would be improved by 1000 times through the use of Terahertz frequency and spatial multiplexing.

7. Conclusions and Future Lines

The use of hyperautomation and artificial intelligence systems is identified as another future implementation to be applied in our design to carry out preventive maintenance on old parts before the occurrence of a probable incident. The advantage of using hyperautomation is establishing robotic processes that control the water level of the supply network based on the data analyzed by artificial intelligence, which would largely avoid human action, and hence possible human failures. However, it would always be necessary to have technical operators available for potential unforeseen incidents, as it is a critical infrastructure in which service availability to citizens is the most important thing.

To propose future connectivity for the architecture model, we propose the 6G network, which will be able to meet future requirements, as more sensors will be needed to be connected simultaneously. However, it should be noted that there is no 6G standard, so we will have to wait for the technology to mature and become standardized before it can be applied in critical infrastructure. Future researchers might use the proposed framework to design interdisciplinary architectures within the Smart Cities paradigm. The proposed architecture model can be used to establish the minimum requirements for dedicated simulators to study the operation of IoT networks dedicated to water distribution systems, such as the EPANET simulation model proposed by the US government. This simulator is used to design new water supply infrastructures, to study water quality, establish the number of water pumps and even define the contamination models in the supply chain. Our architecture model could be used in future investigations with EPANET [52]. To provide an IoT monitor solution that meets the required specifications of the water supply chains.

Author Contributions: Conceptualization, C.V.M. and V.M.B.; investigation, C.V.M. and V.M.B.; writing—original draft preparation, C.V.M. and V.M.B.; writing—improving and correcting original version, C.V.M., V.M.B., R.P. and C.M.; writing—review and editing, C.V.M., V.M.B., R.P. and C.M.; supervision, V.M.B.; project administration, V.M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: All authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ACL	Access Control Lists
DDBB	Database
FI-PPP	Future Internet Public–Private Partnership
FTTH	Fiber To The Home
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information Technologies
KPI	Key Performance Indicator
LAN	Local Area Network
LoRa	Long Range
LoRaWAN	Long-Range Wide-Area Network
LPWAN	Low-Power Wide-Area Network
LTE	Long-Term Evolution
LTE-M	Long-Term Evolution Machine
mMTC	massive Machine-Type Communication
NB-IoT	NarrowBand IoT
SLA	Service-Level Agreement
SQL	Structured Query Language
uRLLC	Ultra-Reliable Low-Latency Communications
VRF	Virtual Routing and Forwarding

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Review

Smart City Transformation: An Analysis of Dhaka and Its Challenges and Opportunities

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Abstract: Cities worldwide are experiencing rapid urbanization and an increasing population, creating a pressing need for smart infrastructure to enhance citizen services. Dhaka, the capital of Bangladesh, faces similar technological and socio-economic challenges, making it crucial to transform it into a sustainable smart city. This research analyzes the opportunities and challenges of smart cities and Dhaka through SWOT and PESTEL analyses. The study employs a fuzzy rule-based inference system in a MATLAB simulation to calculate the smart city index based on parameters such as governance, transportation, waste management, utility management, healthcare, and industrial automation. The findings reveal that good governance has the highest impact on the smart city index, followed by transportation. The paper proposes a sustainable smart city transportation framework and management technique, outlining future research directions. The proposed framework is expected to impact socio-economic, technological, and environmental aspects positively.

Keywords: smart city transformation; governance; transportation; IoT; smart grid; environmental sustainability; sustainable development



Citation: Karmaker, A.K.; Islam, S.M.R.; Kamruzzaman, M.; Rashid, M.M.U.; Faruque, M.O.; Hossain, M.A. Smart City Transformation: An Analysis of Dhaka and Its Challenges and Opportunities. *Smart Cities* **2023**, *6*, 1087–1108. <https://doi.org/10.3390/smartcities6020052>

Academic Editors: Véronique Flambard, SadiaBenamrouz-Vanneste and Abir Karami

Received: 20 February 2023
Revised: 4 April 2023
Accepted: 4 April 2023
Published: 7 April 2023



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1. Introduction

Rapid urbanization and population growth are causing various socio-economic, technological, and environmental issues in the cities of developing countries, such as poor governance, traffic congestion, inadequate healthcare, education, and housing facilities, utility management problems, and environmental pollution. Dhaka, the capital of Bangladesh, has been ranked as the third least livable city in the world due to its lack of modern citizen services and basic facilities [1]. The city authorities aim to improve the infrastructure to offer better services to citizens, but this is associated with various stakeholder challenges. These challenges relate to real-time applications such as utility supply, healthcare, transportation, waste management, digitized education, and governance. Addressing these challenges through good governance and innovative technologies is crucial for Dhaka to become a smart city [2]. To develop a smart city, it is crucial to solicit input and feedback from citizens to address local issues and meet their needs [3]. Policies and frameworks should be designed to provide smart city services to citizens in a straightforward and accessible manner. Research on smart cities has shown that inadequate resources, accountability, and infrastructure contribute to poor service delivery in developing countries [4].

With the continual emergence of modern technologies, urban residents around the globe are increasingly interested in integrating smart technology into their city environments. However, implementing technological upgrades and overhauls is a complex and expensive process that requires adequate planning. Information and communication technologies, such as the Internet of Things (IoT), involve sensors, objects, and machines with unique identifiers and are widely used for real-time data transfer between network components. These technologies offer citizens real-time services while maintaining privacy and security with minimal human and machine intervention [5–7]. The significant growth of the global population poses challenges for governance, transportation, utility supplies, and socio-economic and environmental sustainability, particularly in highly populated areas. IoT-based smart cities present a promising solution, although internet access and speed throughout the city are crucial for establishing a smart city framework [8,9]. Incorporating geographic data from IoT devices can enhance governance structures, improve traffic and waste management, standardize healthcare facilities, optimize utility consumption, and reduce environmental pollution in a smart city framework, as suggested in [10].

The effectiveness of IoT infrastructure within a city can be hampered by inadequate and low-speed internet facilities [11]. Case studies on the digitization and smartening of cities in the European region are observed in the literature utilizing IoT devices [12,13]. Therefore, improving internet bandwidth and ensuring proper access are crucial for the success of the IoT framework. A project is underway in Bangladesh, in collaboration with the Dhaka North City Corporation (DNCC) and Local Government Engineering Division (LGED), to improve urban governance, develop GIS-based maps, and deliver smart services to citizens. Additionally, Japan and South Korea will fund several smart city projects in Bangladesh [14]. However, challenges such as transparency and accountability, insufficient infrastructure capacity, internet connectivity and speed, and limited access to online apps and web portals must be addressed [15,16].

Smart city assessment techniques have been developed in research, considering various parameters, including governance, modern technologies, citizens, economy, livability, and environment [17]. Another study has described the main parameters for smart cities as environment, socio-economic factors, technology, legal aspects, and governance [18]. However, various other segments, such as transportation, waste management, utility management, healthcare management, and industrial automation, must also be considered in developing smart cities. Research has been conducted on transforming different cities around the world into smart cities. To the best of the author's knowledge, no study has been conducted on smart city implementation using modern technologies in Dhaka, integrating governance, transportation, healthcare management, utility management systems, waste management technology, and industrial automation technologies. Therefore, this paper's main attempt is to design a transformational model for Dhaka's paradigm and discuss the execution procedure for the transformational model.

The specific contributions of this study include the following:

1. Outline the challenges and methods from the existing literature employed in different cities to foster smart city transformation;
2. Conducted SWOT and PESTEL analyses to determine challenges and opportunities for smart city transformation;
3. Designed a smart city prediction tool using a fuzzy inference system in MATLAB software R2023a;
4. Developed a smart city transformation framework, including different stages using modern technologies;
5. Designed smart city management techniques with proposals for Dhaka, Bangladesh.

This paper is structured into different sections. The first section is a literature review that overviews contemporary literature on smart city transformation in conventional cities. It also includes information about the current state of Dhaka and smart cities around the world. The second section outlines the methodology used in the smart city transformation model. The third section presents a strategic analysis and a fuzzy rule-based model for the

smart city prediction technique. The fourth section describes the conceptual framework for smart city transformation and its impacts. The fifth section proposes guidelines for transforming conventional cities into smart cities. Finally, the conclusion in the seventh section summarizes this study's limitations and future research directions.

2. Literature Review

It is necessary to have a comprehensive and sustainable plan that addresses technological, economic, and environmental aspects during the smart city transformation. However, various obstacles can hinder such a project's cost-effectiveness and timely implementation. Therefore, researchers need to identify the challenges and opportunities of implementing smart city solutions in cities with poor livability standards. An intelligent city utilizes innovative technologies to enhance the quality of services provided to its citizens, improving efficiency, consistency, and security. As urbanization continues to increase, the development of smart cities has become vital. This literature review has three parts: first, it examines the challenges faced by different countries when implementing smart city solutions; second, it presents an existing framework for transforming smart cities; and third, it outlines smart city transformation barriers and solutions in developing countries.

This research reviewed existing literature from Google Scholar by searching for the keyword "Smart City Transformation" from 2010 to 2023. A total of 862 original research articles and 91 review articles were found, with case studies investigating several cities. Only case study papers with a transformation framework were selected for this research.

2.1. Challenges of Smart City Development in Different Countries

The literature review summarizes recent studies investigating the obstacles encountered in the development of smart cities in different countries. Table 1 presents the findings of these studies in a concise and accessible format for easy reference and visualization. Table 1 provides insight into countries' common challenges when implementing smart city solutions.

Table 1. Challenges of smart city development in different countries.

Source	Method	Place	Challenges
A Al Enezi et al. [19]	Reviewing papers for identifying challenges for IoT in smart city development	Kuwait	Mind scaping, investment, security/privacy
N P Rana et al. [20]	Fuzzy analytical hierarchy process method for prioritizing barriers in innovative city development	India	Thirty-one barriers are indicated and classified into six groups, i.e., governance, economic, social, technological, environmental, and legal and ethics
H HKhan et al. [21]	Reviewing research works relevant to innovative city development	Pakistan	Budgetary problems, lack of resources, lack of social awareness and adaptation, technological capacity, lack of smart city framework, lack of sustainable strategies, system incorporation
S Khan et al. [22]	Prioritizing challenges using the weighted aggregated sum/product assessment (WASPS) method	India	ICT infrastructure, population, budget, security and privacy, data sources and features, data quality, people need social polarization, green energy, data, and information sharing.

Table 1. Cont.

Source	Method	Place	Challenges
N Sidek et al. [23]	IoT implementation in services using a review of contemporary research and determined challenges	Malaysia	Individual readiness, system/information/service quality, and government regulatory policies
L Oyedele et al. [24]	Using a systematic review of research author analyzed the feasibility of the implementation of a smart city	Nigeria	Corruption, lack of human and material resources, regulatory policies, harmony between stakeholders
K Hoang VietBach et al. [25]	Analyze the smart city development phase using the SWOT tool	Dalat City, Vietnam	Understanding current and future challenges, project complexities, technical challenges and institutional capacity, physical infrastructures, and network connectivity
L Pazmiñoet al. [26]	Developed a framework for IoT deployment in Ecuador	Ecuador	Industry, infrastructure and technology, security and privacy, legal aspects, education, and society
ME Akiner et al. [27]	Analysis of challenges of smart city transformation using Urban Information system and Geographical information system	Turkey	Challenges are in energy, environment, water, transportation, urban services, security, and healthcare facilities
G Meiwanda et al. [28]	Presented an in-depth analysis of the barriers to smart city development	Pekanbaru city, Indonesia	Governance speed, agility, adaptability, and social and public services
Y Li et al. [29]	Challenges and suggestions for smart city development using IoT	China	Challenges in four aspects-applications, technology, standards, and security issues
De Melo Cartaxo et al. [30]	Case studies for digitization and smartening of two cities in the European High North region	Norway and Finland	It recommends combining development, sustainability, and human well-being for smart city transformation
Haarstad, Håvard et al. [31]	Examines the role of sustainable development in smart city construction	Stavanger, Norway	It discussed innovation, technology, economic entrepreneurialism, and sustainability towards smart city development, where the inclusion of good governance is pivotal.

2.2. Literature Studies on Existing Smart City Transformation Framework

This section provides an overview of the current literature on transforming cities into smart cities using innovative technologies. Ibrahim et al. [32] proposed a theoretical logic model for transforming cities into sustainable smart cities. Meanwhile, Kumar et al. [33] presented a framework consisting of planning, physical setup, ICT infrastructure setup, and deploying smart solutions. Kuru et al. [34] designed a transformation framework called TCitySmartF with four dimensions: engagement with stakeholders, development of smart city infrastructure, integration into smart city domains, and integration with national and international environments. The framework aims to incorporate distributed services and assets, deliver effective, user-friendly solutions and real-time aid services, enhance sustainability, and promote economic expansion and competitiveness.

In a study, a benchmark model is developed considering a novel Relative Area Index (RAI) based on traffic assignment theory that is proposed to measure multi-scale urban road networks. It fosters the robustness of transforming conventional cities into smart cities in relation to the transport sector [35]. Another study investigates the role of low-carbon

technology (LCT) in sustainable urban development, focusing on three main aspects such as energy conservation, emission reduction, and carbon capture, storage, and utilization technologies [36]. A review of the expansion and adoption of digital twins in smart city transformation concludes that they improve operational efficiency and governance levels and highlights the need for accelerating their adoption [37].

A study proposes a data-driven approach to smart city deployment that considers technological and stakeholder perspectives, focusing on data privacy and security [38]. Another study examines the factors that affect the transformation of conventional cities into smart cities in Australian cities, including population density, unemployment level, and labor productivity [39]. The study provides insights for urban policymakers, managers, and planners to make informed decisions regarding smart city policies and planning. Finally, a study proposes an Enterprise Architecture Framework (EAF) to address the challenge of integrating pervasive systems in smart cities that involve multiple stakeholders and actors [40].

Hamalainen et al. [41] proposed a framework of four dimensions—strategy, technology, government, and stakeholders—to strengthen governance and sustainability in smart city initiatives. The framework was applied to Helsinki City, Finland, to maintain operations and implement smart city projects. Mishra et al. [42] presented a novel architecture incorporating IoT, AI, and cloud computing in smart cities to benefit the ecological system. A conceptual framework [21] was proposed to identify challenges for smart city development, including budgetary problems, lack of resources, social awareness and adaptation, technological capacity, a lack of a smart city framework, a lack of sustainable strategies, and system incorporation. The challenges facing smart city networks are discussed in this research, and ways to overcome these challenges are suggested. Cohen's smart city wheel framework defines a smart city, which includes smart governance, economy, environment, mobility, people, and living facilities [43]. Privacy and security, data quality, scalability, complexity, and a lack of IoT-based governance are critical factors hindering IoT implementation in smart city projects [44]. A comprehensive IoT implementation model is needed to consider these factors.

The concept of smart city transformation is mainly performed in developed countries where governance, investment, infrastructure, and social awareness are high enough compared to developing countries. Hence, developed countries faced fewer difficulties in smart city transformation than developing countries.

2.3. Barriers and Solutions for Smart City Transformation in Developing Countries

The smart city transformation in developing countries is more challenging compared to developed countries. The reason behind these challenges is poor governance, inadequate infrastructure, funding, skilled personnel, a lack of stakeholder engagement, data security, and privacy, as described in a study [45]. This study concludes that transparent governance and a strict regulatory framework can foster smart city transformation in developing countries. Another study in a developing country, Vietnam, conducted a survey and indicated that online government services could limit corruption during city service development [46]. This study reveals that promoting ICT infrastructures, strategic decisions, operational management, and good governance can help accelerate city transformation.

A study conducted on the urban transportation system in Lusail City, Qatar, proposes implementing a smart road network, light rail transit, two-wheeler and pedestrian networks, parking facilities, water taxis, and electric vehicle (EV) charging stations. These interventions aim to transform the urban transportation system and make Lusail City a smart city [47]. This paper mentioned numerous benefits to the travelers of this city, although maintaining the operation of these interconnected networks will be more challenging. Research in the context of Nigeria concludes with a fuzzy-synthetic analysis that identifies barriers to smart city development in several aspects, such as governance, economic, social, technological, environmental, and legal issues [48]. However, prioritization of the problems is needed for implementation purposes.

An analysis was conducted in the context of India to determine the strength and priority of aspects of smart city transformation [49]. This study identified 31 sustainable smart city enablers and used a clustering approach to assess the aspects' significance. In that analysis, the strategic and policy-oriented enablers score the highest importance, followed by ICT infrastructure development, energy and environment, transportation, and social contexts. The smartness of the cities is assessed using fuzzy synthetic analysis in a study conducted in Kumasi city, Ghana, including six dimensions: economy, living, governance, environment, mobility, and people. Based on the index obtained from fuzzy synthetic evaluation, the cities' readiness is measured in this study, which considers a survey of the city's citizens [50]. Research conducted on the smart city framework for developing countries depicts a model for the sustainable development of cities that prioritizes national and local sustainability policies, infrastructure, investment, services, data availability, and citizen participation [51].

Previous research has primarily focused on developing frameworks based on a few dimensions of cities [52,53], and there is a lack of monitoring and controlling issues for the sustainable operation of smart city networks. The research proposes a fuzzy rule-based smart city prediction technique and a smart city management system to address these issues, covering all dimensions of a smart city and using modern ICT technologies for monitoring and controlling operations cost-effectively.

3. Methodology

Dhaka, Bangladesh, is facing numerous challenges related to urbanization, including traffic congestion, air pollution, insufficient public services, and inadequate infrastructure, among others. With a population of over 20 million, Dhaka is also the fastest-growing city globally, exacerbating the challenges further. To address these challenges, the government is exploring ways to leverage technology and innovation to transform Dhaka into a smart city. The transformation can help make the city more sustainable, efficient, and livable for its inhabitants.

The research methodology shown in Figure 1 involves using SWOT and PESTEL analyses to identify challenges and opportunities for smart city transformation. A fuzzy inference system in MATLAB software creates a smart city prediction tool that considers governance, transportation, healthcare, utilities, waste management, and industrial automation. A smart city transformation framework is developed using modern technologies, and smart city management techniques are proposed for Dhaka, currently ranked as the third least livable city in the world.

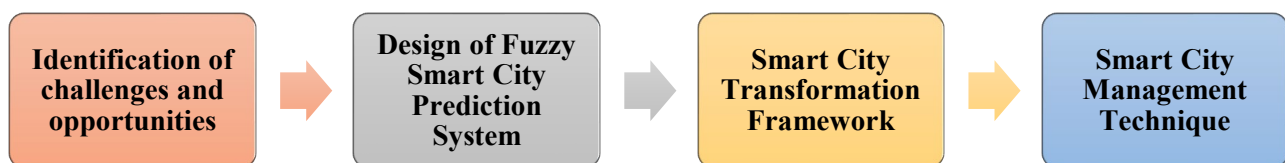


Figure 1. Methodology.

Current Status of Dhaka, Bangladesh, and Smart Cities in the World

Smart cities have become a priority in global development, with innovative facilities attracting investment and recognition. The Smart City Index 2019, created by the Intelligent World IMD City Observatory and the Singapore University of Technology and Design, ranks 102 cities worldwide [54]. Based on the index, the top ten most innovative cities are Singapore, Zurich, Oslo, Geneva, Copenhagen, Auckland, Taipei City, Helsinki, Bilbao, and Dusseldorf. Singapore is ranked as the top smart city due to its advanced safety and monitoring systems for air pollution and traffic. Auckland, Taipei City, Helsinki, Bilbao, and Dusseldorf are among the top 10 smart cities worldwide, per the IMD Smart City Index 2019. Auckland ranks 6th due to its integrated transport system and excellent digital governance, while Taipei City ranks 7th for its advanced digital infrastructure and efficient public

services. Helsinki is placed 8th for its focus on innovation and sustainability, and Bilbao ranks 9th due to its extensive use of renewable energy sources and urban regeneration projects. Finally, Dusseldorf is ranked 10th due to its efficient waste management system and emphasis on energy-efficient buildings.

Many other cities are increasing due to their innovations toward a smart city. Firstly, Bilbao is perfect for transparency and a sound governance system. London is an innovative city due to Wi-Fi connectivity with renewable energy integration. In the field of sustainable development, the city of San Francisco is famous for innovation and is a zero-waste city with an 85 percent recycling capacity. However, the concept of an intelligent city may vary based on significant aspects, such as governance, mobility, health, security, and environment. The smart city will be covered effectively by all these aspects. In the case of Southeast Asia, the cities are called rising smart towns, except for Singapore, because they are already at the top of the world. The other cities are Mandalay (Myanmar), Phuket (Thailand), Danang (Vietnam), Bangkok (Thailand), Seoul (South Korea), New Clark City (Philippines), Jakarta (Indonesia), and Hanoi (Vietnam) [54].

Dhaka is the world's most densely populated area, where one-third of the urban population lives. Additionally, it is a commercial and administrative city in Bangladesh. Compared to other cities in the world, Dhaka is the third least livable city according to the 2019 Annual Global Livability Index, EIU report. It is mentioned that Dhaka's instability scored 55 points: 29.2 in healthcare, 41.7 in the education system, 40.5 in culture and environment, and 26.8 in infrastructure. In Figure 2, it is seen that the crowded city area with traffic jams in Dhaka is placed as the 3rd most miniature livable city in the world.



Figure 2. Traffic congestion in Dhaka, Bangladesh.

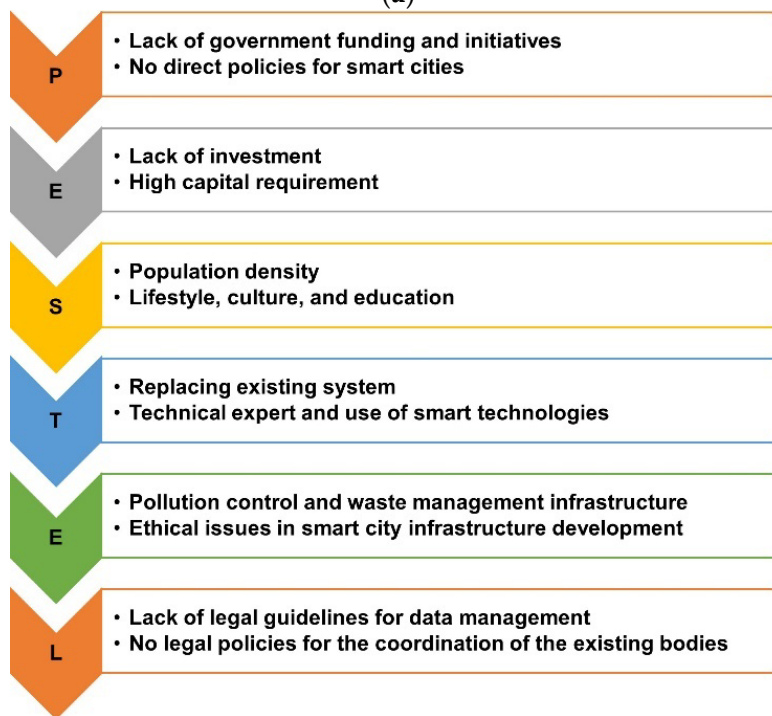
4. Strategic Analysis for the existing Smart Cities

In this section, strategic analysis and SWOT analysis are performed for the existing intelligent cities in the world from other contemporary research, whereas the PESTEL analysis of the challenges of Dhaka, Bangladesh, for transforming into a smart city is presented.

These strategic analyses identify challenges and opportunities for smart city transformation. SWOT and PESTEL analyses are popular tools for project managers to make informed decisions. SWOT stands for Strengths, Weaknesses, Opportunities, and Threats, whereas PESTEL stands for Political, Economic, Social, Technical, Environmental, and Legal. SWOT analysis has two essential parts: internal (Strengths and Weaknesses) and external (Opportunities and Threats), demonstrating the existing challenges and opportunities for smart cities. Furthermore, PESTEL analysis shows the challenges encountered in conventional Dhaka, Bangladesh. Based on the literature observed on the aspects of Dhaka, the SWOT and PESTEL analyses are determined [55–58]. Figure 3a shows the SWOT analysis, whereas Figure 3b presents the PESTEL analysis for determining challenges and opportunities in smart city transformation.

Internal Factors	Strengths (S)	Weakness (W)
	<ul style="list-style-type: none"> • Innovative and smart technology • Real-time monitoring • Processing time and cost reduction • Enhanced efficiency and easy use 	<ul style="list-style-type: none"> • Data privacy and security • Complex system design • No built-in infrastructure • Implementation duration
External Factors	Opportunities (O)	Threats (T)
	<ul style="list-style-type: none"> • Good governance System • Prompt healthcare and education services • Traffic management and road safety • Effective utility management • Increasing productivity • Environment friendly 	<ul style="list-style-type: none"> • Data vulnerability • High Investment required • Technology adoption problem • Trained personnel for management

(a)



(b)

Figure 3. (a): SWOT analysis for existing smart cities. (b): PESTEL analysis for Dhaka, Bangladesh.

4.1. Fuzzy-Based Smart City Prediction Technique

Based on the identified barriers in the SWOT and PESTEL analyses, essential parameters such as governance, transportation, healthcare facilities, utility management systems, waste management systems, and industrial automation were selected for the smart city transformation. A fuzzy rule-based smart city prediction framework was shown in Figure 4, where these parameters were considered input variables and the smart city was the output variable. The input variables are “governance”, “transportation”, “utility management”, “waste management”, “healthcare facility”, and “industrial automation.” The centroid-based defuzzification method was used in the fuzzy inference system. The input and output variables for the fuzzy inference system are presented in Figure 5.

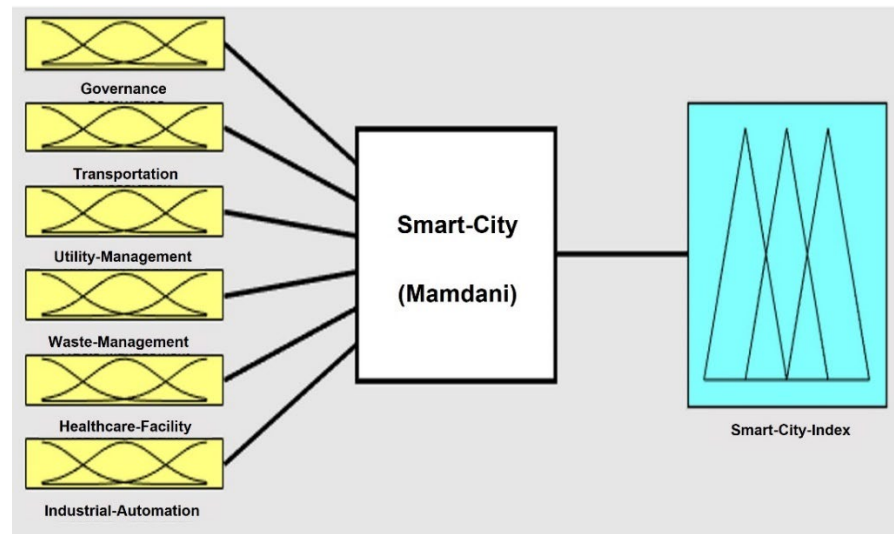


Figure 4. Fuzzy rule-based smart city prediction tool considering six input parameters.

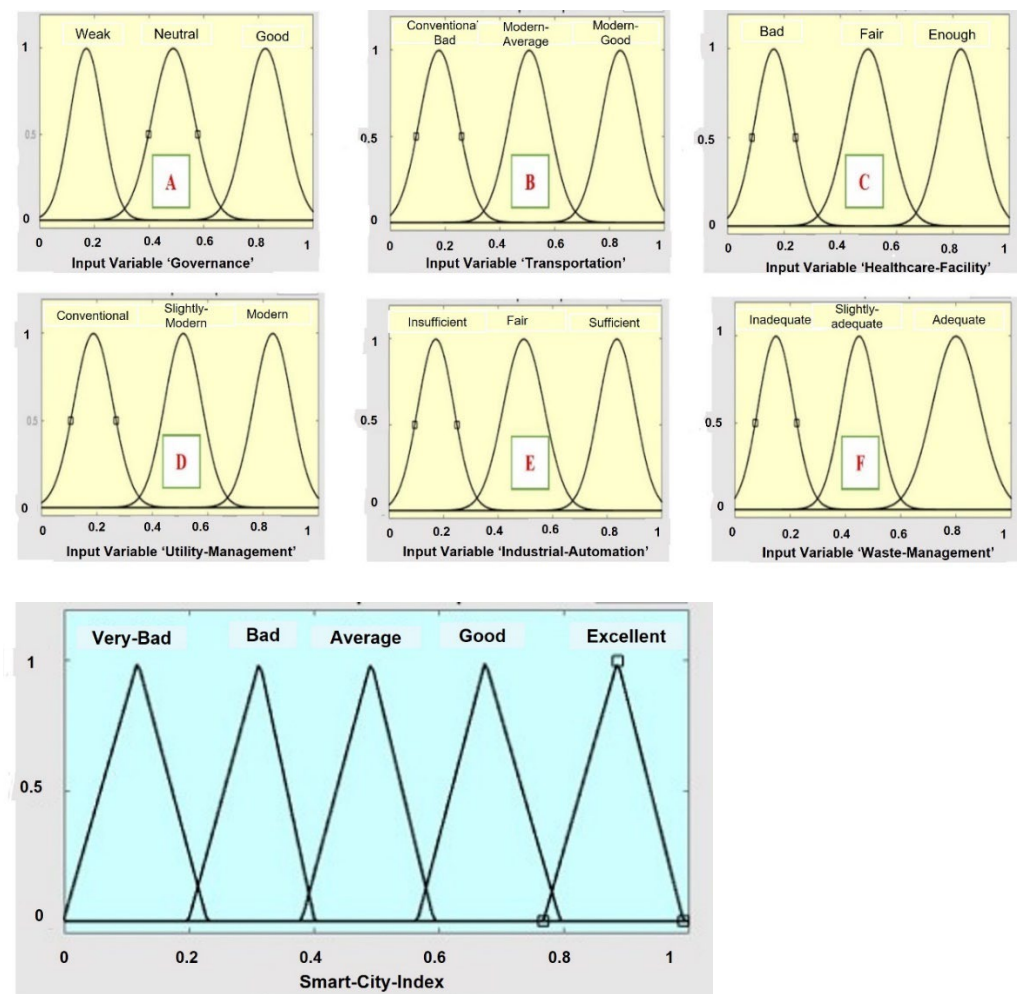


Figure 5. Fuzzy input and output variables with membership functions.

Input and Output Variables

Three Gaussian membership functions are used in all input variables, and five triangular membership functions are used in the output variable. All the input and output variables vary from 0 to 1.

Thirty fuzzy “if-then” rules are included in this system, as shown in Figure 6, where the output variable varies depending on the combinations of input variables.

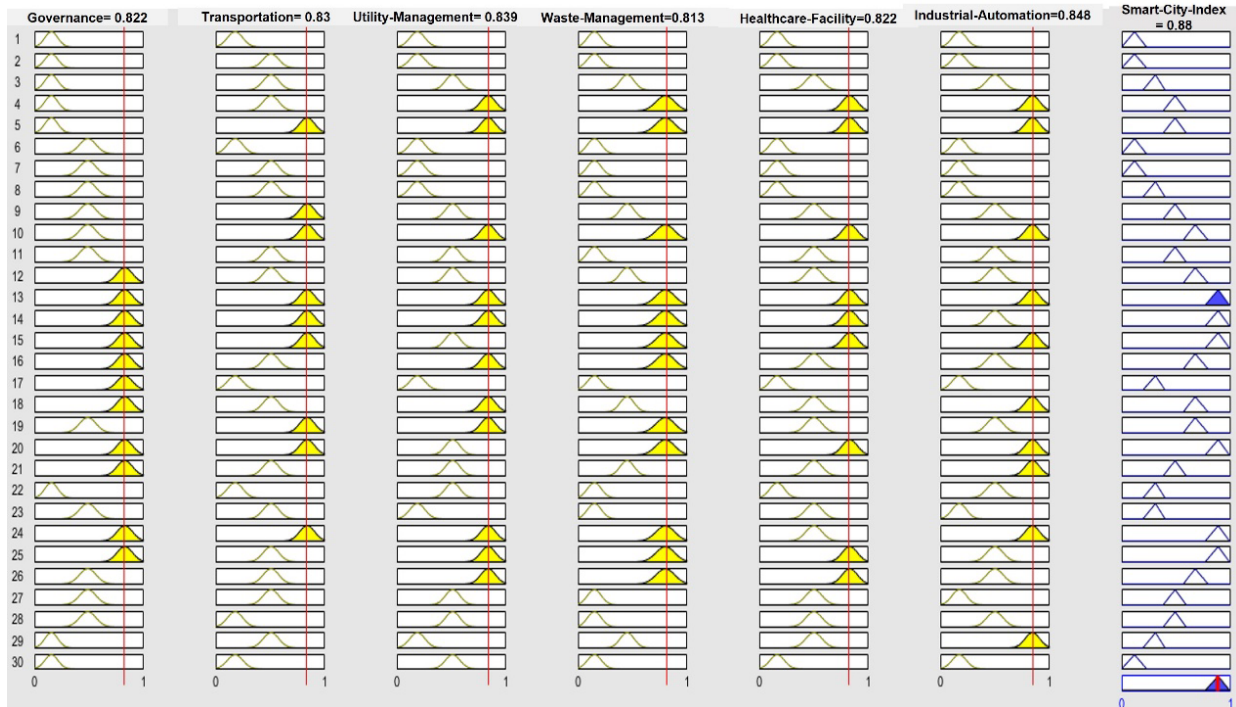


Figure 6. Fuzzy rule viewer.

Input variable “Governance” has categorized as three membership functions named “Weak”, “Neutral”, and “Good”, whereas “Transportation” has three membership functions named “Conventional_Bad”, “Modern_Average”, and “Modern_Good”. “Utility_management” has three categories of membership functions named “conventional”, “slightly_modern”, and “modern”, while “Waste_Management” has three membership functions named “Inadequate”, “Slightly_Adequate”, and “Adequate”. “Healthcare_Facility” refers to three membership functions named “Bad”, “Fair”, and “Enough”.

In a fuzzy logic system, input variables are described by membership functions that define how each input value is related to different degrees of membership in a set or category. In this case, each input variable has three membership functions describing different conditions or states the variable can take on. On the other hand, the output variable represents the degree of smart city development, and it is described by five membership functions that indicate how the input variables influence the output. The smart city index ranges from 0 to 1, where 0 represents a conventional city and 1 illustrates a fully developed smart city.

Figure 7 displays the surface views of the output variable in relation to the input variables. This means that the figure illustrates how the output value changes as the input variables change. The graph shows the combinations of input values and their corresponding output values.

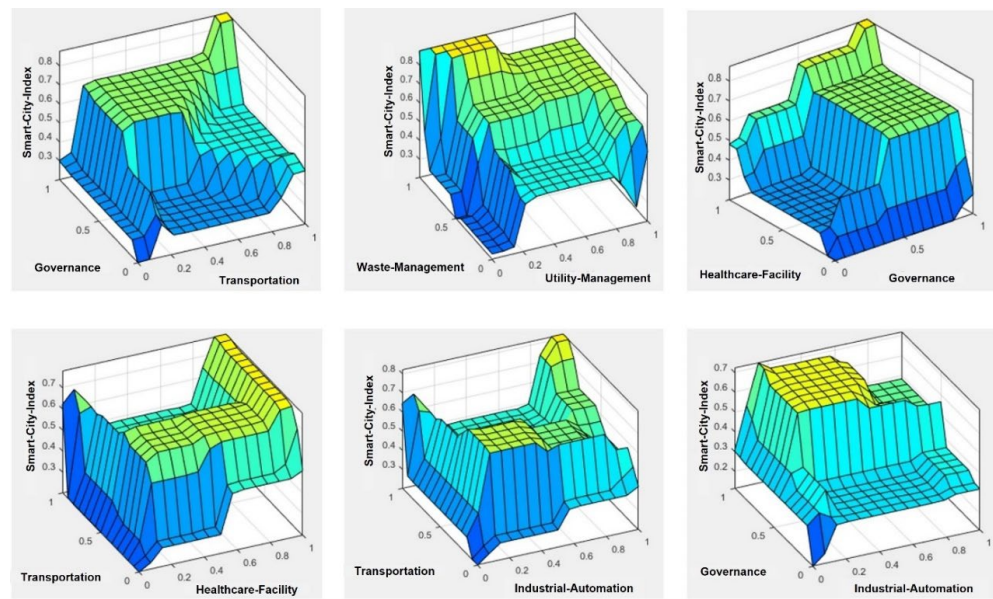


Figure 7. Surface view plot of smart city prediction scheme considering six key parameters.

Overall, this fuzzy logic system provides a way to model and analyze the development of smart cities using multiple input variables and a single output variable. By using membership functions to represent the relationships between inputs and outputs, the system can capture complex and uncertain relationships between variables and provide valuable insights into the development of smart cities.

4.2. Proposed Framework for Transforming Dhaka into a Smart City

This article proposes a framework for achieving sustainable transformation in Dhaka. This framework comprises five distinct phases that must be followed in order: identification and prioritization, planning, physical setup, development of IoT infrastructures, and monitoring and controlling. Each stage has a specific set of actions and goals that must be achieved to transform Dhaka into a smart city. These details are illustrated in Figure 8, which visually represents the framework and its various components.

(i) Identification and Prioritization Phase

In this phase, the challenges and barriers to implementing IoT for smart city transformation are identified using recent relevant research. After that, the SWOT and PESTEL analyses are executed to identify the city system's strengths, challenges, and opportunities.

(ii) Planning Phase

In the planning phase, policymakers must prioritize development efforts based on identified problems, redesign government policies for sustainable development, gather information from citizens, estimate the budget, and conceptualize solutions for identified barriers.

(iii) Physical Setup Phase

In the implementation phase, the policy developed in the planning phase is implemented to improve the city's performance. Before incorporating intelligent technologies into the city's network, basic facilities relevant to the transformation must be implemented. The processes required for this step include decentralization, the provision of adequate housing facilities, the development of roads and transportation systems, smart utility management, the implementation of environmental protection and control measures, waste management and recycling, and the formulation of strict legal policies. These steps are crucial to ensuring that the city's infrastructure is in place before introducing smart technologies.

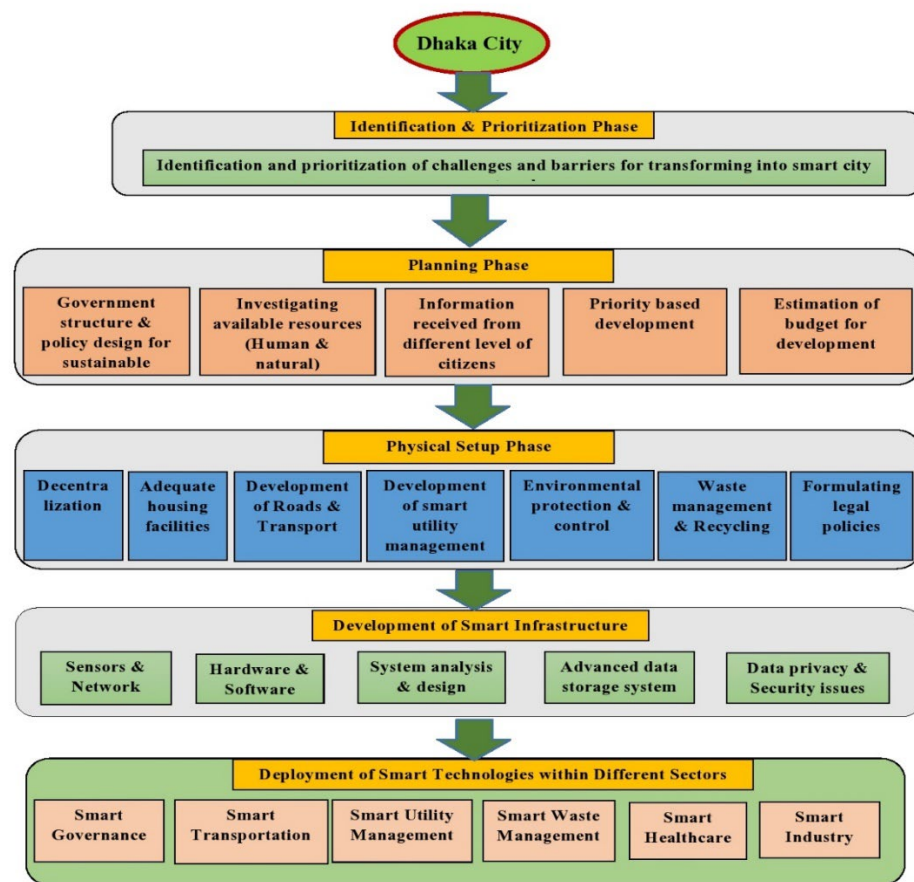


Figure 8. Smart city transformation framework for Dhaka.

(iv) Development and Deployment of IoT Infrastructure Phase

In this phase, the requirements for developing IoT infrastructure are fulfilled. It incorporates sensors, hardware, software components, system analysis and design, data storage facilities, and data protection systems. These components are essential for enabling smart technologies to function effectively in the city. By implementing IoT infrastructure, the city can collect and analyze real-time data to optimize resource usage, enhance services, and improve the quality of life for its citizens.

(v) Continuous Monitoring and Controlling Phase

For sustainable and intelligent solutions to the problems associated with the city area, the IoT infrastructure should be kept under direct control and monitoring by the city authorities. Initially, the project can be more vulnerable due to the lack of proper expertise and knowledge to handle these devices. Moreover, the lack of consciousness and the ignoring of rules and policies may threaten the sustainable development of IoT in Dhaka. To ensure the quality and sustainability of the implemented project, regular maintenance of the project needs monitoring and control. Therefore, continuous monitoring and handling of the activities would be essential for transforming a city into a smart city.

5. Proposed Smart City Framework

The concept of a smart city revolves around leveraging advanced technologies and data analytics to improve the overall quality of life for its citizens. By deploying sensors, networks, and advanced analytics tools, cities can collect and process large amounts of data from various sources, including transportation systems, energy networks, public safety systems, and more.

5.1. Impact of the Framework

A smart city strengthens governance, improves transport and healthcare systems, saves energy, is concerned about environmental sustainability, incorporates updated policies, and maximizes societal adoption of modern technologies. In this section, the impacts are explained.

5.1.1. Impact on Governance

Developed countries have embraced smart governance and sustainable development by leveraging modern technologies to establish advanced infrastructure. Developing countries such as Bangladesh have also started adopting digital technologies, resulting in positive outcomes and benefits for citizens. Implementing web portals, online platforms, and mobile apps has directly empowered citizens, and the “access to information act” has helped ordinary citizens learn about their rights. In addition, the “access to information act (A2I)” in different government organizations in Bangladesh empowered ordinary citizens to know about their rights [59]. At present, citizens are confronting situations about a local government plan due to the embezzlement of the budget that leads to sluggish performance, and the consequence ends up with an extended duration [60,61]. The implementation of an intelligent city using modern technologies would result in significant changes in the governance system of the city. The modification primarily accentuates some outcomes, which are outlined as (a) the transparency of the governance system needs to improve, (b) the enhanced accountability of the in-charge personnel is required, (c) corruption will be reduced, and (d) lastly, the execution time will be alleviated.

5.1.2. Impact on Transport

The primary modes of transportation in Dhaka are motorcycles, rickshaws, public buses, Lagunas, private cars, CNG, minibusses, and taxis. The number of personal vehicles is increasing daily, which is predicted using linear extrapolation that in 2025 and 2030, there will be around 213,268 and 272,107 cars, respectively. This extrapolation shows that the demand for private vehicles increased, which is a primary challenge for the city authorities, although during 2020–2021, it slightly decreased due to the COVID-19 situation.

Figure 9 demonstrates statistics of registered private cars in Dhaka based on the report [62]. Daily public transport such as buses, autos, and CNG shares 1,691,729 trips (70.22%) and private vehicles such as taxis and motorcycles share 310,658 visits (12.89%) except for walking and cycling modes [63]. Due to the traffic congestion in Dhaka, 2.9 percent of gross domestic production (GDP) is reduced, whereas 6 to 10 percent of GDP is lost in the country’s other cities [64]. Research on the respondents in five groups estimated that traffic congestion costs USD 1010.76 per year per commuter, whereas the per-capita income is around USD 1211.70 [65]. It loses revenue, resulting in significant challenges to living standards and leading to the development of smart cities.

A news report discloses that the average traffic speed in Dhaka is 6.4 km per hour (kph), which will be 4.7 kph by 2035 with current vehicle growth. It also claims that the strategic transport plan could improve the average traffic speed by about 13.7 kph [66]. The times required to travel from Uttara, Dhaka, to different places in the city between 7 am and 10 am are indicated by green bars. The yellow bars represent the estimated time required to complete the journey at the smart city transportation speed of 13.7 kph. Figure 10 compares travel times for the distance between Uttara and different places in Dhaka.

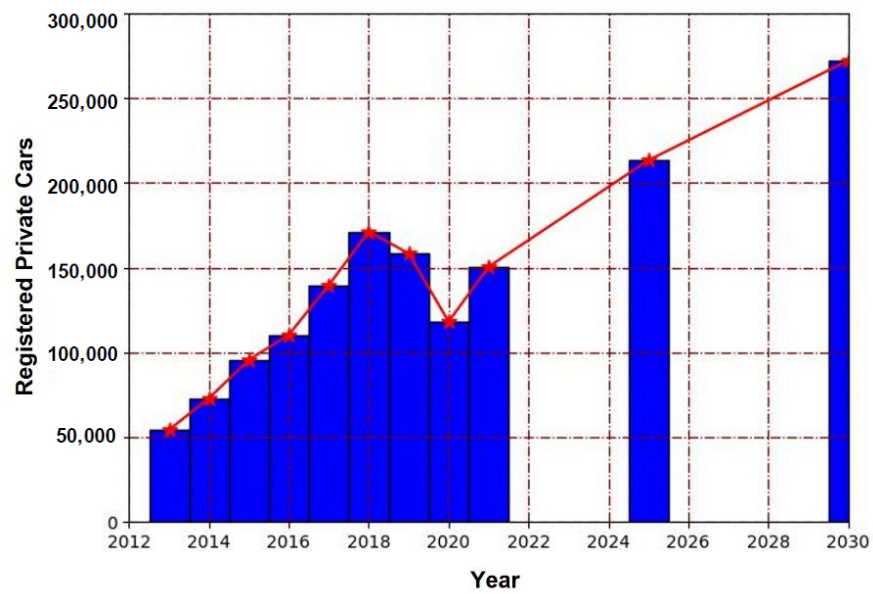


Figure 9. Statistics of registered private cars in Dhaka.

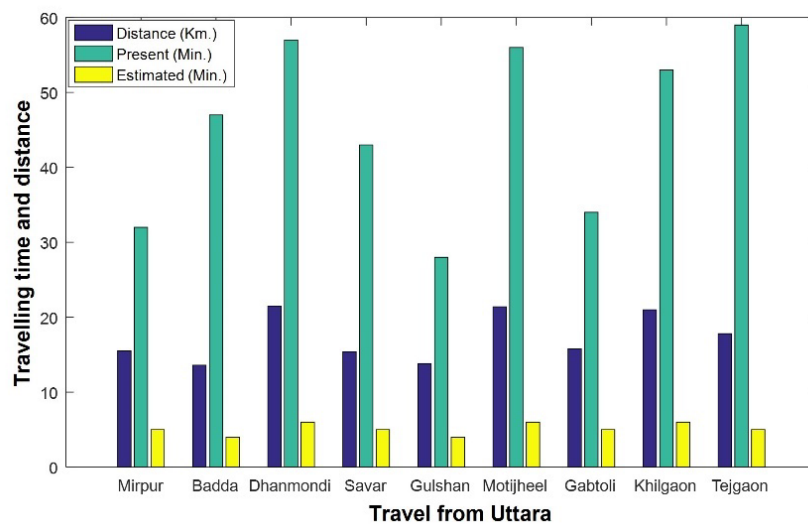


Figure 10. Comparison of traveling time for the distance between Uttara to different places in Dhaka.

5.1.3. Impact on Utility Management System

The utility management system of Dhaka consists of three managing sectors: water, gas, and electricity. “Dhaka Water Supply and Sewerage Authority (DWASA)” published the demand and supply of water in terms of million liters per day in an annual report for 2018–19 [67]. The data interpreted in the graph is the prediction by the linear regression method based on the data published in the annual report. An article claims the system loss of DWASA is 38.78 percent and describes how the transparency of the billing system could bring the system loss down [68]. A study forecasted that in 2050, more than 12.37 million people may be deprived of quality water supply in Dhaka if proper solution steps are not taken [69]. Figure 11 depicts predicted water demand with and without system loss in the upcoming years.

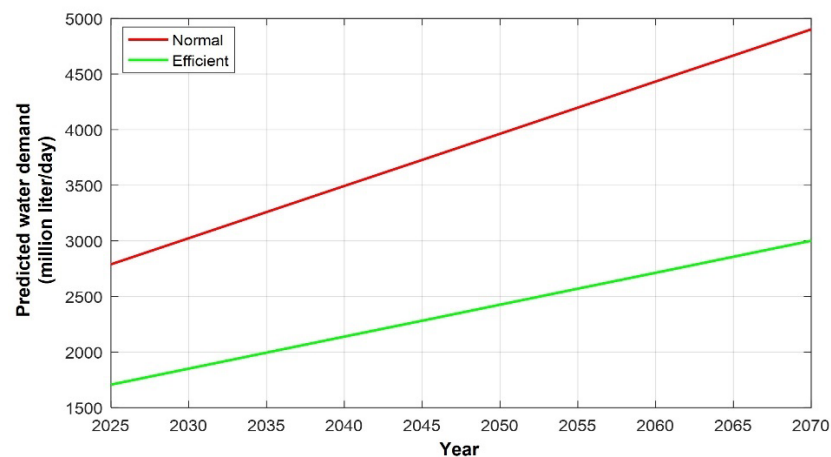


Figure 11. Predicted demand for water per day with and without system loss.

Another report explained that Titas Gas Transmission and Distribution Company Limited faced a system loss of 3 to 12 percent in 2019 due to the absence of meters [70]. It also claimed the transparency of the billing process is an issue. Dhaka Electric Supply Company Limited is one of the distribution companies that the dwellers of Dhaka consume electricity from for their daily needs. The annual report published in 2020 says the system loss of this company is now 6.23 percent [71].

Figure 12 shows the expected electricity demand for the upcoming years in Dhaka. In Dhaka, two power distribution companies, Dhaka Power Distribution Company Ltd. and Dhaka Electric Supply Company Limited, are continuing projects for the automated and underground distribution systems. In addition, renewable solar panel installation guidelines for all residential and commercial buildings in Dhaka have a tremendous environmental impact on reducing GHG emissions.

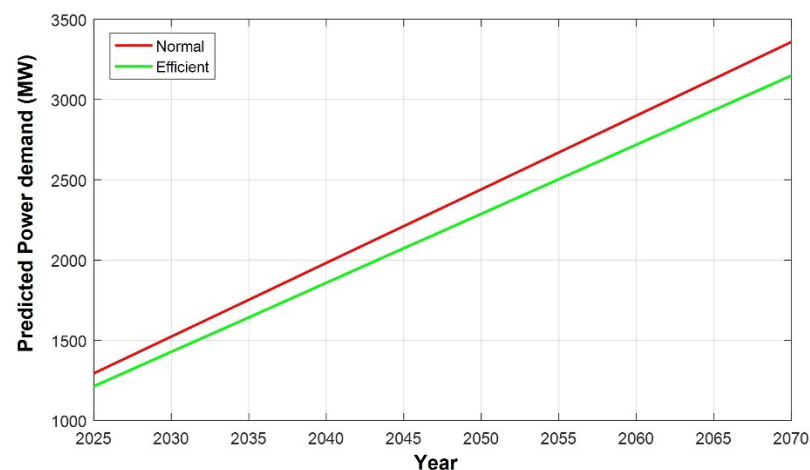


Figure 12. Predicted power demand of Dhaka with and without system loss.

5.2. Proposal for IoT-Based Smart City Management Technique

Transitioning from a conventional city to a smart city requires an efficient management plan to ensure the proper functioning of smart technologies and infrastructures. The management scheme must integrate infrastructure, data, and smart solution services to provide citizens with better facilities and services. The first step that city authorities must undertake is selecting sectors that require improvement. Subsequently, each industry must ensure effective data management practices, including data collection, processing, decision-making, and output services. Adequate government funding and technological infrastructure are essential for successfully implementing these tasks. However, during

the data processing phase, the security and privacy of data must be a priority. To illustrate the proposed smart city management technique for the developed smart city, a graphical representation is presented in Figure 13.

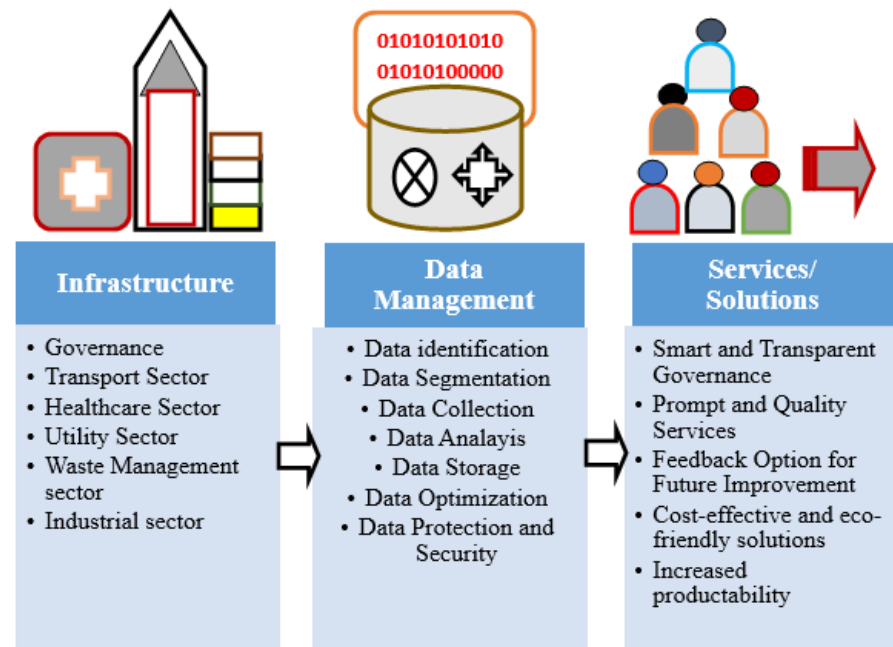


Figure 13. Proposed smart city management technique.

5.3. Policies for Sustainable Smart City Development in Dhaka

The low liveability index depicts Dhaka as more vulnerable due to the lack of facilities for fundamental rights, traffic conditions, pollution, criminal offenses, etc. Therefore, the government realized it needed to hire innovative solutions to achieve smart city facilities. This section describes the several challenges that must be overcome to make Dhaka a smart city.

- Decentralization of the administrative offices, industries, and education institutions: Dhaka, with a population density of 44,500 per square kilometer and a total population of 20.20 million, faces numerous challenges due to its rapid growth [72]. Over 80 percent of administrative offices, industries, and educational institutions are in Dhaka, making it even more vulnerable. The first step should be decentralization to reduce the population burden and transform it into a smart city. Decentralization has been shown to improve the overall efficiency of systems and promote sustainability, as indicated in several research papers [73]. Additionally, decentralization coupled with the use of ICT can make a city more livable by providing intelligent solutions for every need [74]. Therefore, Dhaka's authority needs to explore alternatives to replace the institutions at the district level and monitor all branch activities using innovative technologies;
- Transformation of the transport sector into a smart one: The rapid growth of population and private vehicles has resulted in traffic congestion and air pollution in Dhaka. Only 5% of the population uses personal cars, occupying 29% of the city's space, reducing working hours, and causing traffic jams [75]. Inadequate traffic control, policy oversight, corruption, and a lack of road safety add to the problem. Integrating renewable resources such as solar and biomass can help reduce air pollution, and electric vehicles can be a promising solution for reducing carbon emissions [76]. Stand-alone solar and hybrid solar-biogas-based charging stations can be established in different parts of the city to enable proper charging [77,78]. IoT-based smart devices and artificial intelligence can also be utilized to reduce traffic congestion cost-effectively [79].

- Online monitoring of traffic systems can help improve road safety and transform Dhaka into a sustainable and smart city;
- IoT incorporation in industries: Integrating IoT devices into the manufacturing, textile, and tourism industries can significantly enhance efficiency and contribute to economic growth [80]. Bangladesh's ready-made garment (RMG) industry has achieved global recognition, but monitoring activities, production, profits, human resources, and pollution is not regularly conducted. Proper control and management of waste disposal are also necessary to address environmental concerns [81]. However, many industries in Bangladesh continue to operate with conventional technologies, which decreases productivity and increases costs and time. Integrating innovative technologies may also lead to a temporary loss of production during implementation. Therefore, policy-makers must conduct a feasibility study and strategic analysis before implementing these technologies to ensure a smooth transition and maximize benefits;
 - IoT in waste management: In Dhaka, every day, 4200 tons of waste, i.e., municipal solid waste and healthcare industry waste, are generated, which leads to environmental pollution [82]. The waste-to-energy (WTE) project can be a good option for recovering energy and recycling it into new products. Research in South Africa said that the WTE project manages solid wastes and reduces environmental pollution [83]. IoT-based waste management promotes real-time monitoring of garbage levels, selecting waste transport routes, and segmenting waste, improving the quality of city life. Therefore, utilizing IoT-based smart waste management techniques can be an excellent way to make a liveable city;
 - IoT in environmental protection and monitoring: The rapid proliferation of population, urbanization, and the transportation sector are responsible for overall pollution in a city. The increasing pollution is raising the chance of health risks for the citizens. However, it must monitor the environment strictly to reduce health risks due to a polluted environment. Closely monitoring waste disposal and enforcing strict laws may help in controlling pollution. Therefore, collecting and analyzing data based on artificial intelligence will be a new research field and promote environmental sustainability [84];
 - Strengthening governance system: A robust governance system is a powerful tool for making a city smart. However, in Dhaka, corruption, illegal use of the law, increased criminal offense, unethical work, and substantial human interaction weaken the governance system [85]. Robust internet connectivity with available sensor networks can improve performance within a smart city. Therefore, infrastructure and trained professionals are necessary to maintain innovative integrated systems using investment from the government or city authorities.

5.4. Implications

The implications for research in smart city transformation are significant. Firstly, this study highlights the need for a multidisciplinary approach incorporating various factors, including governance, transportation, waste management, healthcare, and industrial automation, in predicting and implementing smart city transformation. SWOT analysis is performed from different intelligent city literature perspectives from several countries. Additionally, data privacy and security, complex architectural design, high capital requirements, technology adoption problems, and expert personnel for the management are considered significant challenges. In contrast, PESTEL analysis reveals the challenges of Dhaka's transformation.

Further research could delve deeper into each area's specific challenges and opportunities to identify effective solutions. Secondly, this study emphasizes the importance of citizen engagement in smart city transformation. Future research could investigate the most effective ways to involve citizens in planning and implementing smart city projects.

This study uses a fuzzy rule-based model for smart city prediction, which could be further developed and improved. A fuzzy-based prediction technique has been designed

to rank smart cities based on six input parameters. The method employs thirty “if-then” rules to obtain the smart city index in the MATLAB environment. Governance is the most crucial parameter among the six input factors, followed by “Transportation” and “Utility_Management”. The results show that poor governance can significantly affect the smart city index even if all other indicators are excellent. The smart city transformation framework comprises five phases: identification, planning, physical setup, development of smart infrastructure, and deployment of smart technologies in various sectors. The identification and planning phases require expert analysis, contemporary research, and observations from existing smart cities to develop policies and budget requirements. Good governance is necessary to maintain a budget and implement smart technologies successfully. Future research could explore using other data analytics techniques, such as machine learning and artificial intelligence, to improve the accuracy and efficiency of smart city prediction and decision-making. Fourthly, this study discusses the impact of modern technologies on smart city transformation, and future research could examine the social, economic, and environmental effects of these technologies in more detail.

Overall, this study provides valuable insights into the challenges and opportunities of smart city transformation and opens up several avenues for further research in this area.

6. Conclusions

Using smart technologies in urban areas can offer several advantages, such as enhanced governance, more efficient utility management, and increased productivity. Nonetheless, considerable hurdles must be addressed, such as data privacy/security concerns, technology integration, and a shortage of skilled personnel. To overcome these challenges, strategic analysis tools such as SWOT and PESTEL can be used to identify key obstacles and opportunities for innovation. The fuzzy rule viewer can then provide a clear view of the city’s current transformation and progress as a smart city. Solutions based on smart infrastructures, data management, and smart solutions/services can be proposed to address these challenges.

To transform Dhaka into a smart city, important factors include offering online services to citizens, implementing real-time monitoring for traffic and healthcare systems, digitizing education systems, and promoting a knowledge-based society. Investing in smart technologies and promoting smart utility management are also important. It is important to recognize that the challenges of smart city development can vary across different countries and regions and that the solutions proposed in this research may not be fully applicable in all contexts. It is also important to consider the physical infrastructure required for a smart city network and issues related to funding, time, data security/privacy, and network connectivity.

In future research, it may be useful to conduct feasibility analyses of IoT-based smart cities in specific contexts, considering socio-economic, technological, and environmental factors. This could help to identify the most effective strategies for smart city development in different regions and to address the challenges and opportunities specific to each context.

Overall, while this research provides valuable insights into the challenges and solutions for smart city development, many areas still require further research and exploration. By continuing to study and develop smart city technologies and strategies, we can work towards creating more efficient, sustainable, and livable urban environments for citizens worldwide.

Author Contributions: The author’s contributions are given as follows—Conceptualization, A.K.K.; Methodology, A.K.K.; Software, A.K.K. and S.M.R.I.; Validation, A.K.K. and M.A.H.; formal analysis, A.K.K., M.K., and M.M.U.R.; investigation, A.K.K. and S.M.R.I.; writing—original draft preparation, A.K.K.; writing—reviewing and editing, M.A.H., M.M.U.R., and M.O.F.; Resources, A.K.K., M.K., and S.M.R.I.; visualization, A.K.K. and M.A.H. All authors have read and agreed to the published version of the manuscript.

Funding: No funding received for this research.

Conflicts of Interest: The authors declare no conflict of interest regarding the publication of this manuscript.

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Article

Factors Affecting Car-Sharing Services

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Abstract: Car-sharing systems, i.e., short-term car rental services, are solutions indicated as an alternative to individual motorization; they can be used in an increasing number of cities around the world. These services, along with their intensive development, are becoming more and more complex. Due to their complexity, they involve not only an increasing number of stakeholders or infrastructure elements, but also indicate numerous links with the functioning of cities, especially smart cities. To properly implement or improve the car-sharing system, both in terms of operational issues regarding the system's functioning or changes in the vehicle fleet, it is important to be familiar with the elements that make up car-sharing, as well as the factors that affect it. This work aims to present the factors affecting car-sharing, as well as the transport model of car-sharing services. This work fills the research gap stemming from the lack of comprehensive studies and knowledge on car-sharing. A detailed analysis of the literature shows that there are six main groups of factors affecting car-sharing: economic and technical, transport, social, environmental, organizational, and other issues; among these factors, more than 150 quantitative and qualitative criteria can be distinguished. Furthermore, the work also showed factors that are a niche in the literature and can be the basis for further research on car-sharing. Detailed familiarity with these factors could translate into increased profitability and, above all, success in the functioning of on-the-market services. This article supports the implementation and improvement of car-sharing services. In addition, it supports scientists in the preparation of scientific papers and mathematical models in the field of car-sharing and the factors that affect it.

Keywords: car-sharing systems; car-sharing services; car-sharing functioning; car-sharing operation; shared mobility; mobility management; smart cities; smart cities development; new mobility; transportation engineering



Citation: Turoń, K. Factors Affecting Car-Sharing Services. *Smart Cities* **2023**, *6*, 1185–1201. <https://doi.org/10.3390/smartcities6020057>

Academic Editors:

Véronique Flambard,

Sadia Benamrouz-Vanneste and

Abir Karami

Received: 5 April 2023

Revised: 18 April 2023

Accepted: 19 April 2023

Published: 20 April 2023



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1. Introduction

In recent years, we have been dealing with the very intensive development of urban centers due to the migration of society. Current figures indicate that 55% of the world's population now lives in urban centers [1] and this proportion is expected to increase by at least 13% by 2050, adding approximately 2.5 billion people to urban centers [2]. Along with the shift in society, the growing interest in the universality of 5G networks [3], and the desire to make ever-more services available remotely [4], this will translate into a even greater propagation of smart cities. It is worth emphasizing, however, that the increased influx in communities, apart from many advantages that will translate into the development of urban centers, will require an efficient transport system. Proper mobility will be possible thanks to the use of new mobility services that will replace classic forms of transport. New mobility services will also be one of the leading elements in Smart City 4.0 [5] and Smart City 5.0 [6].

Car-sharing systems are one of the numerous solutions aimed at improving mobility in cities. The principle of its operation is the use of one vehicle by many renters for short-term trips. Although the first car-sharing systems date back to 1948 [7], the numerous recent developments in car-sharing services are related to the ongoing technological progress in

the field of digitization [8]. Statistics show that car-sharing systems are currently offered by 236 operators in 59 countries around the world [9]. It is forecast that revenues in the car-sharing segment will reach USD 12.88 billion in 2023 [10]. Furthermore, revenues are expected to show an annual growth rate (CAGR 2023–2027) of 5.64%, which translates into a projected market size of USD 16.04 billion by 2027 [10]. The intensive development of systems is also associated with the growing number of users of car-sharing services. This number is growing every year around the world, regardless of continent. An increase in interest in these services has been particularly visible since 2015 when the number of system users reached 5.8 million worldwide; this figure further increased to 36.02 million in 2017 [11].

Currently, among other forms of shared mobility, such as scooters or bicycles, car-sharing services are considered to be one of the most convenient and autonomous forms of new mobility solutions [12]. Despite this fact, among the car-sharing services available on both the European and global markets, one can observe the number of closures, takeovers of companies, or implementation of services on only a pilot basis. In such situations, various arguments are given, including that the system had an ill-matched business model [13], funds were not properly managed, the project turned out to be economically unprofitable [14], information found about the fleet of vehicles was improperly matched to the needs of users [15], customer expectations were not met [16], or that the scope of operation of the services was incorrectly defined [17]. Observing the reasons for the malfunctioning of the systems, it can be argued that car-sharing services are very complex and susceptible to numerous multi-criteria external factors. Many researchers emphasize that there is a real need for thorough research motives to participate in the processes of the shared economy and the criteria involved [18–21] because knowledge of the complexity of shared mobility is necessary to increase public awareness of shared mobility services [22–24]. Based on this assumption, a lot of scientific studies have been conducted in the field of factors affecting both the shared economy, shared mobility, and car-sharing. These studies include both theoretical and practical issues based on various types of field research, surveys, and research experiments. The results are very diverse in terms of, i.a., the type of factors, the level of their importance for various stakeholders, and the location area for which the case was considered. For example, Böcker and Meelen pointed out that motivations to participate in the sharing economy depend on the sociodemographic characteristics of the participants, the role of the participant as a user or supplier of goods, and the types of common goods [25]. A Deloitte study, in turn, showed that the key to the success of the sharing economy is lower costs, the possibility of using sustainable consumption, and the convenience of use [26]. In comparison, Smith showed that convenience in terms of reducing time and stress is a key advantage of shared mobility [27]. In the case of car-sharing, Szymkowiak and Żelichowska indicated savings (time, money), atmosphere (attitude to the brand, relationship with other users of the system), and expectations (user opinions, type of car affecting the comfort of travel) as key factors influencing the popularity of services [28]. However, Jie et al. indicated that gender is the most important factor in predicting whether a person will use short-term car rentals [29]. Furthermore, they emphasized that also employment status, annual income, attitude toward the benefits of shared mobility, the possibility of accessing shared mobility, and the reasons for shared mobility positively correlated with the possibility of using shared mobility [29]. In turn, Nicholas and Rajon Bernard, in analyzing car-sharing success factors, emphasize the importance of aspects such as parking policies [30]. They indicate that the parking policies for car-sharing must be at least equal to those for private cars [30]. As an incentive for electric vehicles, city parking can be given away as an in-kind contribution [30]. For less densely populated cities and rural areas, the city government will likely be required to provide financial support and aid in charger installation [30]. For comparison, Alzahrani et al. suggest that the most essential criteria for car-sharing consumers are insurance coverage, reliability, rental cost, drop-off options, and gas cost [31].

Despite the indication that many factors influence car-sharing, in numerous scientific works no study was found that would constitute a compendium of factors segregated depending on the subject area. To fill this research gap, this work is devoted to an interdisciplinary determination of factors affecting car-sharing systems. For this purpose, a comprehensive literature review was carried out. Creating a knowledge summary containing a full list of factors influencing car-sharing, along with references to individual literature items, will eliminate problems related to the multitude of factors indicated in individual research works or the lack of indication of a given factor which, for one given territory, may not be important yet may be important to another urban center. This study may be helpful to a large group of stakeholders, such as:

- Scientists (when looking for variables that could describe a given system during mathematical modeling of car-sharing, creating optimization models, or building surveys and indicating alternatives to the assessment for respondents);
- Practitioners–operators (when making analyses on how to manage a company or modernize business models);
- Municipal authorities (when assessing projects or analyzing public–private car-sharing partnerships);
- People unfamiliar with car-sharing who want to check what shared mobility entails.

The work has been divided into four sections. Section 1 presents the general scope of the article, while Section 2 is devoted to the adopted research methodology. In Section 3, the results of the analysis are indicated. Section 4 provides a summary, further research plans, and limitations.

2. Methodology

To develop a knowledge base on the factors affecting car-sharing services, it was decided to review the literature. The task of the selected research method was to define the research query, indicate keywords, define the database to which the search will be directed, indicate whether reviews of the literature fill the research gap of the query to which the article refers, determine what type of documents are in the database, specify inclusions and exclusions, conduct a detailed analysis, synthesize documents, and indicate the results [18].

Among the various available methods for literature analysis, we selected the method based on the current state of knowledge and the integrative method [32]. This complex type of literature review requires a systematic approach, is inclusive, and reduces bias without highlighting the importance of the particular topics under consideration [33,34]. In addition, the proposed method also differs from other types of classical reviews, such as the realistic review or the so-called realistic synthesis, which focus primarily on understanding the forces behind the success or effectiveness of the intervention, or the integrative method, which covers a wide range of perspectives on a given problem [35,36].

The proposed method considers all the factors influencing car-sharing specified in the given research works without indicating the factors of influence determining whether a given factor turned out to be crucial for a given area or not. It aimed to develop a compendium of factors without imposing on the recipient an aspect that, in the case of his research, could turn out to be less important than another. The indicated research method applies to topics related to urban aspects, such as smart cities and the forms of transport used in them, which is confirmed by the works of Yigitcanlar, et al., Butler et al., and Rana et al. [37–41]. The literature review was performed using the methodology of Booth et al. [42]. The analysis included the following steps [42]:

- (1) Indicating of the research objective of the literature review;
- (2) Conducting a full search, acquisition, and download of articles in the literature;
- (3) Extracting and evaluating items of the obtained literature;
- (4) Synthesizing and analyzing the obtained results in detail;
- (5) Presenting and sharing results and conclusions.

The first step in following the methodology was to define the research goal. Our goal was to define the factors affecting car-sharing. The scope of the study was defined through an extensive review of documents available on car-sharing in the publicly available scientific database Scopus. The Scopus database was indicated because it is a leading scientific database widely used for systematic literature reviews [43]. Boolean functions were used to search for individual volumes in the database. Such functions provide the possibility of a thorough logical analysis, ensuring the sense and truthfulness of the theorems sought during the literature reviews [44]. In the first stage, the term “car-sharing” was searched in the titles, abstracts, and keywords contained in the Scopus document database. The focus was on works written in English. The author’s name was excluded from the search to avoid citing their research. The detailed search formula was as follows (1):

$$GS = DOC_{TIT\ ABS\ KEY} = (car - sharing) AND !EX_{AN} = (TUROŃ) = 1701\ documents \quad (1)$$

where:

GS—general search,

DOC_{TIT ABS KEY}—documents including “car-sharing” phrase in the titles, abstracts, and keywords,

EX_{AN}—exclusion of the name of the author of this article.

Based on a general search, 1701 documents in the form of articles, monographs, books, and conference papers that contained the phrase “car-sharing” in their titles, abstracts, or keywords. The number of searches turned out to be very high because the term “car-sharing” is used both in many different meanings and in various scientific disciplines not necessarily related to transport. The results showed that the term car-sharing is presented by scientists in a very broad and multi-criteria way. Therefore, in the next step works were sought that would focus on the factors affecting car-sharing both at the stage of implementation and operation of services. The detailed search formula was as follows (2):

$$\begin{aligned} DS &= DOC_{TIT\ ABS\ KEY} \\ &= (factors) OR DOC_{TIT\ ABS\ KEY} (implementing) OR DOC_{TIT\ ABS\ KEY} \\ &= (operation) OR DOC_{TIT\ ABS\ KEY} = (functioning) AND DOC_{TIT\ ABS\ KEY} \\ &= (car - sharing) AND !EX_{AN} = (TUROŃ) = 136\ documents \end{aligned} \quad (2)$$

where:

DS—detailed search,

DOC_{TIT ABS KEY}—documents including the terms “factors”, “implementing”, “operation”, “functioning”, and “car-sharing” in titles, abstracts, and keywords.

A detailed search found 136 documents; more importantly, a more precise analysis of the obtained excerpts showed that, among the documents, there were works that referred to car-sharing in a very general way, for example, indicating it only in the form of a keyword of a given scientific work. Therefore, it was decided to perform a third, even more, precise and limited search, according to the Formula (3):

$$\begin{aligned} PS &= DOC_{TIT\ ABS\ KEY} = (factors) OR DOC_{TIT\ ABS\ KEY} \\ &= (functioning) OR DOC_{TIT\ ABS\ KEY} (implementing) OR DOC_{TIT\ ABS\ KEY} \\ &= (operation) OR DOC_{TIT\ ABS\ KEY} = (functioning) AND DOC_{TIT\ ABS\ KEY} \\ &= (car - sharing) AND !EX_{AN} = (TUROŃ) = 41\ documents \end{aligned} \quad (3)$$

where:

PS—precise search.

3. Car-Sharing Factors—Results and Discussion

As a result of the literature review in the form of precise searches, 41 documents were obtained. Among the 41 analyzed documents, a total of 151 individual criteria affecting car-sharing were identified at the stages of implementation and operation. The specified factors were both quantitative and qualitative variables. Due to the multitude of factors, a synthesis was completed; the factors were then divided depending on the thematic areas to which they belonged. Six thematic areas were identified:

- Economic and technical issues;
- Transport issues;
- Social issues;
- Environmental issues;
- Organizational issues;
- Other issues.

Each of the identified thematic areas is described in detail in Section 3.

3.1. Economic and Technical Factors

The first of the thematic areas are aspects related to financial matters. This area is very complex. Interestingly, it includes not only costs related to the operation of the car-sharing service itself and the related operating costs, such as the costs of the service, additional services or packages [45–52], but also the accompanying car-sharing services offered on the market by competitors [53–58]. Detailed factors related to the functioning of the car-sharing system are presented in Table 1.

Table 1. Costs of car-sharing.

Detailed Factors	Variable Type	Investigation Method	Reference
	Quantitative		
The cost of the car-sharing service per kilometer	X	Literature review; survey	[45–47]
The cost of the car-sharing service per minute	X	Survey	[45,46]
Stop-over cost	X	Survey, case study	[45,46]
Daily tariff	X	Case study	[48]
Night tariff	X	Case study	[48]
The cost of registering in the system	X	Case study	[48]
Deposit amount	X	Case study	[48]
The cost of the car-sharing service package	X	Case study	[49]
Financial bonuses for using car-sharing	X	Case study	[50]
Additional costs, i.e., the possibility to go outside the zone	X	Case study	[45,46,49]
The cost of violations (e.g., improper use, parking)—fines	X	Case study	[50,51]

The analysis conducted indicates that the costs of other forms of transportation available in the city, ranging from public transport to new mobility services, are also significant factors that influence car-sharing [32–35]. Detailed factors are connected to the costs of other means of transport in Table 2.

Table 2. Costs of using other means of transport.

Detailed Factors	Variable Type	Investigation Method	Reference
	Quantitative		
The cost of renting a vehicle in a classic rental company	X	Case study	[55,56]
TAXI service cost	X	Case study	[57]
Amount of discount on urban collective transport	X	Empirical study	[56]
The cost of a ticket in urban collective transport	X	Empirical study	[47]
The cost of the bike-sharing service	X	Case study	[58]
The cost of the scooter-sharing service	X	Case study	[58]

It is worth mentioning that the literature also indicates several costs related to the maintenance and use of personal vehicles as factors affecting car-sharing. Detailed factors for maintaining an individual vehicle are presented in Table 3.

Table 3. Costs of maintaining an individual vehicle.

Detailed Factors	Variable Type	Investigation Method	Reference
	Quantitative		
Vehicle service cost	X	Trip data	[52]
Vehicle insurance cost	X	Trip data	[31,53]
The cost of 1 L of fuel	X	Survey, Trip data	[31,52,53]
Car loan/leasing installments	X	Trip data	[52–54]
The cost of additional services (e.g., vehicle washing, tire change, etc.)	X	Survey, literature review	[52–54]

An additional important group of factors are the aspects related to the costs of public transport available in the place where car-sharing operates or is to operate. Detailed factors are presented in Table 4.

Table 4. Costs of using the urban transport system for users of individual vehicles.

Detailed Factors	Variable Type	Investigation Method	Reference
	Quantitative		
Environmental fee for entering the city	X	Survey	[59]
Public parking cost	X	Trip data	[51]
The cost of private parking	X	Trip data	[51]

Analyzing in detail the literature on the indicated economic costs of car-sharing, it is worth emphasizing that no factors were found that would be directly related to the operating costs of car-sharing operations resulting from business models, which seem to be important issues for the correct and, above all, profitable operation of the enterprise.

3.2. Transport Factors

Another thematic group of the analyzed factors are issues related to factors related to the implementation of the transport service. The group of such factors is quite extensive. Among the analyzed literature, factors related to the car fleet used in car-sharing services found include defining issues related to the size of the vehicle, its engine performance and safety, and environmental issues [15,37]. Fleet considerations are presented in Table 5.

Table 5. Factors related to car-sharing fleet.

Detailed Factors	Variable Type		Investigation Method	Variable Type
	Qualitative	Quantitative		
Car class	X		Survey	[15]
Car size	X		Survey, Case study	[60]
Boot capacity		X	Survey	[15]
Convenience of use		X	Survey	[27]
Engine performance		X	Case study	[60,61]
Energy/fuel consumption		X	Trip data, Survey	[27,62]
Vehicle cost		X	Survey	[15]
Vehicle safety level		X	Survey	[62]
Vehicle warranty		X	Survey	[62]

The second thematic group in the field of transport is aspects related to shared transport. It includes factors related to the presence of other forms of shared mobility, such as short-term bicycle, car, or scooter rentals in the city, as well as factors directly related to the operator's service, e.g., the availability and attractiveness of the vehicle, distance to the nearest vehicle, car relocation issues, or accessibility of the system or type of system from the point of view of the business model. Detailed factors related to shared mobility are presented in Table 6.

Table 6. Factors related to shared transport.

Detailed Factors	Variable Type		Investigation Method	Variable Type
	Qualitative	Quantitative		
Availability of the bike-sharing service	X		Survey	[59]
Availability of an already existing car-sharing service	X		Literature review	[49,62]
Availability of the scooter-sharing service	X		Survey	[58]
Availability of the kick-scooter-sharing service	X		Survey	[58]
Availability of car-sharing parking spaces	X		Survey	[47,62]
Vehicle location		X	Trip data	[49,62,63]
Actual vehicle availability	X		Case study	[49,63]
Vehicle fuel/charge level		X	Trip data	[43,44]
fleet attractiveness	X		Survey	[63]
Distance to the nearest vehicle		X	Trip data, case study	[49,63]
Number of operator-owned charging points		X	Case study	[43]
Number of vehicles available		X	Case study	[62]
The possibility of leaving the vehicle in another city	X		Case study	[63]
System area limitations	X		Case study	[62]
Availability of dedicated operator parking spaces	X		Case study, survey	[30,54]
Number of dedicated operator parking spaces		X	Case study, survey	[30,54]
Range of the car-sharing operator (local/global)	X		Literature review	[62]
Vehicle fleet diversity (vehicle classes)	X		Survey	[15,49]

Table 6. *Cont.*

Detailed Factors	Variable Type		Investigation Method	Variable Type
	Qualitative	Qualitative		
Possibility of self-refueling of the vehicle by the user	X		Survey	[49]
Relocation of vehicles in the city	X		Case study	[43,62]
Minimum age required to use the system		X	Case study	[14]
System type	X		Case study, literature review	[43,49,63]

Factors related to transport infrastructure constitute a separate subgroup. They are presented in Table 7. Interestingly, in its scope the literature defines only issues such as bus lanes, parking spaces dedicated to electric vehicles, or park and ride car parks. To the best of the authors' knowledge, no issues related to the total number of parking spaces or places dedicated to car-sharing (and not only car-sharing based on electric vehicles) were found.

Table 7. Factors related to infrastructure.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Number of bus lanes		X	Trip data	[64]
Number of parking spaces dedicated to electric vehicles		X	Trip data	[65]
Number of park and ride car parks		X	Trip data	[66]

Moreover, no reference was made to the number and availability of public electric vehicle charging stations or mobility hubs dedicated to car-sharing.

Another sub-group within transport issues is issues related to the organization of transport in a given area. These aspects concern both traffic engineering and transport management in the city, e.g., traffic volume, speed limits, the availability of public charging stations and their capacity, or the presence of intelligent transport systems. A detailed summary is presented in Table 8.

Table 8. Factors related to organizational issues.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Traffic		X	Trip data	[67]
Speed limit zone		X	Trip data	[67]
Restricted vehicle entry zones	X		Case study	[47]
Privileges for urban collective transport	X		Case study	[47]
Information integration about all means of public transport	X		Case study	[68]
Operating costs of collective transport		X	Case study	[68]
Spatial and functional integration with other means of public transport	X		Case study	[69]
Convenience of transfers	X		Trip data	[70]
Mass transit travel speed		X	Trip data	[70]
Availability of information (e.g., timetables)	X		Trip data	[70]
Level of public transport driving safety	X		Case study	[69]

Table 8. Cont.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Level of personal safety of public transport passengers	X		Case study	[69]
Waiting time at stops for a public transport vehicle		X	Case study	[69]
The convenience of the ticketing system (ease of purchase, variety of the ticket offer, ticket validity with different carriers, etc.)	X		Case study	[47]
Privileges for electric/hybrid vehicles	X		Case study	[71]
Number of electric vehicle charging stations		X	Case study	[71]
Electric vehicle charging time using a public charging station		X	Case study	[71]
The presence of parking spaces dedicated to electric vehicles	X		Case study	[71]
Number of TAXI service operators		X	Trip data, case study	[57]
Presence of the ITS system	X		Case study	[64]

A separate group within the thematic area of transport is factors directly related to urban collective transport occurring in the area where the car-sharing system is or would be operating. A detailed summary is presented in Table 9.

Table 9. Factors related to urban collective transport.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Accessibility of urban collective transport	X		Case study	[47]
Punctuality of urban public transport	X		Case study	[69]
Diversity of urban collective transport	X		Case study	[68]
Level of comfort of urban collective transport	X		Case study	[68]
Condition of urban collective transport rolling stock	X		Case study	[68]
Travel time by public transport		X	Case study	[68]
Time loss/delays in urban collective transport		X	Case study	[47]
Service for socially diverse groups of residents	X		Case study	[69–71]
Frequency of transport means (number of daily trips)	X		Case study	[72]
Number of operators servicing urban collective transport		X	Case study	[69]
Direct connections (no transfers)	X		Case study	[68]
Percentage chance of securing a seat		X	Case study	[69,73]
Operating range of the municipal public transport operator (local/global)	X		Case study	[69]
The failure rate of vehicles used in public transport		X	Case study	[47]
Number and length of routes		X	Trip data	[69]

3.3. Social Factors

The third of the thematic areas is factors covering social issues. These include detailed information on users or potential users of car-sharing systems, such as their age, education, or earnings. Interestingly, among the factors, there are also aspects referring to the experience of using shared mobility services and the general approach to sustainable and

ecological forms of transport. It seems that the range of factors is wide and related to both personal and professional issues, as well as TO the approach to transport. Detailed factors are presented in Table 10.

Table 10. Social factors related to current or potential car-sharing users.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Sex	X		Survey	[49,59,74]
License to drive motor vehicles	X		Survey	[14,74]
Domicile	X		Survey	[49,59,74,75]
Home-work distance	X		Survey	[75]
Education	X		Survey	[50]
Social status	X		Survey	[76,77]
earnings		X	Survey	[14,75,76]
Possessed electronic equipment, e.g., a smartphone with the Internet	X		Survey	[14,75]
Number of owned vehicles		X	Survey	[77]
Number of kilometers driven by car per year/month		X	Survey	[77]
Number of kilometers driven by car per day in the city		X	Survey	[14,75,77]
City travel time		X	Survey	[14,75]
Accessibility to a family vehicle	X		Survey	[14,75]
Technological advancement	X		Survey	[14,75,77]
Using car-pooling services such as Uber	X		Survey	[64]
Pro-ecological attitude of users	X		Survey	[67,78]
Passion for a particular brand of vehicles	X		Survey	[74]
Perception of the vehicle as a luxury good	X		Survey	[74]
Willingness to test drive a given vehicle	X		Survey	[74]
Sharing economy experience	X		Survey	[75]
Brand perception	X		Survey	[28]
Opinions of other customers about the brand	X		Survey	[28]

3.4. Environmental Factors

The fourth of the thematic groups is aspects related to environmental issues. In this group, there are factors directly related to the characteristics of individual cities and the occurrence of certain levels of pollution or noise in their area. The presence of policies or restrictions directly related to the issue of sustainable development was also indicated. Among the indicated factors, for example, the factor defining urban plans in the field of development of pro-ecological solutions was missing, as was a detailed definition of good and bad practices characteristic of a given urban center. A detailed list of factors is shown in Table 11.

Table 11. Factors related to city features.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Ecological restrictions in cities, e.g., eco-zones	X		Case study, Survey	[75]
The noise level in the city		X	Case study	[79]
Pollution level in the city		X	Case study	[80]
The policy of sustainable transport development in the city	X		Case study	[67,78]
Ecological restrictions in cities, e.g., eco-zones	X		Case study	[67]

A separate group of factors is issues related to the environmental performance of the vehicle fleet. It defines both the number of vehicles with alternative drives and their emissions. A detailed summary is presented in Table 12.

Table 12. Factors related to environmental issues associated with the car-sharing fleet.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Number of electric cars	X		Case study	[67,78]
Number of hybrid cars	X		Case study	[81]
Number of EURO6 cars	X		Case study	[81]
CO ₂ emission level of car-sharing vehicles	X		Case study	[82]

3.5. Organizational Factors

The fifth group of factors is aspects related to the organizational issues of the functioning of car-sharing systems. These include, for example, the method of registration in the system implemented by the operator, the approach to customer service, or the accessibility of the system application offered. A detailed summary is presented in Table 13.

Table 13. Organizational factors of car-sharing functioning.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Accessibility of the IT system for the user	X		Case study	[49,63,83]
Contacting customer service	X		Case study	[68]
Location of customer service offices	X		Case study	[62,68]
Method of data verification during registration	X		Survey	[44]
Accessibility of the system for people from abroad	X		Survey	[58,68]
Operators liability for damage to the vehicle	X		Case study	[68]
The users responsibility for damage to the vehicle	X		Case study	[68]
How to book a vehicle	X		Case study	[43]
How to open the vehicle	X		Case study	[68]
Additional vehicle equipment, e.g., a child seat	X		Case study	[68]

3.6. Other Factors

The sixth group consists of other factors that influence car-sharing. These are factors over which neither operators nor users have influence. These issues include weather and atmospheric changes, as well as weather forecasts and predicted rainfall or temperature

changes that affect consumers' attitudes to using car-sharing services. A detailed list is shown in Table 14.

Table 14. Factors related to weather conditions.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Season	X		Empirical study	[49]
Temperature		X	Empirical study	[49]
Rainfall		X	Empirical study	[49]
Weather changes	X		Empirical study	[49]
Weather forecasts	X		Empirical study	[49]
Season	X		Empirical study	[49]

In addition to the weather, other factors over which neither users nor operators have influence are issues related to the type and time of day. A detailed summary is presented in Table 15.

Table 15. Factors related to days of using the systems.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
The time of the day		X	Survey, case study	[49,74]
Working days	X		Survey, case study	[49,74]
Weekends	X		Survey, case study	[49,74]
Holidays	X		Survey, case study	[49,74]

The last group of factors that are not influenced by users or operators are factors directly related to the type of city or its history, administrative issues, or the number of inhabitants. A detailed summary is presented in Table 16.

Table 16. Factors related to the demographic and social structure of the city.

Detailed Factors	Variable Type		Investigation Method	Reference
	Qualitative	Qualitative		
Cty area	X		Survey	[58]
city type (administrative)	X		Survey	[83]
The number of residents		X	Survey	[58]
Tourist attractiveness	X		Survey	[58]
Number of inhabitants in given transport zones		X	Case study	[83]
Monuments in different locations	X		Survey	[58]
Location of strategic places, e.g., railway stations	X		Case study	[83]
Distance of the main city from other cities		X	Case study	[49,63]
City type (historical/modern)	X		Case study	[49,63]

4. Conclusions

To sum up, this work made it possible to achieve the goal of developing a comprehensive list of factors affecting car-sharing services. In its scope, six main thematic groups of areas with which the factors are related, i.e., economic, transport, environmental, social,

organizational, and other issues, have been defined. Among the indicated thematic groups, over 150 criteria have been identified that have an impact on car-sharing services. These factors have been cataloged and presented with references to the literature. The largest group of factors is issues related to transport. That list is a collection of information that can be used both by scientists when preparing research in the field of car-sharing or building identification or optimization models. It also supports operators in carrying out analyses on the implementation or functionality of their current services.

Although many factors have been identified in the literature, it seems that the list is not exhaustive. Among the indicated aspects, several important aspects were excluded. The first is the lack of factors related to the financial operational issues of car-sharing services. These factors seem to be very important, especially from the point of view of the need to determine the profitability of the project. Another aspect not discussed in the literature is the lack of references to the transport infrastructure directly dedicated to car-sharing of any type, rather than just electric vehicles. The literature does not mention mobility hubs or public parking spaces for car-sharing. Such initiatives are becoming increasingly common solutions in the era of implementing sustainable transportation schemes. In the literature on the factors affecting car-sharing, little is said about business models. Although the type of system is an important factor, there is no information related to the individual elements that make up the business model, e.g., relations with the environment, revenue streams, etc. From a legislative point of view, there is also no indication of the rights or restrictions imposed on car-sharing services. Factors related to cooperation with, for example, urban centers, which seems to be crucial, especially in the implementation of public–private car-sharing, have not been noted either. The indicated aspects may become a guideline for further research exploration when performing analyses on car-sharing services because they constitute the current research gaps.

Like any research paper, this study also has limitations. The main limitation is the focus on researching the literature only within the scope of the Scopus database. This database, despite being the most valued in the academic community, may not contain all works on factors affecting car-sharing. The limitations introduced by the research method may not cover all studies presenting factors influencing car-sharing. Moreover, it should be emphasized that there may be works where the authors mentioned factors affecting car-sharing using different nomenclature; in these cases, the publication could not be included in the searches.

In future scientific works, the authors plan to analyze the importance of individual factors for various groups of stakeholders to indicate the leading trends and maps on the impact of individual criteria. Moreover, the authors also plan to analyze the factors affecting car-sharing based on other literature search methods, as well as bibliometric databases alternative to the Scopus database, such as Web of Science. This type of study will allow comparisons regarding the repeatability of criteria, as well as determine the selection of the appropriate research methods for literature analysis in the field of shared mobility.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the author.

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

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Article

Generating Natural Cities Using 3D Road Network to Explore Living Structure: A Case Study in Hong Kong

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Abstract: Compared with administrative cities, natural cities can be generally referred to as the areas generated based on the density of different urban facilities (e.g., point of interest, road network, etc.). To some extent, natural cities are outperformed in some related urban studies, such as urban living structure analysis. Nevertheless, traditional ways of generating natural cities are mostly limited to the planar space. Modern cities such as Hong Kong are vertical cities with high buildings, 3D road networks and land uses. Therefore, traditional nature cities could be biased when applied to 3D cities. In this work, a 3D road network in Hong Kong is adopted to extract true road intersections and generate modified natural cities to explore urban living structures. Numerous living structure units are classified into two parts: tiny and serried ones representing natural cities and vast ones representing rural areas. The classification method applies head/tail breaks, and a clustering algorithm was fitted for heavy-tailed distribution. According to the living structure theory, the living structures of the proposed natural cities and traditional natural cities based on the same road network in Hong Kong are compared. The findings show that the distribution of modified natural city regions is more reasonable compared with typical ones. The improved model will more clearly show the inherent living structure of the city and will allow an analysis of the relationship between the part and wholeness of the city.

Keywords: natural cities; living structure; head/tail breaks; complex system



Citation: Xiao, Z.; Peng, Z.; Yu, Z.; Liu, X. Generating Natural Cities Using 3D Road Network to Explore Living Structure: A Case Study in Hong Kong. *Smart Cities* **2023**, *6*, 1485–1506. <https://doi.org/10.3390/smartcities6030070>

Academic Editors: Véronique Flambard, Sadia Benamrouz-Vanneste and Abir Karami

Received: 10 April 2023

Revised: 19 May 2023

Accepted: 22 May 2023

Published: 24 May 2023



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1. Introduction

Over millennia, whether in the birthplace of civilisation or in the new world after the period of geographical discovery, humans have tacitly built different styles of settlements on the earth's surface along the storyline of 'settlement—town—city'; however, the structure of human settlements is a dissipative system that requires an external input of energy to maintain it [1,2]. Urban structures are becoming more complex as human civilization and socioeconomic class grows more finely split. There are three classic models, the concentric zone model [3], the sector model [4] and the multiple nuclei model [5]; these models have been used to study the morphology of urban structure since the early days of the modern city, and their complexity has increased over time as they have been proposed. With the development of socioeconomic activities and building technology, cities have expanded both horizontally to the earth's surface and in a vertical dimension [6]. Exploring urban structure from a 3D perspective helps urban planners or citizens who live in a metropolis understand the ongoing change in city morphology [7].

Natural cities, from a topological perspective, are core areas in a large geographic space; previous empirical methods explored urban structures from a Euclidean geometry perspective [8]. A whole city is seen as a group containing small units at a proposed scale; the size of the small units depends on how precisely the scale needs to be observed. As scales move towards the microscale, a small unit will be divided into more tiny units.

All units are divided into different levels by head/tail breaks [9]. Head/tail breaks are a classification method for data conforming to a heavy-tailed distribution, and areas of units generated from road networks meet this restriction [10]. The term “natural city” refers to a naturally occurring distribution of active human activity in a city that is produced from the bottom up and is not predetermined by legislation [11]. Its boundaries are fluid and vary as human activity concentrations shift in response to societal trends.

Because space, roads, and blocks all exhibit the scaling feature, these hierarchical load-bearing items may be employed to highlight the city’s inherent distinctions [12]. Due to the rules of physics not enabling humans to pass through solid structures or geographical obstacles and the fact that private flying aircrafts for teleportation are not yet prevalent, most human movement now follows lines of communication to their destinations. Ground transportation is a highly prevalent mode of transportation, and regardless of the kind of transportation employed, roads are the framework that allows us to travel conveniently and swiftly [13]. When a city’s road network is employed as a research vehicle, the city can be split into a huge number of living structure units formed by the road network. Unit regions are discovered to have a heavy-tailed distribution rather than a normal distribution. That is, there are far more small units than large ones in terms of unit area. The units may be separated into two parts based on the mean value of all of their areas, with a small number of large ones above the mean value in the head and a large percentage of tiny ones below the mean value in the tail (for more detail, please refer to [14]). A smaller unit’s placement suggests that the road network in its neighbourhood is denser and can support more people in terms of infrastructure and that the unit is more accessible in the greater urban road network than bigger units, allowing for more planned routes through the unit [15]. The small units in the tail are categorized as natural cities, while the large units in the head are classified as rural regions [16]. According to empirical research that uses New Economic Geography (NEG) models, the uneven distribution of economic activity in different sections of the city may be related to agglomeration economies, which are connected by accessibility [17,18], and spatial circumstances can benefit local firms through co-location [19].

In the above-mentioned classical natural city generation process, the road networks and units are generated in 2D space. The city area and rural region are defined by the density of the road network intersections as urban infrastructure, with the denser area identified as the city area. During data processing, the names, capacities, speed limits, and other properties of the streets are ignored in order to remove human influence, and they are considered only as sides of the undirected graph. This means that the intersections of all roads are considered road intersections in the 2D space, while some of the 3D roads that may not intersect with each other are neglected. It could bring bias to the generation of natural cities.

The remainder of the work is organised as follows. Section 2 compares previous researchers’ distributions and elucidates the relationship between their opinions and this work. Section 3 introduces the methodologies of head/tail breaks, natural city generation, and level distinguishment. Section 4 introduces the study area and datasets. Section 5 reports a comparison between classic representation and modified representation. Section 6 further discusses the implications of 3D structures in the city taken into consideration and points to future work. Finally, Section 7 draws a conclusion.

2. Literature Review

Researchers have used several models to explore the distribution of human activity in cities, most of which begin with the displacement and direction of human movement trajectories [20]. For example, Silm and Ahas [21] studied human activity spaces in terms of form and cause, and Schönfelder and Axhausen [22] measured the extent of activity spaces by quantifying the probability of each agent reaching a certain area. There are other studies that use human-generated data to mine human behavioural patterns, such as Gao et al.’s study of smartphone data to investigate the spatiotemporal aspects of

behaviours [23]. Yu et al. proposed a data-driven analytical framework to locate city areas with different functional characteristics in tourists' travel reviews [24]. Because cities are hubs of human activity, this data might indirectly reveal which places are city hotspots. The concept of living structures proposed by Jiang [25] treats urban spaces as a whole and analyses the distribution of human activities intuitively from a fractal perspective. Contrary to the assembly of a mainframe computer, where the function of each part is known in advance, and the parts are combined in a clever way using spatial relationships to form a computer that can light up, cities can be seen as an organic wholeness built up by many successive small changes, with the property of growth in the accumulation of the temporal dimension [26]. Buildings, towns, and cities may all have living structures, displaying self-similar fractal qualities and scaling hierarchy, a typical aspect of complex systems. These living structures also interact with one another. When structures at the same level are treated as nodes, the connections between them do not have a path between every two nodes, as in a strongly connected graph, but instead, follow the degree distribution in a scale-free network. Their degree distribution follows a heavy-tailed distribution rather than a specific mean indication [14,27].

In Alexander's and Jiang's work [14,28], urban structures are delineated at different levels, which suggests that there are far more small objects than large ones [8] and indicates living structures in cities. The smaller ones represent the hotspots of the city and carry most of the urban functions. Small objects and the city can be viewed as a hierarchy in terms of spatial relationships, assuming that the city can be viewed as a wholeness and that within the city, it can be subdivided into levels based on the functions it carries, such as the composition of the transportation network, and the history of the city's development; this is similar to how the grain of a leaf of different thicknesses located on the leaf blade distributes in the leaf flesh tissue for transport and support [29]. The borders utilized to identify the primary level of the hierarchy are like thick leaf veins that sustain the city's basic framework. The greater the level of hierarchy, the greater the presence of little living structures.

Previous studies on 3D urban spatial structures have been based on remote sensing data. By adopting high-resolution remote sensing data, Huang and Wang explored the effect of 3D urban spatial morphology on land surface temperature in different urban functional zones at a fine scale [30]. Chen et al. exploited the nighttime light intensity of the earth's surface to identify locations and borders of urban centres [31]. Wu et al. delineated 3D building characteristics from high-resolution light detection and ranging data, then extracted and differentiated local building patterns [32]. Yang et al. used the Mobile laser scanning (MLS) technique to extract and delineate 3D roads composed of many road cross-sections to obtain complete, correct, and high-quality roads [33].

Some studies on 3D road networks have considered the interaction between urban road networks and citizens. Sun et al. studied Hong Kong's three-dimensional pedestrian network, dividing the roads into multi-height levels, and found that pedestrians needed to travel much longer distances in the three-dimensional urban structure than in the road network and required more time to reach their final destinations when using footbridges or underpass facilities [34]. Chen et al. blended digital surface models (DSM), OpenStreetMap, and FABDEM to extract a large-scale 3D urban analysis that considered the verticality of the urban road networks; the model can be used as a tool to estimate time and fuel consumption through traffic congestion [35]. The study by Yeh et al. helped vehicles distinguish which level they are currently in when drivers travel to a multi-layered road network using the angle difference method [36].

The literature review revealed multiple research gaps: (1) The classic natural cities generation method was limited to a two-dimension earth surface; it did not take into account the complex 3D situation of a metropolis area and did not respond to the trend of human activities expanding toward the vertical dimension. (2) The studies focusing on 3D urban spatial structure were based on the city model restored from the building level. They did not use roads as materials for analysis. (3) Some studies did not regard the city as a

complex system and did not consider the relationship between the small units of the city to have a hierarchy.

This work aims to consider 3D road networks in the process of natural city generation. The improved model will show more clearly the inherent spatial architecture of the city and will be more in line with human spatial perception, helping people to understand the morphology of the city.

3. Methodology

An analytical framework is proposed in our study to interpret natural cities composed of three-dimensional living structures. As shown in Figure 1, the proposed framework includes three important parts: (1) extracting road intersections from 3D road networks; (2) creating a TIN (Triangle Irregular Network) based on 3D road intersections, and (3) using head/tail breaks to classify polygons in a TIN.

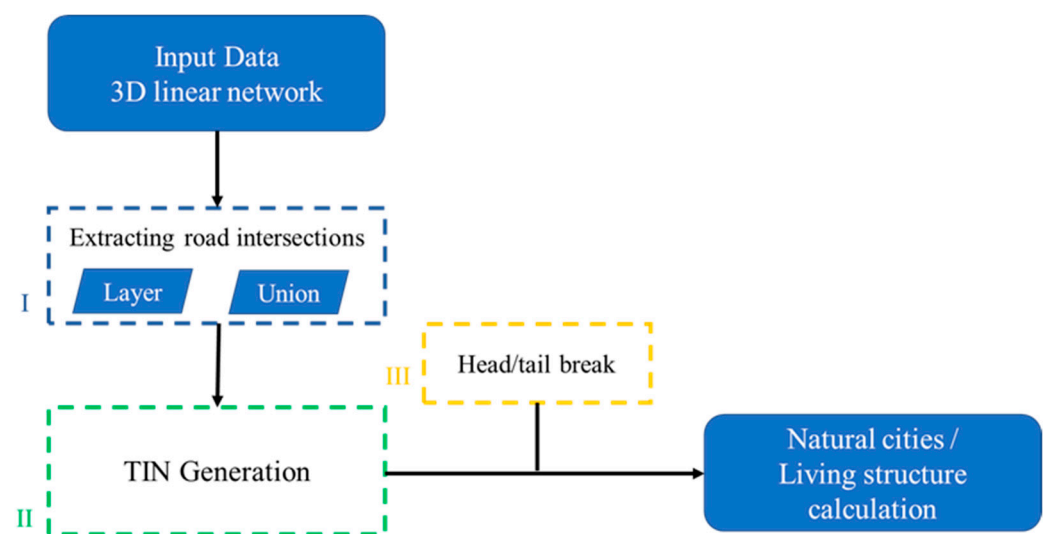


Figure 1. The framework to interpret natural cities composed of three-dimensional living structures.

3.1. Extracting Road Intersections

Road intersections serve as the basis for the formation of natural cities; the greater their density, the greater the accessibility of the region to inhabitants, which can be used as an indicator of whether the area is suitable for urban function. As a result, detecting road intersections from road data is the initial stage in data processing. The classic model extracts road intersections by projecting the geographic data of the road network onto a plane, then locating the line segments whose topology intersects and using their intersection points as road network intersections. This strategy is simple to grasp, and the operation is ideal for popularizing the concept of natural cities.

This work adds to the step of layer identification for matching relationships that exist in cities where roads have intersections in the two-dimensional plane but are skew lines in the vertical dimension. A sample of 3D road networks at different levels (heights) is illustrated in Figure 2, whose three-dimensional road layout is highly distinct. Without considering 3D roads, there will be 19 intersections (No. 1–19, both dark and light nodes). In this work, the 3D information of roads is collected and considered; thus, the 9 intersections (No. 11–19, dark nodes) will not exist anymore.



Figure 2. The illustration of roads in different layers.

Nevertheless, the dark intersections in Figure 2 exist only in two-dimensional coordinates, and there is no possibility of switching road access at this location for vehicles on a cascading elevated road or for walkers in the shade of an elevated road. Light intersections are nodes that have physical access and connect roads of different levels. This work uses the Layer field in OpenStreetMap to find roads that cross or overlap in topological relationships, avoiding roads of different levels from generating road intersections. The pseudocode for the functional implementation is as follows:

```

read OSM data
for id first_road to last_road do
  #Obtain intersection of selected road and other roads
  intersection = road.intersection(otherRoads[this.layer])
  if _is_endpoint = True
    get intersection.coordinates
end

```

Due to the formation of OSM data, the road features are made of numerous short line segments; it is necessary to eliminate the influence of vertices between line segments. We dissolved the same named roads when they had a common endnote without creating multipart features. To find the intersection of a road and other roads, the other roads are dissolved into a whole in each operation in the loop to reduce computation time. Otherwise, the number of roads in the city is so large that computing one by one according to the named roads would take a lot of computation resources and computation time.

Furthermore, by restricting the calculation to a specific level of roads, this phase does not generate non-existent intersections.

3.2. TIN Generation Using Road Intersections

A triangulated irregular network (TIN) is a network that contains a number of small triangles and is composed of only small triangles [37]. In areas where nodes are dense, this also means that the surface of this area is complex, and triangles of relatively small size are generated, as shown in Figure 3. The triangle is larger in areas where the ground situation is simple. The TIN, based on the road intersection, is an important technical node for moving the object of study from the point to the surface and a convenient tool for discovering living structures in the city.

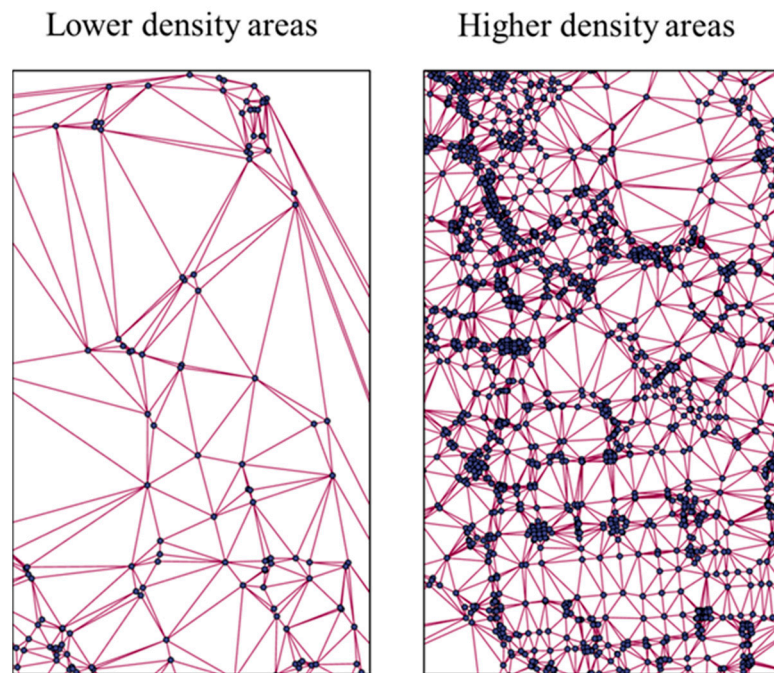


Figure 3. Density differences in TIN based on the road intersection by area.

The Delaunay triangulation procedure is employed in this work to build TINs, with each triangle represented in code by the number of its three vertices, which are ordered in counter-clockwise order. Each edge is generated by the coordinates of its own two vertices, stored in LineString format. The flowchart for this step is as follows (Figure 4):

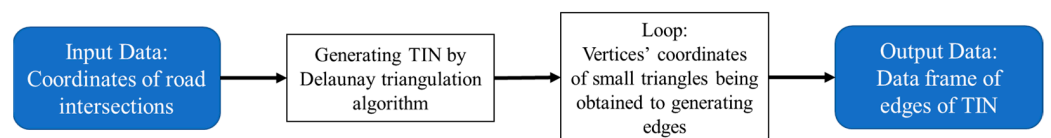


Figure 4. The flowchart of obtaining edges of TIN.

3.3. Head/Tail Break Classification of Polygons in TIN

The edges mentioned in Section 3.2 are objects of the head/tail break classification. It should be noted that although these edges are also linear objects, they are not road segments in the city but rather edges of TINs generated by road intersections, as shown in Figure 5a.

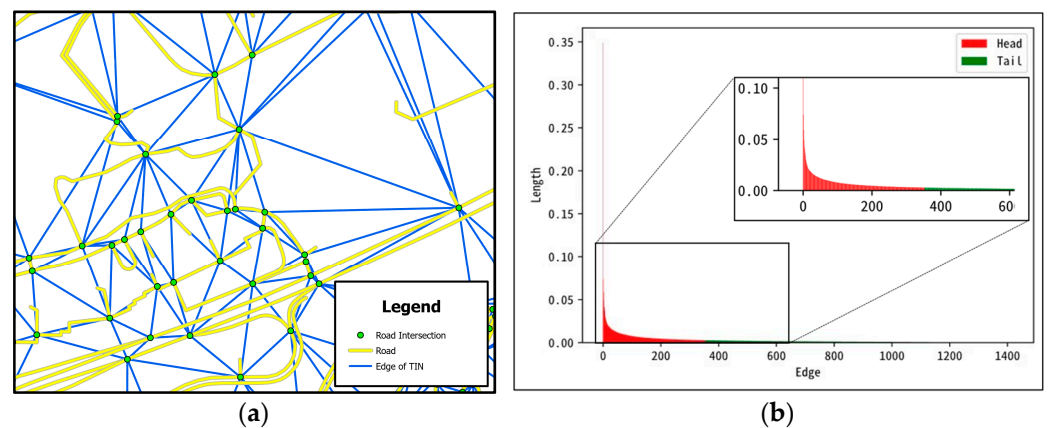


Figure 5. The illustrations of roads and edges of TIN (a) and head/tail break (b).

Figure 5b shows that the lengths of the edges in a city are arranged in order from long to short, which conforms to the long tail distribution, and there are a large number of short-length edges [14]. The arithmetic mean of the entire sample is used as the dividing line between the head and tail parts in this work. Edges with lengths less than or equal to the arithmetic mean are considered the tail part, whereas edges with lengths larger than the arithmetic mean are considered the head part. It is worth mentioning that this technique can be employed not only in data from the entire sample but can also continue to separate new head and tail parts in the head or tail part after the initial repetition. These new areas can be considered the true centre of the city or the true countryside. Polygons surrounded by short edges can be generated by passing the edges from the tail part into the shapely package's `polygonize()` method. In TIN, each polygon is made up of many triangles; therefore, these polygons contain all of the road crossings that are enclosed by shorter edges. The area surrounded by these polygons is the area of the city where the road network is relatively dense, accessibility is good, and it is suitable for gathering human activities, that is, natural cities.

3.4. Living Structure Calculation

In a previous study, Jiang and Rijke [38] proposed a quantifying approach for calculating the beauty of an image. Its operation method is to convert images containing objects into binary images, find connected domains composed of only dark pixels or light pixels in binary images, and apply numbers of monochrome pixels that make up each connected domain to head/tail breaks. Since then, the whole image can be regarded as a collection of connected domains with different areas of hierarchy. The structural beauty degree of this picture is the hierarchy level multiplied by the number of connected domains. This work refers to this thinking and combines it with natural cities, applied to measure the complexity of living structures with multi-level characteristics. This is a subset of the beauty degree mentioned above. This is also an application to understand spatial heterogeneity. The road network can be divided into different groups according to the layer. The ground layer is the earliest and most basic road facility in an area. The farther the vertical position from the ground road is, the higher the level of the hierarchy is. The presence of high-level roads gives this natural city a more complex structure, and its weight in the calculation will be greater from a recursive perspective. Thus, the degree of living structure complexity (L) can be formally defined by

$$L = \sum_{i=0}^n (H_i + 1) \cdot S_i \quad (1)$$

where S is the number of living structure units, H is the absolute maximum value of the number of layers located in a natural city, and i is the layer.

4. Study Area and Datasets

4.1. Study Area

Kowloon is the selected research area in this article, the area within the red box in Figure 6a. It is one of the three traditional geographical designations of the Hong Kong Special Administrative Region (SAR), the other two being Hong Kong Island and the New Territories. Kowloon is located in the geographical centre of Hong Kong, surrounded by sea on three sides, separated from Hong Kong Island by Victoria Harbour. The geographical nature of Kowloon makes it a relatively independent geographical unit, and this will not change as a result of the reorganisation of the administrative divisions. The area within the red boxed line in Figure 6 contains five partition administrative zones. Although the administrative division does not provide a visual depiction of where the more urban services are carried out in the area, its boundaries can be used as a reference to delineate the study area. The road network distribution map of Hong Kong (Figure 6b) also shows visually that the Kowloon area is relatively dense and has a clear geographical distance from other areas with a dense road network and that the road network in its area forms a relatively independent whole.

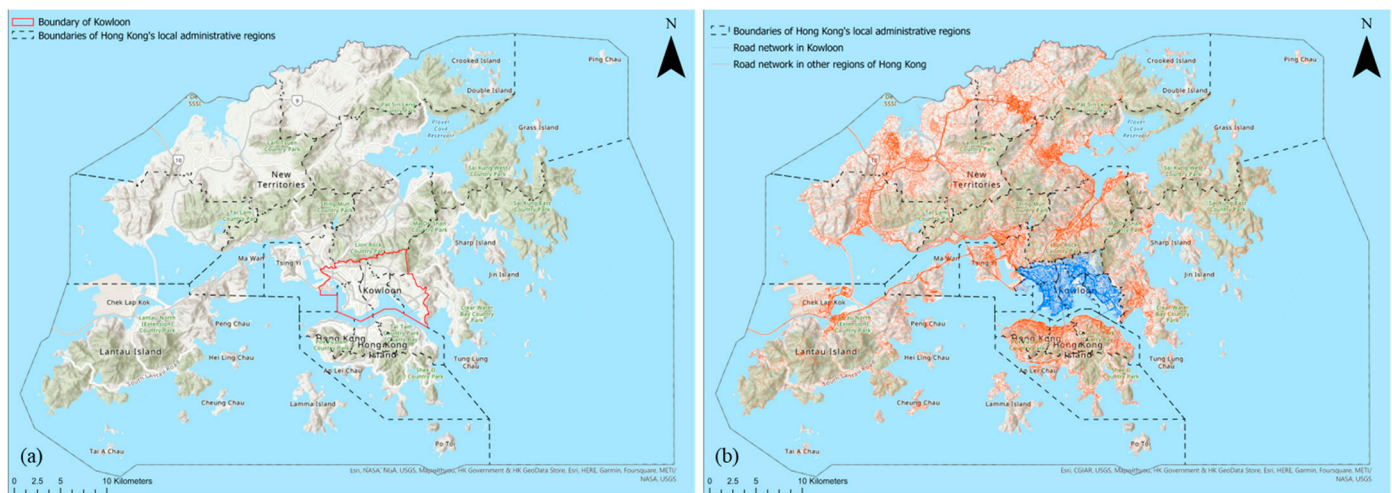


Figure 6. (a) Location of Kowloon in Hong Kong; (b) Distribution of the street network in Hong Kong.

4.2. Datasets

For this study, the road networks in Hong Kong are collected from road shapefiles in OpenStreetMap (OSM). OSM contains buildings, land use, natural places, places of worship, points of interest, railways, roads, traffic, transport, water, and waterways related data; in this work, we only use the data of roads. Road data contains information on the functional class, max speed, layer, and whether it is a one-way road, bridge or tunnel. The road networks in this work contain all the OpenStreetMap road categories, which are not filtered according to their capabilities. The Layer field is key for this work. The boundary data used to determine the study area is from the Hong Kong GeoData Store (<https://geodata.gov.hk/gs/>, accessed on 10 May 2023), a geospatial information service provided by the Hong Kong Special Administrative Region (HKSAR) Government to the general public.

5. Results

In this section, the distribution of modified natural cities and their key spatial patterns are described. Then, the largest natural cities in terms of area will be presented. Finally, the dissimilarities between the natural cities generated by the improved model and those generated by the classical model are described.

5.1. Finding about Study Area

Besides Kowloon being a relatively independent geographic unit, another reason for choosing Kowloon as the study area is the result of the classical natural city generation method based on the whole of Hong Kong. As shown in Figure 7, the Kowloon area contains several of the largest polygons in descending order of area. This result is also very interesting because it has long been believed that Hong Kong Island is the most developed metropolitan area in Hong Kong. It is vital to emphasize that this is an iteration in thought, not data, as previously mentioned because the full set of data has changed.

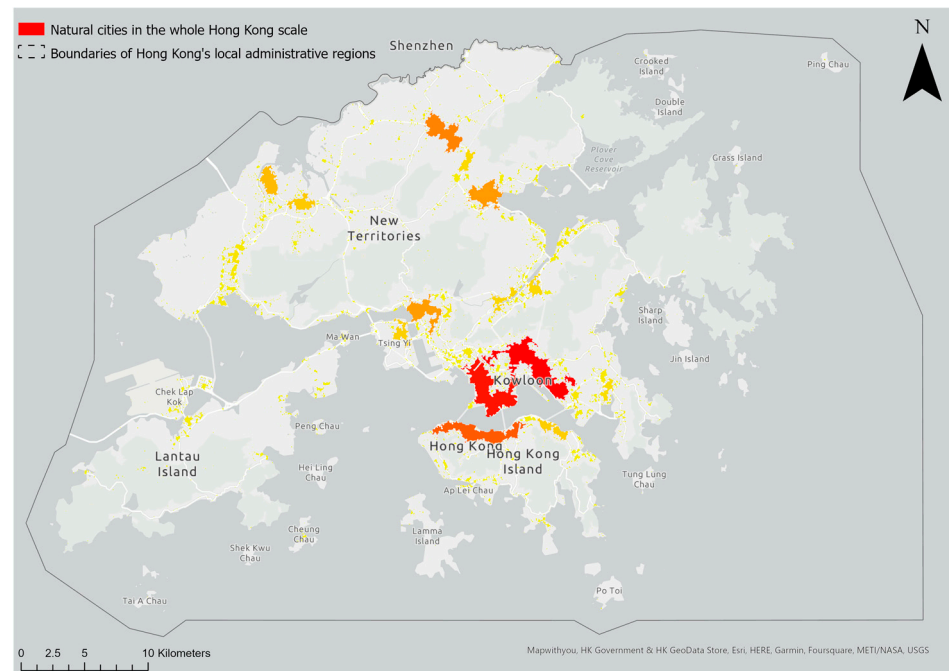


Figure 7. Distribution of classic natural cities in Hong Kong. The colour temperature of the image on the right moves towards cooler tones according to the decreasing size of the natural cities.

5.2. Distribution and Key Spatial Patterns

In the classic model, there are 76,991 road intersections in Kowloon. If a pilot with great eyesight flew over the entire Kowloon area, he would observe how many crossroads there are. The number of road intersections is 62,577 when the modified model recognizes that the roads are at different levels and only considers real-world intersections, a drop of 18.72% from the initial result. If the TIN edges generated by the new model are ordered from long to short, they still follow the long-tail distribution, as shown in Figure 8.

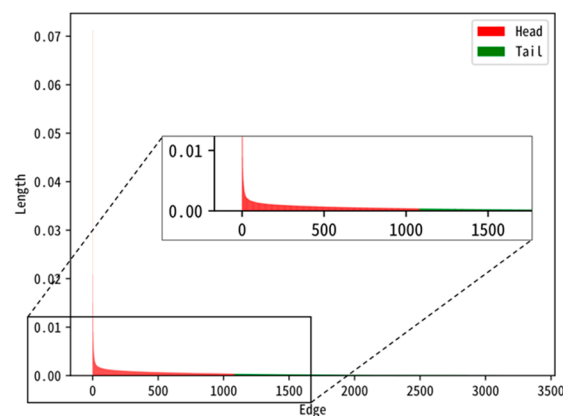


Figure 8. The illustration of TIN edges following a long-tailed distribution.

This work is not an inquiry into whether the area of a natural city conforms to a power-law distribution but to what extent it does. Therefore, this work goes further and uses the least squares fitting method to examine whether the area values of natural cities are consistent with power-law distribution. The least squares fitting method is a mathematical optimisation technique that minimises the total fitting error by minimising the sum of squares of the errors to find the best functional match for the data [39]. Compared to other research that uses the maximum likelihood method to fit the regression function [40], the least squares fitting method is optimal in fitting the sample data, while the maximum likelihood method maximizes the probability that the fitted function fits the sample data [41]. As shown in Figure 9a, the area of the natural city generated by the modified model conforms to the power-law distribution, with a coefficient of determination R^2 very close to 1. The modified model does not violate the a priori conclusion that the distribution of units connected by urban road networks is a scale-free phenomenon. The charts for the probability density function, as shown in Figure 9b, and the cumulative distribution function, as shown in Figure 9c, also confirm the existence of power-law distributions in natural cities.

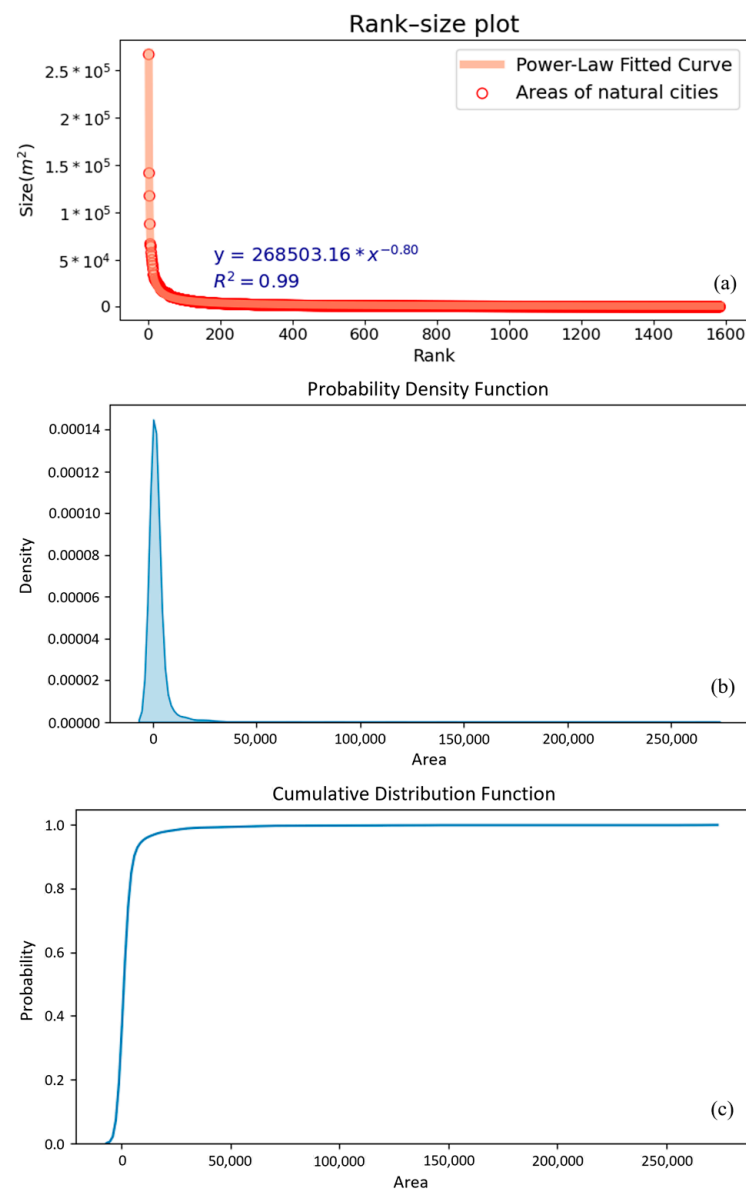


Figure 9. (a) Rank-size plot of areas descending order along the x -axis; (b) Probability density function of areas in ascending order; and (c) Cumulative distribution function of areas in ascending order.

5.3. Typical Area of Natural Cities

There are four large modified natural cities generated after applying layer attributes of road data and head/tail break classification in the algorithm, as shown in Figure 10. Tones move in ascending order of area towards warmer tones in the figure. They are located in Wong Tai Sin, Kwun Tong, Whampoa, and Tsim Sha Tsui, respectively.

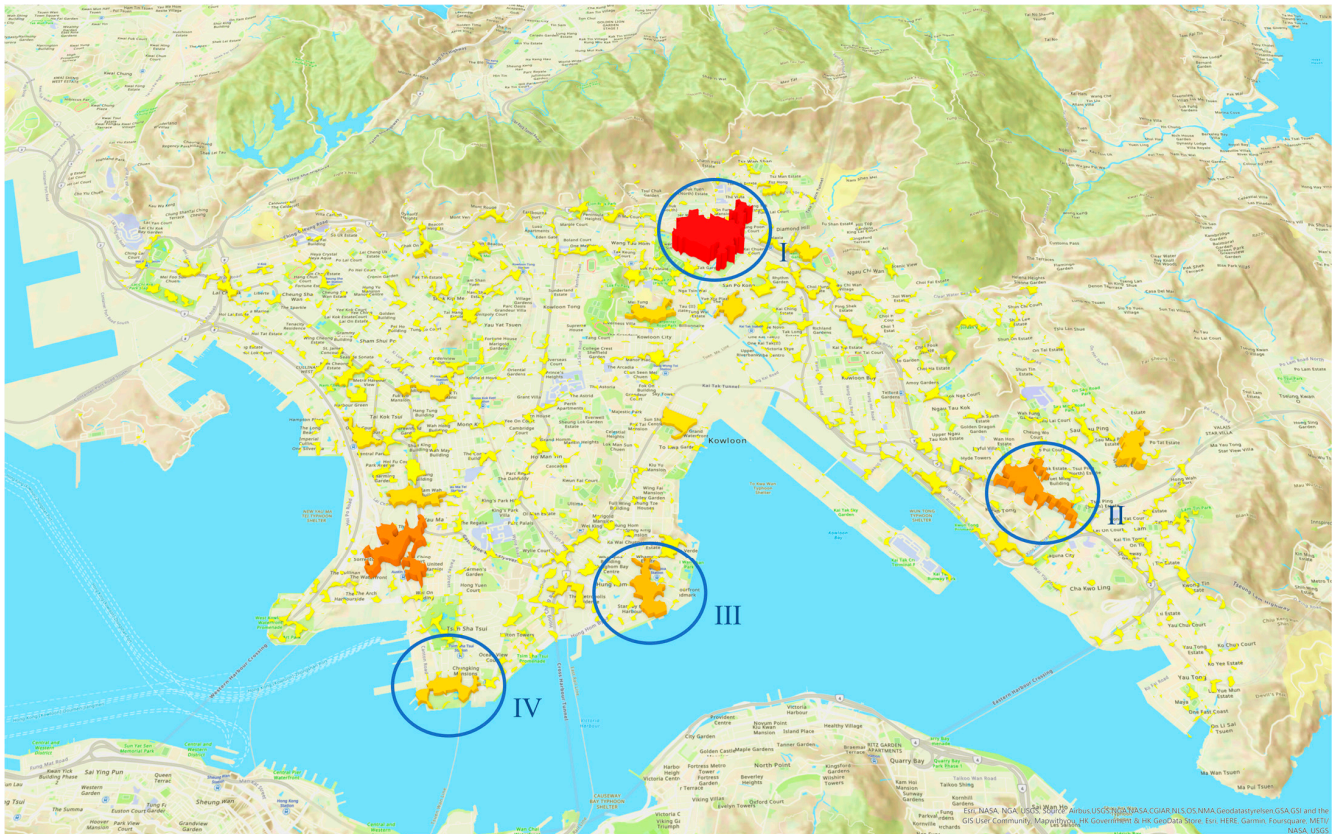


Figure 10. Modified natural cities map of Kowloon: I. Wong Tai Sin, II. Kwun Tong, III. Whampoa, IV. Tsim Sha Tsui.

One of Hong Kong's most prominent temples, as well as numerous high-rise buildings and houses, can be found in the Wong Tai Sin district, which combines the hustle and bustle of the city with the tranquility of religion. The government has also constructed a huge number of public housing estates in the region; thus, there are many people there, as well as numerous supporting commercial facilities and activities organized by the residents themselves. Many of the roads in the region are narrow, and their capacity is not equivalent to that of main roads, but they are abundant and very handy for inhabitants to travel on foot or for private cars to drive and stop.

During the industrial boom years, a dense network of highways was created to accommodate the large volume of traffic, as well as a large number of public housing estates and residential structures to offer houses for industrial workers in the Kwun Tong region. Following the transformation of Hong Kong's economic system, demand for industrial output fell, and the use of landmark buildings began to shift to tertiary supporting roles such as offices and shopping malls, so the population number did not decrease as a result of the loss of industry. Despite the great density of roads in the Kwun Tong area, there are insufficient capabilities, and traffic congestion is widespread today.

Whampoa is the name of a Kowloon common district, not an administrative district. The Whampoa region was once the site of the same-named dockyard, and after the dockyard closed, residential and commercial facilities began to be erected on the site. Whampoa's flat

geography permitted an orthogonal road layout based on Euclidean geometry. The natural city site does not encompass the entirety of Whampoa, but it does include a significant residential community and a public recreational space by Victoria Harbour.

The name Tsim Sha Tsui is derived from the sharp-shaped sandbar at the eastern edge of the Pearl River Delta. Tsim Sha Tsui was the first transport centre in Kowloon after the advent of rail travel in 1910, with one main road and a cluster of lower-level roads running through the region. The area is home to a variety of high-end shopping establishments that draw a steady stream of tourists, as well as numerous high-end hotels. Because of its extensive history, the district is also home to many of Hong Kong’s museums and cultural exhibitions.

All four of the larger regions are certainly hotspots in Kowloon, and the model’s results are quite close to reality. Each of these four regions has a well-developed, convenient, and easily accessible road network, as shown in Table 1, and there is sufficient popularity to use these road networks, as shown in Figure 11. Moreover, rather than simply having a number of passers-by crossing these zones via the road network, the nodes of human activity are also within four regions. The structural beauties of the four regions can be explored further based on the method employed to construct the living structures, and there are quite a few sub-structures among them, both in terms of topology and community function.

Table 1. Quantities and lengths of roads in four large natural cities regions.

Region	Area (m ²)	Amount of Road Segments	Total Lengths of Roads (m)
Wong Tai Sin	266,710	740	24,444
Kwun Tong	117,209	539	14,421
Tsim Sha Tsui	64,986	294	8709
Whampoa	87,477	322	9216

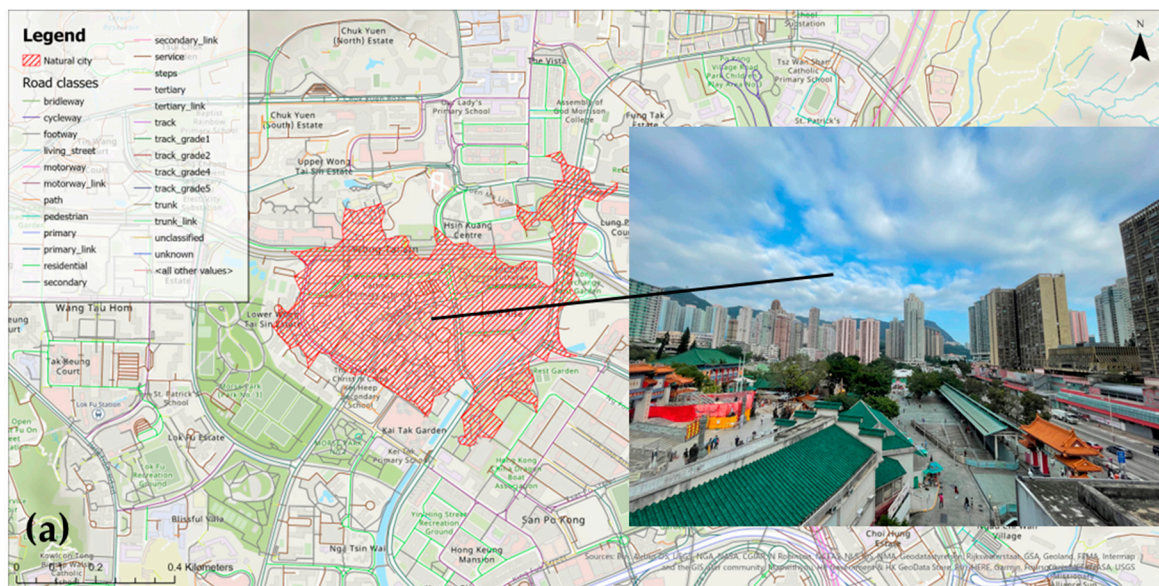


Figure 11. Cont.

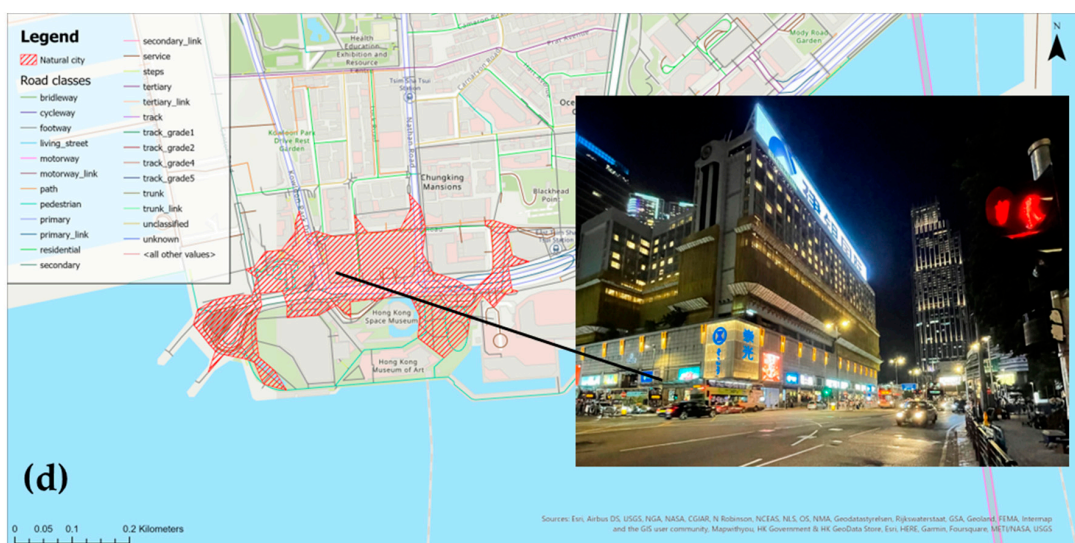
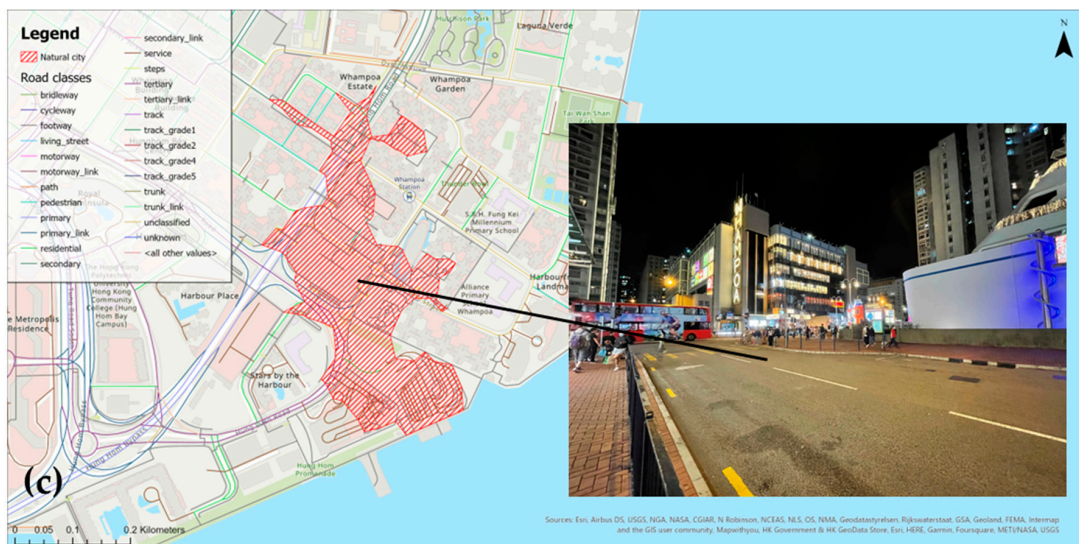
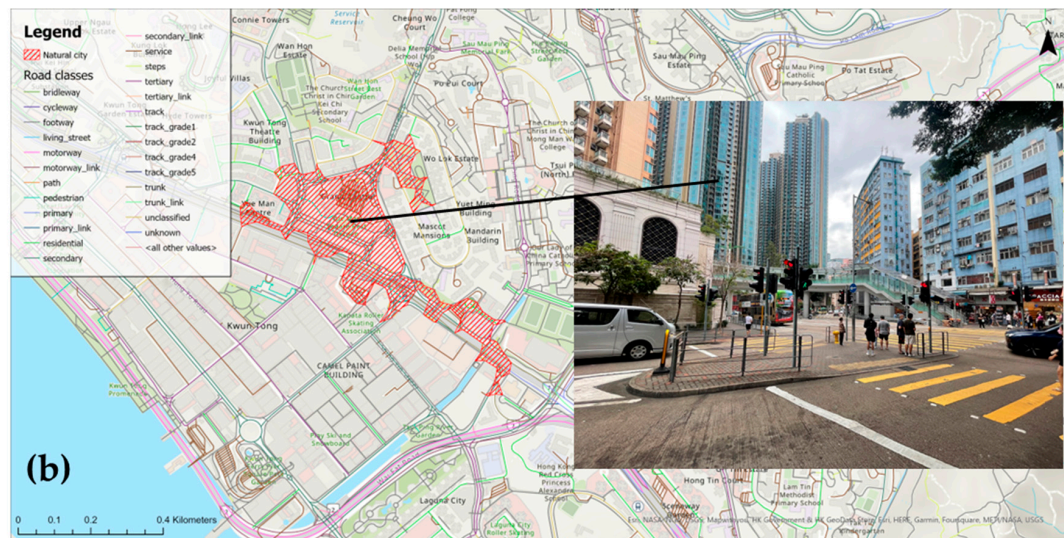


Figure 11. Natural cities distribution and street images of the four regions: (a) Wong Tai Sin; (b) Kwun Tong; (c) Whampoa; (d) Tsim Sha Tsui.

5.4. Comparison between Two Models

The natural cities in Kowloon generated by the classic model and the modified model are shown in Figure 12, with the blue-filled units being classic natural cities and the red-slashed units being modified natural cities. It is clear that the distribution of natural cities is dispersed throughout the Kowloon area rather than concentrated in a single site or linearly along a single traffic route. Because the modified model considers the additional step of road level distinctions when compared to the classical model, the natural urban distribution presented will unavoidably be inconsistent, as shown in Figure 12a. By comparing the two models (Table 2), the new model has reduced the number of road intersections, which is due to the elimination of the bias generated by the classic model at the intersection of roads belonging to different layers. Due to the removal of non-existent road intersections, the edges become longer during the generation of the TIN; the area of the small triangles in the TIN is, therefore, larger than that of the ones in the classical model. Then, the average of small triangles also increases; this means that the threshold separating the head and tail parts is shifted to the right. A remarkable result is that in the area comparison of the 10 largest natural cities, the area of the natural cities from the new model is larger, as shown in Figure 12b. More units were included in the scope of natural cities, and the total area of natural cities also rose. The practical significance is that the original undiscovered areas carrying human activities have been excavated.

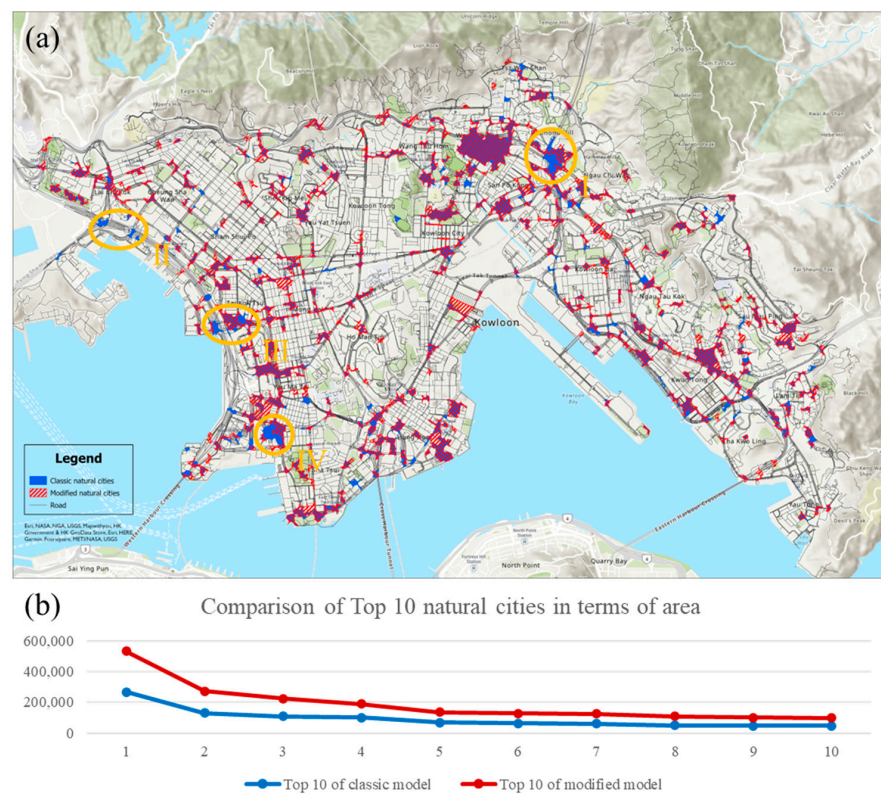


Figure 12. Dissimilarities of natural cities distribution between modified model and classic model (a); and comparison of 10 largest natural cities (b).

Table 2. Statistical data between two models.

	Amount of Road Junctions	Amount of Natural Cities	Area of Natural Cities (m ²)
Classic model	76,991	1391	3,657,366
Modified model	62,577	1585	3,808,369
Comparison	-18.72%	13.95%	4.13%

In Kowloon, we chose four of the more diverse regions to investigate these phenomena. They are Ha Yuen Leng, Lai Chi Kok, Tai Kok Tsui, and Austin, respectively.

An overpass is located in Ha Yuen Leng, a place that belongs to natural cities in the classical model but not in the modified model. Paths of varying orientations converge here but are impassable at the closest spatial distances and subsequently spread out in various directions. There is also a civic park here, with several interior routes for tourists to explore the scenery on foot. Although these trails are easily accessible from the outside world, they are not connected topologically because the park is separated from the outside world by a barrier. This cause reduces the connectivity of the road network in this region; hence, it is deducted from natural cities in the modified model (Table 3).

Table 3. A comparison of the two models in Ha Yuen Leng.

Ha Yuen Leng	Area (m ²)	Amount of Road Segments	Total Lengths of Roads (m)
Classic model	131,484	438	14,939
Modified model	101,657	523	12,558

The classic model’s natural city area in the Lai Chi Kok region is primarily covered by roads, the greatest of which is the crossing of Route three and Route eight in Hong Kong, resulting in a huge number of intersections in the 2D plane. Following field investigation, it was discovered that the local area is an interchange centre with a very complicated spatial structure, as shown in Figure 13. Route three is the most direct route from the New Territories to Hong Kong Island and is the route of choice for a significant number of public transport routes. Route eight is an east-west link between the city and Hong Kong International Airport and is the only trunk line to the airport. However, there is no urban glitz in the region; the viaduct is largely surrounded by container yards and parking lots, and there is one decrepit public housing estate. The other two locations are similarly highway interchanges rather than community centres. As a result, the modified model removes the natural cities mentioned above (Table 4).

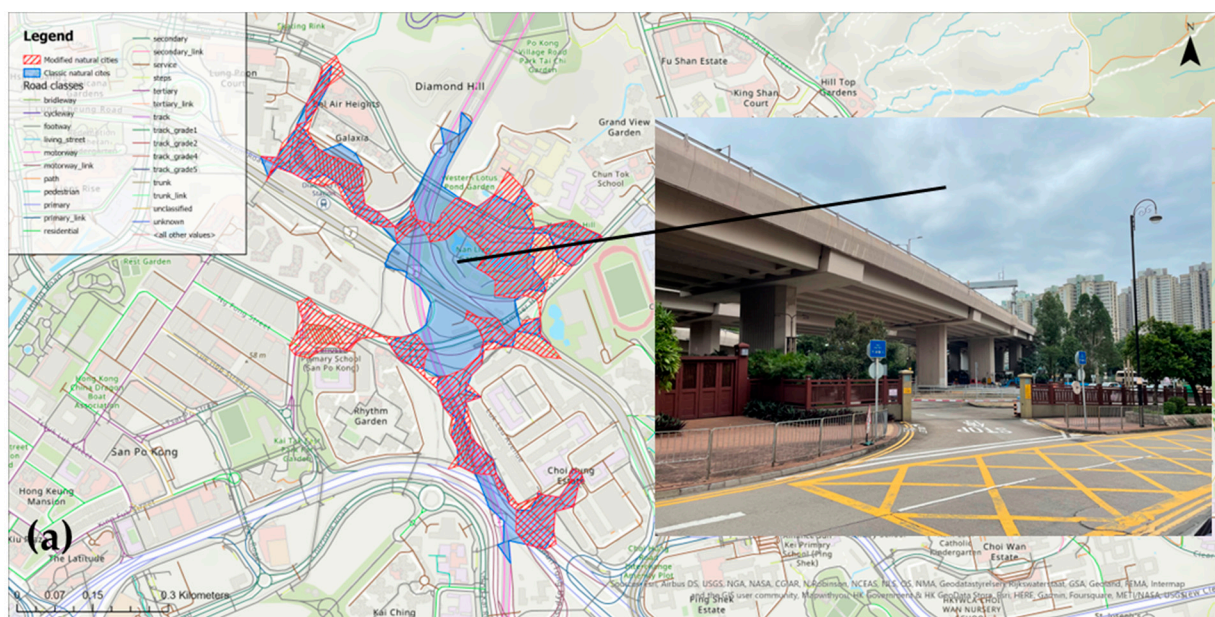


Figure 13. Cont.

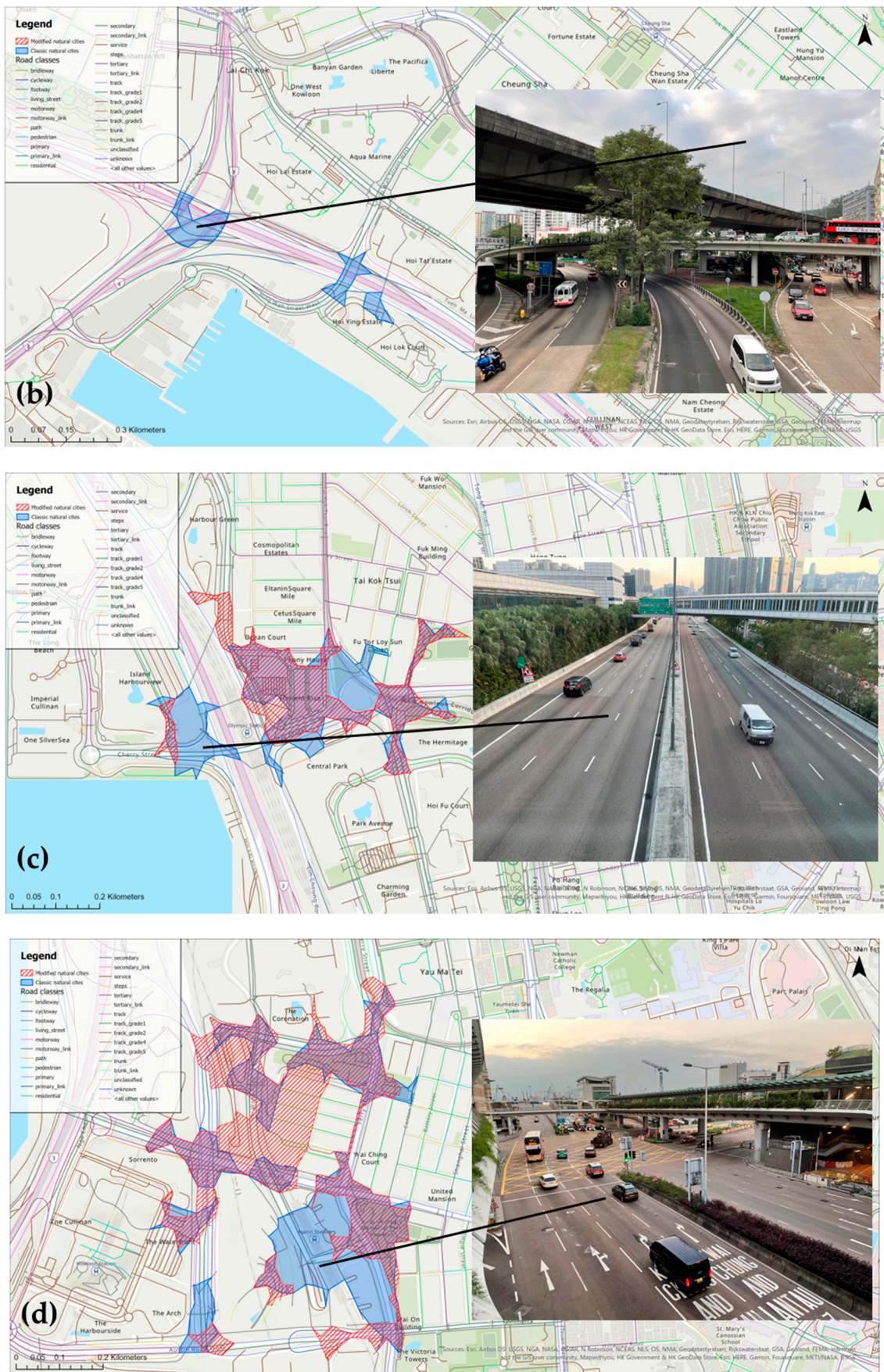


Figure 13. Natural cities distributions derived from two models and street images of the four regions: (a) Ha Yuen Leng; (b) Lai Chi Kok; (c) Tai Kok Tsui; (d) Austin.

Table 4. A comparison of the two models in Lai Chi Kok.

Lai Chi Kok	Area (m ²)	Amount of Road Segments	Total Lengths of Roads (m)
Classic model	21,932	59	2302
Modified model	0	0	0

Tai Kok Tsui is a place name rather than an administrative division. The region encompassed by the typical natural cities in this region comprises vast housing estates, commercial structures, and the previously mentioned Route three north-south arterial road. The Tai Kok Tsui region has a distinctive urban image with arterial highways, railway lines, and footbridges converging in the same area, resulting in a dense mass of road intersections in the 2D plane (Table 5). The railway lines slowly turn to pass underneath the arterial highways, which are thus formed by an elevated structure, and the footbridges span over the wide roadway. In the modified model, these roads will no longer be considered passable to each other because of the inconsistent layer value. Therefore, in the generation of TIN, the nodes of this district are reduced, and the length of the edges on the road is increased to higher than the average of all edges. The large housing estates and commercial buildings belonging to residential areas on both sides of the road have been retained, but the areas overlapping the main roads have been removed, as shown in Figure 13. This result is in accord with the reality that arterial highways are not level with the ground in densely populated areas for people to cross the road, which will increase the accident rate. People have to pass through footbridges with height differences from arterial highways and railway lines to gain accessibility, which also increases the distance.

Table 5. A comparison of the two models in Tai Kok Tsui.

Tai Kok Tsui	Area (m ²)	Amount of Road Segments	Total Lengths of Roads (m)
Classic model	86,628	349	10,261
Modified model	61,450	321	8389

Since Hong Kong West Kowloon Station was established for underground high-speed rail, it is separated from the rest of the surrounding transportation network both categorically and physically. Although the station has numerous internal roads for passengers and a developed upscale residential and cultural exhibition area not far from the exterior, there is still a hard boundary between the interior and exterior. Although there are many railroads and highways in this region, there is a lack of intersections. So, the modified model determines that there are few nodes near the boundary of the high-speed railway station, which increases the length of edges in the TIN (Table 6). It is evident that there is a hole in the distribution of natural cities in the centre of Austin, as shown in Figure 13. The surrounding residential buildings, parks, and green areas form pockets of natural cities and provide Austin's natural cities with more substructures that can be subdivided downwards, enhancing the degree of living structure complexity.

Table 6. A comparison of the two models in Austin.

Austin	Area (m ²)	Amount of Road Segments	Total Lengths of Roads (m)
Classic model	151,271	575	16,912
Modified model	157,237	580	17,819

Taken as a whole, the four cases where natural cities were left off the list, as shown in Figure 13, are either because the adaptation of the viaduct to its surroundings was not considered during the urban construction process, because the decision-makers in the planning process intended to make the region a landmark inconsistent with its surroundings, or

because the region itself does not have the capacity to carry human activities and is simply a classical model that has been misjudged.

5.5. Degree of Living Structure Complexity Calculation

Accompanied by the generated natural cities above, the preconditions for calculating the degree of living structure complexity have been collected completely. The first operation was the spatial join of 1585 natural cities and Kowloon's road network. This step can extract all the roads passing through each natural city. Since 3D roads have viaducts above the ground and tunnels below the ground, these road structures reflect the complexity and inherent hierarchy of the area. To prevent the negative layer of tunnels from reducing the degree of living structure complexity during the operation, this work uses the absolute value of the road layer as a parameter. After obtaining all the road layers' absolute values passed in each natural city, the living structure with the highest value was extracted to quantify every natural city. Calculated by the formula mentioned in 3.4., the Kowloon's degree of living structure complexity (Table 7) is obtained by summing $(5 + 1) \times 7 + (4 + 1) \times 3 + (3 + 1) \times 31 + (2 + 1) \times 103 + (1 + 1) \times 375 + (0 + 1) \times 1066$, and the result is 2306.

Table 7. Absolute maximum values of the number of road layers (H) and numbers of natural cities in different levels (S).

Absolute Maximum Value of the Number of Layers (H)	Number (S)
0	1066
1	375
2	103
3	31
4	3
5	7
Total	1585

6. Discussion

6.1. The Impact of 3D Road Network on Neighbourhood Connectivity

Previous research has proposed the natural city formation model [42]. According to our empirical results, the classic model misses the mark of 3D spatial relationships in metropolitan areas due to complicated traffic intersections. It is an intriguing concept that the classic model uses the road network as a carrier to uncover urban structure [10]. However, not all roads are built on the ground; many are built as bridges or tunnels to reduce occupied land areas or improve traffic efficiency. In a metropolis like Hong Kong, such occurrences are not uncommon [43]. This work used OpenStreetMap data to fit the true direction and topological relationship of roads and generate new natural cities for introducing a new approach to discovering urban area distribution.

Viaducts are the places where the traditional model and modified model differ the most frequently. This is the work's entry point. Natural cities are defined by the concept of finding a location that serves as a hub for human activities and housing based on geographical features [42]. The density of road intersections was important in its construction since the road network functions as the city's blood vessel as in an organism. It is easy to overlook the detrimental influence of the road itself in the early stages of the city when the road network is still rather sparse [44]. At this point, all roads are built on the earth's surface and serve as handy travel routes for residents. There will be no need to bypass, and no roads will be nearby yet inaccessible. When a city reaches a prosperous stage, the differentiated road network competes for space with people's dwelling areas, and not all roads are suitable for being the travel pathways of neighbouring residents [45,46]. This work does not ignore the role of these in improving the traffic speed for urban travel, commuting, and sightseeing. After keeping only true intersections in the road network, it was found that roads of both types are not strongly associated with other roads, and they

often have clear starting and ending points. The influence of residents' behaviour based on the perceptions they have on the environment around their travel needs to be taken into account as if the environment is perceived as a barrier, residents' desire to travel will not be positive, and their extensibility reduces [47,48]. Urban planners need to be aware that the real city is not a directed graph, where the higher the connectivity, the better, and that meaningless gaps in the graph theory are the living spaces of the citizens [26,49]. The road network responds to the city's expanding traffic demand, but itself is differentiated. Meanwhile, differentiation and adaptation are exactly the two complementary laws that organize living structures [25].

6.2. *The Optimisation Compared to the Classical Model*

The range of natural cities generated by the two models is very similar, where there are no roads of multiple layers that intersect. The location of dense road networks is extracted as a result, and the result was found to fit the situation of human activities well with reality. The result also reveals that the classic model is still effective in places with sparse roads and without elevated roads. This result will be more obvious when the scale is enlarged to the entire city, province, or country separated by natural landforms because the need to build complex multi-layer road networks can only exist in urban areas.

In the modified model result, there are also inappropriate areas where the model is too far removed from the classical model. This is caused by the inclusion of the layer attribute as a condition for constructing a road intersection; some of the existing road intersections are removed, and the distance between two nearby road intersections in the decreased region increases. The created TIN edges will be longer as a result, and these edges will not be lower than the mean value in the new ordering, and so will not participate in the generation of natural cities. This issue can be solved by replacing the threshold with a different value rather than setting it to an empirical mean value.

This work has space for improvement. Other metropolises with a large number of viaducts, such as New York and Tokyo, could be utilized as material to validate the algorithm's generalizability in addition to Hong Kong. This work does not take into consideration the various road classes. These variables can be used to improve the model by taking into account whether various classes of roads are passable.

6.3. *Natural Cities and Deconstructionism*

The process of creating natural cities as a result of this study allows individuals to discover a new perspective on their city and obtain a better understanding of the regions where human activity is most concentrated. This viewpoint does not begin with several centres or an overall layout in an urban planning scheme but rather begins with the most basic urban aspects and progresses to a more sophisticated dimension. The resulting design is fragmented and egocentric rather than a Euclidean geometric pattern. Grand infrastructural projects such as overpasses block the movement of nearby citizens, and the accessibility of their neighbourhoods is shared with the accessibility of the city as a whole.

It is important to note that the results of this generation are only representative of the results of the road network generation at the time and not of the hotspot areas of the city that have stayed intact for millennia. The results of each generation will follow the development of the city at that time and the change into an urban form so that the natural city is unstable and open. This is analogous to the philosophical concept of deconstructionism, which argues that structure has no fixed centre and is made up of a sequence of disparities [50]. The main method of deconstructive analysis is to look at the dichotomies in a context and to present the fact that these two opposing facets are, in fact, fluid and impossible to separate completely [51]. The head and tail parts in this work also show this attribute, they are the only two parts of the whole sample data, but the division value between them can change with the development of the urban morphology; several individuals constituting one part will then be grouped into another part. The head and tail parts do not exist in any fixed or absolute form.

7. Conclusions

In this work, we utilize the Hong Kong Kowloon region as the study area, OpenStreetMap as the base data, and adapted the traditional natural cities generation model by adding the layer attribute of roads. The improved model is based on the 3D character of the city's road distribution, without changing the overall distribution features of the classical model, and filters out regions that do not undertake human activities, generating more realistic results. Four regions were selected to verify the authenticity of the natural cities generated in the model, and four regions were selected to verify the scientific validity of the areas removed by the model. This work analyses the distribution of road intersections, using the head/tail break as a basis for the algorithm to identify city areas and rural areas. The improved model shows more clearly the inherent spatial architecture of the city and will be more in line with human spatial perception.

Author Contributions: Conceptualization, Z.X. and X.L.; methodology, Z.X.; software, Z.P. and Z.Y.; visualization, Z.P.; resources, Z.Y.; writing—original draft preparation, Z.X.; writing—review and editing, X.L.; supervision, X.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China (NSFC) (grant number: 42171455), Research Grants Council (RGC), Hong Kong (grant number: 15204121), and Research Institute for Land and Space (RILS) at The Hong Kong Polytechnic University (grant number: CD7M).

Data Availability Statement: The codes used to obtain true road intersections from OSM data are available at the following link, which we will keep updated in further work: <https://github.com/Apollo-geo/ObtainTrueIntersections/tree/main>.

Conflicts of Interest: The authors declare no conflict of interest.

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