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Sustainable Smart Cities and Smart Villages Research

Rethinking Security, Safety, Well-being and Happiness

Edited by
Miltiadis D. Lytras and Anna Visvizi

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Sustainable Smart Cities and Smart Villages Research

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Special Issue Editors

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About the Special Issue Editors

Miltiadis D. Lytras Ph.D., is an expert in advanced computer science and management, editor, lecturer, and research consultant, with extensive experience in academia and the business sector in Europe and Asia. Dr. Lytras is a Research Professor at Deree College—The American College of Greece and a Distinguished Scientist at the King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia. Dr. Lytras is a world-class expert in the fields of cognitive computing, information systems, technology-enabled innovation, social networks, computers in human behavior, and knowledge management. In his work, Dr. Lytras seeks to bring together and exploit the synergies among scholars and experts committed to enhancing the quality of education for all.

Anna Visvizi Ph.D., is a political scientist and economist, editor, and research consultant with extensive experience in academia and the think-tank sector in Europe and the US. As the author of several publications, Dr. Visvizi has presented her work across Europe and the US, including Capitol Hill. Dr. Visvizi's expertise covers issues pertinent to the intersection of politics, economics, and ICT. This is translated in her research and advisory roles in the areas of AI and geopolitics, smart cities and smart villages, innovation promotion, global migration management, and economic integration, especially the EU and BRI. Currently, Dr. Visvizi serves as Associate Professor at Deree College—The American College of Greece. Until December 2018, Dr. Visvizi was Head of Research at the Institute of East-Central Europe (IESW), Poland. In her work, Dr. Visvizi places emphasis on engaging academia, the think-tank sector, and decision-makers in dialogue to ensure well-founded and evidence-driven policy-making.

Preface to "Sustainable Smart Cities and Smart Villages Research: Rethinking Security, Safety, Well-being and Happiness"

Over the last years, sophisticated policy propositions for the sustainable development of rural and urban areas have been recorded. The smart village and smart city concepts promote a human-centric vision for a new era of technology-driven social innovation. This Special Issue is a quality edition that will impact the body of knowledge within this domain, in both industry and research. By promoting a thorough scientific debate on the multi-faceted challenges that our villages, cities, and urban and rural areas are exposed to today, this Special Issue offers a useful overview of the most recent developments in the frequently overlapping fields of smart city and smart village research. A variety of topics including well-being, happiness, security, open democracy, open government, smart education, smart innovation, and migration have been addressed in this Special Issue. These topics define the direction for future research in both domains. The organization of the relevant debate is aligned around the following three pillars:

Section A: Sustainable Smart City and Smart Village Research: Foundations

- Clustering Smart City Services: Perceptions, Expectations, and Responses
- Smart City Development and Residents' Well-Being
- Analysis of Social Networking Service Data for Smart Urban Planning

Section B: Sustainable Smart City and Smart Village Research: Case Studies on Rethinking Security, Safety, Well-being, and Happiness

- Exploring a Stakeholder-Based Urban Densification and Greening Agenda for Rotterdam Inner City—Accelerating the Transition to a Liveable Low Carbon City
- The Impact of the Comprehensive Rural Village Development Program on Rural Sustainability in Korea
- Analyzing the Level of Accessibility of Public Urban Green Spaces to Different Socially Vulnerable Groups of People
- Consumers' Preference and Factors Influencing Offal Consumption in the Amathole District Eastern Cape, South Africa
- Sustainable Tourism: A Hidden Theory of the Cinematic Image? A Theoretical and Visual Analysis of the Way of St. James
- Future Development of Taiwan's Smart Cities from an Information Security Perspective
- Towards a Smart and Sustainable City with the Involvement of Public Participation—The Case of Wroclaw

Section C: Sustainable Smart City and Smart Village Research: Technical Issues

- Detection and Localization of Water Leaks in Water Nets Supported by an ICT System with Artificial Intelligence Methods as a Way Forward for Smart Cities
- A Study of the Public Landscape Order of Xinye Village

• Spatio-Temporal Changes and Dependencies of Land Prices: A Case Study of the City of Olomouc
• Geographical Assessment of Low-Carbon Transportation Modes: A Case Study from a Commuter University
• Performance Analysis of a Polling-Based Access Control Combined with the Sleeping Schema in V2I VANETs for Smart Cities

We want to thank the professional staff of MDPI for the tireless work that made this edition possible. We are at your disposal for any further information on this edition and we invite you to join us in our next editions relating to Smart Cities, Smart Villages and Sustainability.

Miltiadis D. Lytras, Anna Visvizi
Special Issue Editors

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Editorial

Sustainable Smart Cities and Smart Villages Research: Rethinking Security, Safety, Well-being, and Happiness

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Abstract: This Special Issue of Sustainability was devoted to the topic of "Sustainable Smart Cities and Smart Villages Research: Rethinking Security, Safety, Well-being, and Happiness". It attracted significant attention of scholars, practitioners, and policy-makers from all over the world. Locating themselves at the expanding cross-section of the information systems and policy making research, all papers included in this Special Issue contribute to the debate on the exploitation of advanced information and communication technologies (ICT) for smart applications and computing for smart cities and rural areas research. By promoting a thorough scientific debate on multi-faceted challenges that our villages, cities, urban and rural areas are exposed to today, this Special Issue offers a very useful overview of the most recent developments in the multifaceted and, frequently overlapping, fields of smart cities and smart villages research. A variety of topics including well-being, happiness, security, Open Democracy, Open Government, Smart Education, Smart Innovation, and Migration have been addressed in this Special Issue. In this way they define the direction for future research in both domains.

Keywords: smart cities; smart villages; smart urban applications; data mining; analytics; cloud computing and open source technologies; sustainability; entrepreneurship; economic growth; international migration; forced migration; smart technologies; ICT; open democracy; open government; smart education; smart innovation

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1. Introduction: Overview of the Edited Volume

It was a pleasure to have delivered a special issue on smart cities and smart villages research in Spring 2018 (https://www.mdpi.com/journal/sustainability/special_issues/Smart_Cities). Building on our earlier work, drawing from our field research, and driven by a genuine concern about the process and the implications of the rapid depopulation of rural areas, we introduced the concept of 'smart village' in the academic debate in Summer 2017 [1]. At the time of the launch of this Special Issue, we were convinced that through the adoption of comprehensive integrative strategies geared toward socio-economic development and employing recent advances in information and communication technology, ways of navigating the challenge of rapid depopulation of urban areas will be identified [2,3]. Indeed, papers included in this Special Issue not only contributed to the opening of new avenues of research, but also triggered a lively debate on diverse aspects of well-being in urban and rural areas as they evolve [4]. The excellent contributions from all over the world included in that Special Issue allowed us to disseminate the latest high quality interdisciplinary research in the domains of urban computing, smart cities, and, most importantly, smart villages [5]. Thanks to the Special Issue, the concept of smart villages has been firmly established in the academic and practitioners' debate. As significant streamlining of research focus and delineation of the subject matter took place as well, a major breakthrough was attained in the nascent field of smart villages research. To capitalize on that work, today, the imperative is to move to the next stage of the debate.

To this end, the Editors of this volume initiated a new call for contributions that address (but are not limited to) the following issues and aspects related to the diverse aspects of socio-economic processes as they unfold in rural and urban areas and have a bearing on individuals' security, safety, well-being, and happiness:

- Policy-design and policymaking for sustainable development in urban and rural areas
- Public-private partnerships and the development of strategies for sustainable rural and urban development
- The role of multilateral forums, international organizations, and other in streamlining the debate
- The role of the European Union (EU) in the debate on smart villages
- Comparative aspects of smart village and smart city research
- Comparative approaches
- Regional strategies
- Smart city technologies
- Smart village technologies
- Smart services' provision in rural and urban areas
- Revitalization of rural areas through digital and social innovation
- Case-studies
- Conceptual approaches
- Micro-, mezzo-, and macro-strategies, incl. applications, tools, and systems
- Innovation networks in the context of smart village research
- Clusters in the context of smart village research
- Smart specialization in the context of smart village research

After a rigorous review process that took place in 16 months, we finally selected 15 research studies for inclusion to this volume. All of them represent progressive, high quality research that promote the literature in the smart cities and smart villages research. The final selection of papers includes 15 research studies organized in three sections:

1.1. Section A: Sustainable Smart Cities and Smart Villages Research: Foundations

- Lytras, M.; Visvizi, A.; Sarirete, A. Clustering Smart City Services: Perceptions, Expectations, Responses. *Sustainability* **2019**, *11*, 1669.
- Lin, C.; Zhao, G.; Yu, C.; Wu, Y. Smart City Development and Residents' Well-Being. *Sustainability* **2019**, *11*, 676.
- Mora, H.; Pérez-delHoyo, R.; Paredes-Pérez, J.; Mollá-Sirvent, R. Analysis of Social Networking Service Data for Smart Urban Planning. *Sustainability* **2018**, *10*, 4732.

1.2. Section B: Sustainable Smart Cities and Smart Villages Research: Case Studies on Rethinking Security, Safety, Well-Being, and Happiness

- Tillie, N.; Borsboom-van Beurden, J.; Doepel, D.; Aarts, M. Exploring a Stakeholder Based Urban Densification and Greening Agenda for Rotterdam Inner City—Accelerating the Transition to a Liveable Low Carbon City. *Sustainability* **2018**, *10*, 1927.
- Hwang, J.; Park, J.; Lee, S. The Impact of the Comprehensive Rural Village Development Program on Rural Sustainability in Korea. *Sustainability* **2018**, *10*, 2436.
- Rahman, K.; Zhang, D. Analyzing the Level of Accessibility of Public Urban Green Spaces to Different Socially Vulnerable Groups of People. *Sustainability* **2018**, *10*, 3917.

- Alao, B.; Falowo, A.; Chulayo, A.; Muchenje, V. Consumers' Preference and Factors Influencing Offal Consumption in Amathole District Eastern Cape, South Africa. *Sustainability* **2018**, *10*, 3323.
- Lopez, L.; Nicosia, E.; Lois González, R. Sustainable Tourism: A Hidden Theory of the Cinematic Image? A Theoretical and Visual Analysis of the Way of St. James. *Sustainability* **2018**, *10*, 3649.
- Wu, S.; Guo, D.; Wu, Y.; Wu, Y. Future Development of Taiwan's Smart Cities from an Information Security Perspective. *Sustainability* **2018**, *10*, 4520.
- Bednarska-Olejniczak, D.; Olejniczak, J.; Svobodová, L. Towards a Smart and Sustainable City with the Involvement of Public Participation—The Case of Wroclaw. *Sustainability* **2019**, *11*, 332.

1.3. Section C: Sustainable Smart Cities and Smart Villages Research: Technical Issues

- Rojek, I.; Studzinski, J. Detection and Localization of Water Leaks in Water Nets Supported by an ICT System with Artificial Intelligence Methods as a Way Forward for Smart Cities. *Sustainability* **2019**, *11*, 518.
- Xu, L.; Chiou, S. A Study on the Public Landscape Order of Xinye Village. *Sustainability* **2019**, *11*, 586.
- Burian, J.; Macků, K.; Zimmermannová, J.; Kočvarová, B. Spatio-Temporal Changes and Dependencies of Land Prices: A Case Study of the City of Olomouc. *Sustainability* **2018**, *10*, 4831.
- Sultana, S.; Kim, H.; Pourebrahim, N.; Karimi, F. Geographical Assessment of Low-Carbon Transportation Modes: A Case Study from a Commuter University. *Sustainability* **2018**, *10*, 2696.
- He, M.; Guan, Z.; Bao, L.; Zhou, Z.; Anisetti, M.; Damiani, E.; Jeon, G. Performance Analysis of a Polling-Based Access Control Combining with the Sleeping Schema in V2I VANETs for Smart Cities. *Sustainability* **2019**, *11*, 503.

2. Conclusions: Contribution of the Edited Volume

The overall collection of research studies provides an integrative discussion for the key issues and challenges related to Smart Cities and Smart Villages Research, and several soft issues associated to this scientific domain including Happiness, Well-being, Security, and Safety. Below, we provide a partial discussion on key findings and ideas communication in this edition:

- The research on Smart Cities and Smart villages requires multi-disciplinary studies: the integration of sophisticated technology enabled services for social services requires better understanding of user clusters and preferences. The perceptions of users and their expectations from the use of smart cities and smart villages services need documentation and in-depth analysis. Various research tools need to be deployed for this purpose and furthermore significant contribution is required on social dashboards for the aggregation and exploitation of visual analytics related to smart cities data.
- Soft issues in Smart Villages and Smart Cities research such as well-being and happiness must be considered as core issues in any smart city development plan. Towards this direction, the measurement with objective metrics for these factors is a key priority for the sustainability of any smart city development plan.
- The evolution of data in the context of smart cities and smart villages and the development of a smart cities data ecosystem requires strategizing of data provision in social networks and advanced exploitation of micro-contents. The aggregation of data in a single, open, cloud-based data warehouse will permit advanced sentiment analysis for updating indexes related to happiness and well-being.
- Various best practices promote the idea and the experience of happiness and well-being in Cities and Villages. For example, the case study on Greening Agendas for Rotterdam Inner City—Accelerating the Transition to a Low Carbon City.
- The Impact of the Comprehensive Rural Village Development Program on Rural Sustainability in Korea is a good lesson for similar initiatives worldwide.

- The key issue of Accessibility of Public Urban Green Spaces to Different Socially Vulnerable Groups of People summarizes another key direction towards sustainable villages and cities and promotes socially aware policy making and actions.
- The integration of location-aware services and the integration of geo-spatial for value adding services for smart cities and smart villages is another key direction for safety, well-being, and happiness.
- The issues of Public Participation and Open Democracy are also recognized as key pillars towards happy cities.
- Several technical issues also add to the rich picture of the phenomenon: Detection and Localization of Water Leaks in Water Nets Supported by an ICT System with Artificial Intelligence Methods as a Way Forward for Smart Cities; Land Prices and Management; Geographical Assessment of Low-Carbon Transportation Modes: A Case Study from a Commuter University.

We are happy for delivering this edited collection in the literature. The promotion of smart cities and smart villages research will be a trend for the next years. The understanding that happiness and wellbeing are key targets of any Smart Cities and Smart Villages strategy is a basic step towards sustainable and social inclusive economic growth.

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Article

Clustering Smart City Services: Perceptions, Expectations, Responses

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Abstract: Smart cities research evolved into one of the most vibrant fields of research and policy-making with sustainability and well-being becoming the *bons mots* of the debate. The business sector, i.e., the developers and the vendors, form an equally important group of stakeholders in this context. The question is to what extent that debate yields the kind of output that the end-users would expect and would consider useful and usable. A plethora of smart city services exists. Literature suggests that a myriad of new ICT-enhanced tools could find application in urban space. Methodologically speaking, the question is how to link these two meaningfully. The objective of this paper is to address this issue. To this end, smart city services are mapped and clusters of services are identified; end users' perceptions and expectations are identified and observations are drawn. The value added of this paper is threefold: (i) at the conceptual level, it adds new insights in the 'normative bias of smart cities research' thesis, (ii) at the empirical level, it typifies smart city services and clusters them, and (iii) it introduces a practical toolkit that policymakers, regulators, and the business sector might employ to query end-users' perceptions and expectations to effectively respond to citizens' needs.

Keywords: smart cities; information and communication technologies; technology clusters; innovation transfer; sustainability; analytics; ICTs; policy making

1. Introduction

Several dimensions of—what has been termed elsewhere—as 'the normative bias' of smart cities research thesis exist, including conceptual and empirical dimensions [1,2]. The term itself can be defined as the propensity of the research community to propose and discuss ever more sophisticated ICT-enhanced solutions to increasingly varied niche societal problems and needs. Whilst, in the long-run, this approach can defend itself, in the short-run it is necessary that valid functional connections between research on smart cities and the challenges faced by our society are identified, conceptualized, and exploited on an empirical ground. This requires that the great variety of stakeholders involved in the making of smart cities, including their needs, perceptions, expectations, and capacities, are factored into the smart cities debate equation. Whereas in the long-run, this approach can defend itself, in short-run, it is necessary that valid functional connections between research on smart cities and the challenges society faces are exploited. This requires that all stakeholders, their needs, perceptions, expectations, and capacities are factored in the discussion on ICT-enhanced services and their availability not only in cities and urban space but also in rural areas, including smart villages. The objective of this paper is to explore this issue. To this end, this paper examines the link between the end-users of smart services and the industry, i.e., the actual providers of

ICT-enhanced applications meant to improve the wellbeing of citizens. The argument is structured as follows: first, based on literature review and outcomes of a pilot survey, criteria of categorization of smart services are established and the existing smart city services are divided into categories (clusters). As a result, a map of smart city services is devised. This map is then used to correlate citizens' perceptions and expectations of ICT-enhanced services with the awareness of vendors, policymakers, businesses in terms of what is needed and their capacity to respond to respective needs. In this way, in the concluding part, the key findings and a few recommendations are outlined.

Querying the 'Normative Bias' of Smart Cities Research Thesis and Its Implications

Fertilized by insights from a variety of disciplines, research on smart cities flourishes. Today, valuable insights to the debate are brought by researchers affiliating themselves with urban and regional studies, sociology, politics, international relations, political economy, and certainly computer science [3–6]. Ideally, the plethora of insights would have allowed the research community to build a multidimensional framework enabling a comprehensive study of issues and matters pertinent to the field of smart cities. But it is not the case; the field remains fragmented. To some extent, smart cities research has turned into a battlefield where diverse critical insights, diverging conceptual approaches, diverse normative imperatives, compete for the right to define the field. In addition, the computer science community sees smart cities research as a formidable testing ground for ideas based on the prospect of utilization of ever more sophisticated technologies. Clearly, this variety of approaches and perspectives applied to smart cities' research bears a great number of opportunities. At the moment, however, challenges seem to outweigh them. It is imperative therefore that an inter- and multi-disciplinary smart cities research agenda consolidates. To this end, more reflection on the conceptual precepts of the debate is needed. This includes the perennial questions of ontology and epistemology in smart cities research. Only in this way the vast field of smart cities research can be delineated, the numerous avenues of research that the field avails itself to can be identified, and finally, synergies exploited.

Consensus has consolidated that smart cities research ought to be part and parcel of the broader debate on sustainability. It is in this context that this paper highlights the interconnections and metaphors that emerge between the information and communication technology community (including computer science, information systems, computer networks, computer security etc.), social sciences, business-related research, and policy-makers. Establishing a strategic fit among these groups and, thereby, exploiting synergies that insights each of these groups bring to the discussion on smart cities constitutes a value contribution to this research. In this study, we are building upon our previously published research [1–3] and we are elaborating on the concept of smart city services and linking end-users' perceptions and expectations with the industry's awareness of and capacity to respond to these needs. In our research, a smart city service is defined as *an integrated value carrier for the integration of citizens' and communities' quality of life and wellbeing based on advanced technological enablers (ICT)*.

The strategic objective of this research is three-fold:

- To understand what are the key technological enablers that support smart services in urban and rural areas. For this purpose, an extensive analysis of related research concluded to seven clusters of information and communication technologies that are discussed further in Section 3.
- To analyze what are the basic and innovative smart services under each category, showing the perceptions of smart city users about their intention in the use of these services and the added value they are bringing to them. In our previously published research [2] we concluded that three different major types of smart users exist. The motivation here is directly related to our so-called "normative bias" in smart cities research. One aspect of this bias can be the following: computer scientists have the capacity to deploy various technologies to offer smart cities services and to believe that these services will be accepted by users and will deliver value to them. The key question is if their expectations related to the adoption of their services meet also the perceptions and expectation of users of smart city services.

- To provide a policy-making, strategic roadmap for the readiness of smart city users and citizens to adopt specific types of services and to highlight which are the areas or services that will have limited interest. Obviously, such a contribution is significant for the Industry and the technology providers of smart city services. It is also critical for policymakers to reveal problematic areas or highlights areas and factors of concerns by smart city users.

The industry perception and awareness of usefulness and value-added of smart city services is also an ultimate target of this research: what to make of it? Can vendors, regulators, policy-makers, decision-makers, and businesses drive end-users' perception and awareness of smart city services? These additional questions will be answered as future research directions in the current study.

2. Literature Review

The pace of evolution in the domain of technology is amazing. In the group of well-established and streamline technologies like databases and computer networks, new arrivals of emerging technologies like the internet of things, cloud computing, big data, or virtual and augmented reality, bring new promises and new expectations to computer scientists. In the same context, citizens and communities are eager to enjoy secure, reliable, trusted, high performing services that will solve problems and will deliver value.

The overall understanding of the current evolution in ICT is that sophisticated information systems integrate the following features that can be integrated into smart cities solutions [1–3]:

- Databases and Data Warehouses technologies: advanced services for distributed, large scale data repositories capable of managing both structured and unstructured data [7]. In the context of smart city services, Data warehouse technology is a core technology. Issues related to data protection, data privacy, and data regulation have emerged and required delicate treatment.
- Content Management and Collaboration Platforms: The variety of data in structured and unstructured formats, as well as the variety of micro contents produced and consumed in different application contexts, such as social networks, e-commerce platforms and information or business portals, is challenging the design and provision of smart city services [2,3,7].
- Advanced Computer Networks technology: a wide range of new generation computer networks has arrived providing a variety of constitutional and integrative components for smart city services. 5 g networks, Internet of Things together with mobile networking and distributed sensor networks are only a few of the possibilities of our times [7–11]. In the same context also social networks, social media and innovative collaborative, community-driven technologies [9,10].
- Big Data and Analytics technology: Decision making oriented and policy-making driven approaches enhance the discovery of hidden patterns over big data and offer unique visualization options to policy and makers. Especially within the context of smart city research, these approaches have gained critical share and the potential for social impact is great [7,11–14].
- Social Mining and Social Impact technology: The utilization of users' profiles in local, and global context permit unforeseen capabilities for opinions mining, social mining and sentiment analysis over content and micro contents [7,15–17]. The utilization of these advanced computational techniques targets directly to the social component of smart city applications. With the increasing interest of businesses and the industry for personalized services and the recent updates on data privacy protection regulation measures set new limitations and barriers to a widespread taxonomy of social mining application for smart city services [18–20].

The evolution of information and communication technologies in the last decade resulted with the arrival of several highly promising technologies including Artificial Intelligence, Internet of Things, Cloud Computing, Cognitive Computing, Virtual, Mixed and Augmented Reality, Sensors and 5G networks, and many others. As a result, the design of urban applications and smart city systems becomes more complicated and sophisticated. At the same moment, there is a paradox that we must analyze further: while computer scientists and ICT experts claim for the value of these technologies to real users of smart cities applications, there are not many types of research that elaborate on the perceived value of sophisticated smart city services by real users.

In our view, technology has a critical social purpose in the context of smart cities. It must be beneficial for the society and has to respond to key social problems. Technology must be transparent and should deal with critical ethical concerns about security and privacy. Additionally, information and communication technologies in the context of smart cities research should take care of justice and equal treatment of all human entities, and by any means should not promote exclusion and must promote inclusiveness and social responsibility. One more feature of smart cities technology is that it must be flexible, open and extendable and should be deployed with the justification of resources and costs consumed. The adoption of ICT should be creative, promote collaboration and integration of ideas, beliefs, and opinions. Finally, yet importantly, ICT for smart cities research should build bridges between social, cultural and other gaps of citizens and capitalize on diversity.

Given the previous communication of features for smart cities technologies in the next section, we set up the context and the basis of our research model and investigation. From a huge, diverse and complementary literature review and industry review of ICTs and platforms, we conclude by *six combined clusters of technology enablers* and fifty pilot applications of smart city innovations. The ultimate objective of our study is to analyze how real users of smart city applications perceive the value of core technologies and relevant services towards the quality of their lives.

- Content Management systems
- Networking Technologies
- Data Warehouses & Distributed Systems
- Analytics and Business Intelligence
- Emerging Technologies
- Smart City Innovation Technologies

In Figure 1, these clusters are highlighted. For our research, it is extremely important to link these clusters with value adding smart city services.

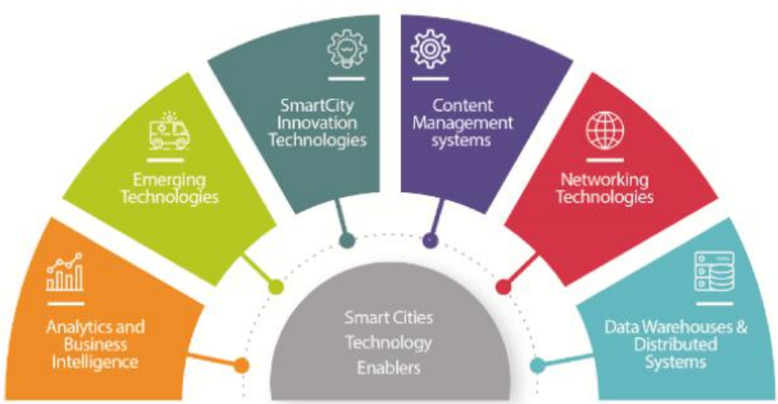

Figure 1. Smart Cities enabling technologies.

The technology landscape is an evolving ecosystem. It is hard to try analyzing it in the context of a static snapshot at a given time. In Figure 2 below, we organized, based on our perceptions and extensive literature review, the key ICTs Technology Clusters of our times that enable and support smart cities applications. We do believe that this is a meaningful overview that enables a dialogue for the vision of Smart Cities in our days.

Figure 2. Information and Communication Technology clusters for Sustainable Smart Cities applications (the Authors).

Content Management Systems: The technological cluster of Content Management Systems (CMS) is a diverse and multifaceted domain. In most of the scenarios related to knowledge dissemination, or joint workflow management, CMS is a reliable and efficient technology. Different solutions and applications fall into this category; the dominant ones are those depicted in Figure 2:

- Learning Management Systems (LMS),
- Document Servers,
- Workflow Systems,
- Collaboration Platforms,
- Micro-content Systems.

Networking Technologies: The evolution of Computer Networks technologies and its convergence with Telecommunications was probably one of the most recent influential integrations. Computing and Telecommunications can be seen now as an integrative whole which enriched the user experience with several services and unique experiences permitting innovative thinking on the domain. It seems that there is no limit anymore for the development of channels for the distribution of information.

- Distributed Sensor Networks/Systems (DSN)
- Wireless and Broadband,
- Satellite Communication,
- Social Networks,

- Mobile Platforms.

Data Warehouses & Distributed Systems: Our society is a data-driven society. A variety of data are generated, stored and used in different infrastructures and schemas. Additional value is generated by a sophisticated transformation of data to insights. Advanced decision making and managerial support can be performed. One of the greatest challenges of our times is to manage consistent information in a timely and accurate manner. Big Data research is a new paradigm for the processing of data without direct human intervention. Intelligent miners over distributed data frameworks like Hadoop is a new value proposition, http://hadoop.apache.org/

- Data Integration,
- Application Integration,
- Cloud Computing: Cloud,
- Open Architectures,
- Big Data.

Analytics and Business Intelligence

- Decision-Making Systems,
- Advanced Modelling and Business Planning,
- Machine Learning,
- Reporting and Visualization.

Emerging Technologies: The main feature of Technology is its evolution. It is hard for technology to keep for a long time the characterization of innovative. From the other side though, every few years we have technologies that for the first time define a brand-new market. It is just like short innovative circles occurring periodically and the innovation process seems to be a spiral ongoing process with new tools and technologies in the short term. It is also significant to realize that this is not by default a sustainable process. Without a strategic vision for the adoption of technologies especially in a so critical context such as smart cities, unfortunately, we will have many unsuccessful investments with a short beneficiary horizon. The following is an indicative short list of emerging technologies with an estimated great impact for the next years:

- Haptic and Wearables,
- Open Source Software and Open AI,
- Augmented Reality,
- Internet of Things,
- Cognitive Computing.

Within this interesting research context, the evolution of smart cities research requires significant integration of four domains. First of all, it is required to interpret the value contribution of emerging technologies and ICTs in the local social context [21]. The creation of pilot, innovative smart cities eco-systems in the local context promotes the added value of interdisciplinary smart cities research [22]. In another direction [23] the integration of ICTs for the promotion of technology-driven innovation and entrepreneurship imposes the need to understand the social dimension of businesses and to cultivate this culture in the local context. Additionally, the update of the production model and innovations in the agriculture domain and farming [24], links directly smart cities research to critical sustainable development goals. The digitization of services linked to environmental management is also a bold new direction of research [25]. One of the most interesting research dimensions is related to the realization of the needs of the digital citizen [26]. In such a diverse and complicated socio-technical research context for smart cities where also behavior and attitudes play a critical role, it is challenging for our research to codify tacit knowledge of smart cities users. We have from the beginning of our effort to state the limitations of our research: The generalization of findings should always take into consideration the social context of our research. The human factor in smart cities research is always the most important factor for interpretation of findings. The same stands for the social construct.

In the next section, we are elaborating on our research model and the key research questions of our study.

3. Research Methodology and Research Model

The arguments elaborated in this paper derive from critical analysis of the existing debate on smart cities. These have been enriched by a pilot survey that garnered 102 responses (see Appendix A) from a carefully selected international focus group. The respondents, highly educated individuals, have been selected on the basis of their ability and their propensity to use smart city services. The hypothesis against which the so-constructed focus group was established was that a positive direct correlation exists between respondents' education level and their awareness, ability, and propensity to use smart city services. Drawing from the literature review and critical analysis, a research model was developed (See Figure 3 below) and the questionnaire was constructed. Given the breadth of the questionnaire and the ground the answers covered, the survey and its outcomes offer answers to several research questions. Indeed, this paper adds to our earlier work [2].

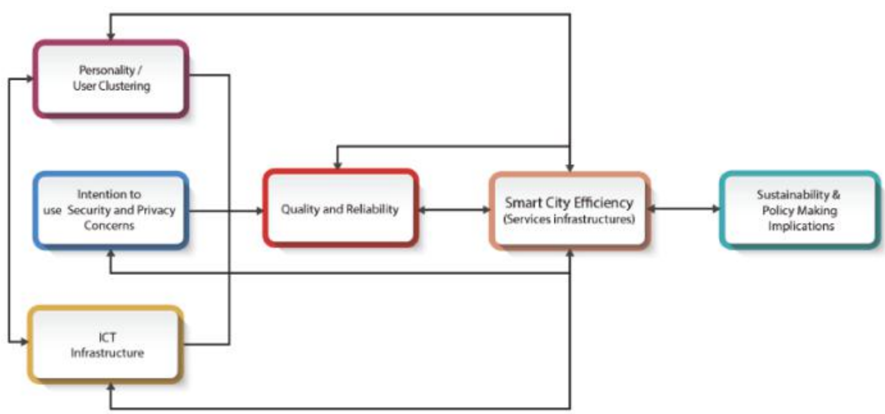

Figure 3. The integrated research model of our study [3].

The discussion in this paper employs findings associated with the following research variables: intention to use smart city services; the existence of enabling ICT infrastructure; quality and reliability of the existing infrastructure; sustainability and policy-making implications. Likert-type questions were developed to measure respondents' perceptions and expectations to relevant issues, constituting respective research variables in this context. These were complemented by an integrated meta-analysis of the responses.

Our research model is an amalgamation of desktop research, quantitative and qualitative research. The stages of our research methodology are summarized as follows (Figure 4):

- Outline the conceptual framework, based on 'the normative bias' of smart cities research thesis [1–3],
- conduct a thorough literature review on ICT-enhanced services in smart cities context,
- devise an outline of existing smart city services,
- establish criteria of categorization of ICT-services, and
- identify clusters of smart city services and elaborate on them.

In the following move, drawing on the outcomes of a pilot international survey conducted in 2018, [2]

- citizens' perceptions and awareness of smart city services they have access to are examined and
- grouped according to the clusters of smart city services' defined earlier.
- Against this backdrop, citizens' perceptions and awareness of smart city services are correlated with vendors', policymakers', businesses' etc., prerogatives in the field of smart city services.
- In this way, in the concluding part, a set of recommendations for respective stakeholders is outlined.

Figure 4. Research Methodology of our study.

The insights, concerns, and considerations inspired by the rich body of literature on smart cities that exists guided the process through which the research objectives of this study were formulated. These included the following questions:

- What are the perceptions of smart city services users for the selective technology-enabled smart cities services and applications?
- Which are the key enabling technologies that are adopted from smart city services users in their daily life?
- What are the interpretations of these perceptions for the design of future smart city services?
- What are the sustainability and policy-making implications of our research?

In the next section, we present the main findings of our research.

4. Reading the Outcomes of the Pilot Study

In our research, we tried to codify the perceptions of smart city users related to seven key clusters of information and communication technologies. (ICT infrastructure in our research model):

1. Content Management Smart cities services and applications
2. Collaboration platforms for Smart cities services and applications
3. Networking Technologies for Smart cities services and applications
4. Data Ware Houses and Distributed Systems for Smart cities services and applications
5. Analytics and Business Intelligence for Smart cities services and applications
6. Emerging Technologies for Smart cities services and applications
7. Smart City Innovation for Smart cities services and applications

For each of these technology clusters, we specified a number of indicative smart cities applications (see Appendix A, for the full set of smart cities services under consideration).

4.1. Perceptions of Users for Technology Clusters Ratings

In Figure 5, we present the average rating of users for each of the technology clusters. It is extremely interesting to elaborate on some of the key findings:

- The average rating for the frequent use of diverse technologies for the provision of smart city services is ranging from 34% to 46%. This, in fact, provides a critical mass of users for smart city services. A question for future research is related to advanced policy-making: what are the required strategies and policies to support people who are concerned by the efficiency of services to adopt and to integrate into their lives.
- A significant part of responders ranging from 19% to 25%, defines themselves as users of smart cities applications with great motivation to adopt smart cities services, enabled by all the seven clusters of smart cities enabling technologies.
- As a direct interpretation of the above findings, it is evident from our empirical study that almost two-thirds of responders constitute a group of light and heavy smart cities services. In fact, it seems that the adoption of various services in the past years resulted in increased motivation and intention to use smart cities services.
- A significant part of responders is also skeptical about the use of ICTs for smart city services. Based on the findings of our research, this group of people is ranging from 11% to 13% of the total population. This is a key finding of our research and for sure, future research should analyze further the qualitative characteristics for their disposition to use smart services. In most of the cases, these are related to privacy and security concerns.
- One more key finding is that content management and networking services have currently the greater number of users with a strong outlook also for use in the near future.

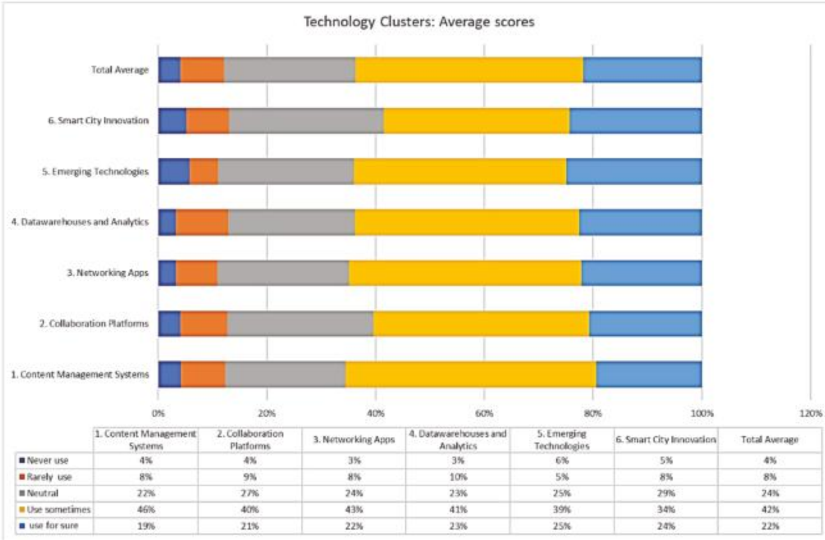

Figure 5. Technology clusters for Sustainable Smart Cities applications: Overview of rating by real users.

4.2. Perceptions of Users for More Favorable to Use Applications

In Table 1, below, we summarize the key findings related to the rating of smart cities services. Most of the users seem very happy to use and eager to use in the future a variety of smart cities applications that fall into technology clusters we presented. Given the limitations of our study, for sure, we cannot generalize these results to the global population, but given the characteristics of our sample, these are some interesting findings:

Table 1. More favorable to use smart city applications.

Indicative Smart City Application	Overall Score
News and insights smart systems related to City Life (perceptions about quality of life, opinions and ideas for prosperity and response to critical social problems)	3.8
Open educational spaces (integration of Massive Open Online Courses in a simple access point)	3.8
An advanced cognitive computing-based healthcare system for diagnosis	3.8
A global smart urban network connecting research institutions all over the world for the promotion of a humanistic vision	3.8
A wide area network with distributed scientific committees and ongoing open source projects	3.8
The utilization of the smart city infrastructure for the enhancement of youth entrepreneurship or startups networks	3.8
An Augmented Reality (AR) application in the historical centers of World Capitals enabling access to immersive scenarios of content explorations	3.7
The design of an Innovation hub, where innovators, individual or businesses, industrial partners and funding organization collaborate to build joint alliances	3.7
A transparent ecosystem of open and distributed, publicly accessible analytics	3.7
A big data platform for managing inquiries over medical data, for example, automatic planning of medical appointments or services supervising cost control in health expenditures are interesting applications	3.7
Smart Urban applications for digital signatures issuing over distributed documents	3.7
An advanced Question and Answering System with collaborative filtering and automatic suggestions	3.7
A volunteer-based scientific collaborative space with the provision of open projects for participation and delegation	3.7

- A number of responders, holding a Ph.D., are looking for trusted news and insights systems, related to City Life. There is a well-defined market of citizens that are interested in this category of content. Diverse technologies and systems can support such an application.
- There is a high demand for open educational spaces, and one-stop-access learning services in the context of a smart city. The majority of the respondents of our survey indicated that the support of training and learning is a key aspect of a smart cities infrastructure.
- There is a high interest in research collaboration enhancement through services that promote international collaboration and group competencies.
- Users are also interested in applications for the provision of collaborative spaces for start-up ecosystems and the enhancement of entrepreneurship.
- Special interest also citizens show for services and applications that promote cultural and historical heritage in an integrated way.
- In the top priorities of users also is the case of digital signatures which allows flexible, dynamic and real-time services.

4.3. Top 13 Services in Favorable Use—Intention to Use

In Table 2, we also summarize the top 13 services based on the perceptions of participants in our survey. While for sure the generalization of findings has limitations, the responses are indicative and highlight a strong trend: users are interested in trusted news related to the city, are eager to enjoy high-quality healthcare smart services, and also look for innovation and enhanced education and training. E-democracy platforms and services, as well as an application for the promotion of trusted business, innovation and entrepreneurship through research collaboration, are highlighted.

Table 2. More favorable to use smart city services per cluster.

ICT Cluster	Services	−USE	+USE	Favorable+
1. CMS	News and insights smart systems related to City Life (perceptions about quality of life, opinions and ideas for prosperity and response to critical social problems)	21%	79%	58%
3. NETWORKING	An advanced cognitive computing-based healthcare system for diagnosis	26%	74%	48%
4. DW	The design of an Innovation hub, where innovators, individual or businesses, industrial partners and funding organization collaborate to build joint alliances	27%	73%	45%
1. CMS	Open educational spaces (integration of Massive Open Online Courses in a simple access point)	28%	72%	44%
5. Emerging Techs	An Augmented Reality (AR) application in the historical centers of World Capitals enabling access to immersive scenarios of content explorations	28%	72%	44%
1. CMS	Smart Urban applications for digital signatures issuing over distributed documents	28%	72%	43%
3. NETWORKING	A global smart urban network connecting research institutions all over the world for the promotion of a humanistic vision	28%	72%	43%
3. NETWORKING	A wide area network with distributed scientific committees and ongoing open source projects	28%	72%	43%
1. CMS	Governmental platform for discussion on planned reforms and feedback management	29%	71%	42%
4. DW	A transparent ecosystem of open and distributed, publicly accessible analytics	30%	70%	40%
4. DW	The utilization of the smart city infrastructure for the enhancement of youth entrepreneurship or start-ups networks	31%	69%	38%
3. NETWORKING	A volunteer-based scientific collaborative space with the provision of open projects for participation and delegation	32%	68%	36%
2. COLLABORATION	An advanced Question and Answering System with collaborative filtering and automatic suggestions	33%	67%	35%

4.4. Less Favorable to Use/Intention to Use Smart City Services

In this section, it is quite interesting to realize also some services that many users would not be happy to use, based on their value perception or consideration of security, privacy etc. In Table 3, below you can find an overview.

Table 3. Less favorable to use smart city services per cluster.

ICT cluster	Services	−USE	+USE	Favorable+
4. DW	A business miner/insider of social opinions and beliefs through rating mechanisms of business services and quality of customer support	37%	63%	25%
3. NETWORKING	An integrated complains management system over social networks	38%	62%	24%
4. DW	A cloud-based, system for accessing and expanding the smart services	38%	62%	24%
1. CMS	Social campaigns management run by active citizens	38%	62%	23%
2. COLLABORATION	Open shared collaborative spaces for communities of practice in the context of smart cities	38%	62%	23%
5. Emerging Techs	A smart mobile application capable or recommending news alerts to citizens based on their opinions as they are expressed in social media	39%	61%	23%
4. DW	Advanced notification services for status changes related to the human activity	39%	61%	22%
4. DW	A Value adding service between Smart Cities networks (e.g., the Smart City Lighthouses projects in Europe)	39%	61%	22%
5. Emerging Techs	An advanced accessibility application capable of customizing the interface of smart applications to disabled people	39%	61%	22%
2. COLLABORATION	An advanced visualization system for analytics related to individual and group performances in the smart city	39%	61%	21%
6. Smart City Innovation	An application where citizens and other stakeholders vision the City of 2050 or City of 2060 are good initiatives for minds and creativity. The collective wisdom should be exploited for good purposes	40%	60%	20%
3. NETWORKING	A peer to peer application like MyCitySmartConnect for smartphones enabling the effective sharing of files, as well as opinions, ideas, etc.	40%	60%	20%
2. COLLABORATION	An automated message exchanging system between different authorities and organizations in the smart city context, for automating the workflow of distributed processes affecting citizens perceptions about service and support	41%	59%	18%
5. Emerging Techs	An integrated system of Audio Sensors in urban areas detecting the noise and customizing policies for its management and protection of urban areas	41%	59%	18%
6. Smart City Innovation	A smart application that brings together the most talented people in a city and through the exchange of ideas and joint efforts they design new services innovations and systems	42%	58%	17%
3. NETWORKING	A mobile application aiming to aggregate personal contributions about museum exhibits	42%	58%	16%
1. CMS	A Smart City MOOCs system integrated with social mining capabilities and analytics	42%	58%	15%
3. NETWORKING	A supervising system for the dynamic allocation of network resources to different applications run in the smart urban design can secure an excellent quality of services	43%	57%	15%
4. DW	Open Architectures for community-based problem solving	43%	57%	15%
6. Smart City Innovation	An open dialogue platform that for the same problem aggregates the propositions of different scientific or social communities	43%	57%	14%
1. CMS	Customized smart city tollbars over browsers ("LoveMyCity") and rating systems to local services or resources in an urban territory	43%	57%	13%
1. CMS	Smart Services against victimization and harassment etc.	46%	54%	8%
4. DW	Rating Systems over Big Data	50%	50%	1%
2. COLLABORATION	An automatic video annotator of Smart City executive meetings	53%	47%	−6%

5. Discussion and Conclusions

The objective of this paper was to explore the link between end-users' perceptions and expectations regarding smart city services to the industry's (broadly defined) awareness and capacity to respond to citizens' needs and expectations. Some of the key findings outlined in this research are as follows:

- Citizens show different perceptions of different types of services. Most of them are willing to use smart city services that promote them trusted news from local communities, access to learning and training resources plus services that promote innovation and entrepreneurship at a global scale.
- The average rating for the frequent use of diverse technologies for the provision of smart city services is ranging from 34% to 46%. This, in fact, provides a critical mass of users for smart city services.
- A question for future research is related to advanced policy-making: what are the strategies and policies that should be developed to alleviate end-users' concerns regarding the efficiency and credibility of ICT-enhanced services in city/urban space? How to ensure that the existing services add value to citizens lives?
- A significant part of responders ranging from 19% to 25%, defines themselves as have a user of smart cities applications with great motivation to adopt smart cities services, enabled by all the seven clusters of smart cities enabling technologies.
- As a direct interpretation of the above findings, it is evident from our empirical study that almost two-thirds of responders constitute a group of light and heavy smart cities services. In fact, it seems that the adoption of various services in the past years resulted in increased motivation and intention to use smart cities services.
- There are still well-educated people that are really concerned about the use of smart cities services and application. Based on the findings of our research, this group of people is ranging from 11% to 13% of the total population. This is a key finding of our research and for sure, future research should analyze further the qualitative characteristics for their disposition to use smart services. In most of the cases, these are related to privacy and security concerns.
- One more key finding is that content management and networking services have currently the greater number of users with a strong outlook also for use in the near future.
- Users are looking for trusted news and insights systems, related to city life. There is a well-defined market of citizens that are interested in this category of content. Diverse technologies and systems can support such an application.
- There is a high demand for open educational spaces, and one-stop-access learning services in the context of a smart city. The majority of the respondents of our survey indicated that the support of training and learning is a key aspect of a smart cities' infrastructure.
- There is a high interest in research collaboration enhancement through services that promote international collaboration and group competencies.
- Users are also interested in applications for the provision of collaborative spaces for start-up ecosystems and the enhancement of entrepreneurship.
- Special interest also citizens show for services and applications that promote cultural and historical heritage in an integrated way.
- In the top priorities of users also is the case of digital signatures which allows flexible, dynamic and real-time services.
- Users are interested in trusted news related to the city, they are eager to enjoy high-quality healthcare smart services and also look for innovation and enhanced education and training. E-democracy platforms and services, as well as an application for the promotion of trusted business, innovation and entrepreneurship through research collaboration, are highlighted.

One of the key purposes of our study is to link end-users' perceptions and expectations with industry's response [3]. As a critical interpretation of these key findings or our research, given the limitations, we have to comment on the following:

1. Our finding supports somehow, or it is an indication that the argumentation provided by Hollands [19], that "Driven by the profit motive of global high-technology companies, in collusion with the trend towards city governance being wedded to a competitive form of 'urban entrepreneurialism', has left little room for ordinary people to participate in the smart city". A critical number of responders in our study highlighted their concerns and their limited motivation to be parts of smart cities services mostly concerned about privacy, security and trust of ICT-enabled platforms. Based on propositions of Hollands that a key response to the weak performance of the dominant normative bias of ICT's experts and industry partners related to the effectiveness of smart city services, a radical shift in smart cities research concerns considering smartness from different perspectives emanating from small-scale and fledgling examples of participatory and citizen-based types of smart initiatives. This is a bold finding that needs to be interpreted by Industry players and Industrial partners in Smart Cities Services Domain.
2. In close relation to the ideas and opinions expressed by Sennett [20] in "No one likes a city that's too smart", it is extremely interesting to realize that the responders of our survey ranked in the top priorities services that keep technology in the "background" and leave the space for creativity, peer matching, dialogue, research collaboration, skills, and competencies building. For example smart cities services like the ones highlighted in our study "News and insights smart systems related to City Life (perceptions about quality of life, opinions and ideas for prosperity and response to critical social problems)", "Open educational spaces (integration of Massive Open Online Courses in a simple access point", "A global smart urban network connecting research institutions all over the world for the promotion of a humanistic vision", "A wide area network with distributed scientific committees and ongoing open source projects", "The utilization of the smart city infrastructure for the enhancement of youth entrepreneurship or startups networks" show that the smart cities research moves to a new level of maturity where advanced technologies provided by Industry matter only if they facilitate real human needs related to social networking for value-adding purposes.
3. A third significant finding and interpretation for the industry is the reality that most of the users of smart cities services seem to don't care for the sophistication of smart cities infrastructures and services. In a way, they consider technology as a "black box" where the complexity of computing approach does not matter for real users. This is a direct indication that sets design guidelines to Industry providers of smart cities services that the "human" factor matters more than the technology component.
4. An indirect interpretation of our study is also that Industry leaders and providers should adopt user perceptions analysis and studies in a wider context, depth, and breath. Our study was only a pilot study in which the generalization of findings needs to be done considering the social context of our research. Nevertheless, though some key findings provide significant insights that the future of smart cities research needs at least four critical components:
    a. Openness in the meaning of open participatory communities
    b. A balanced approach in terms of the social and technology components
    c. Trust, in terms of transparency of services, data protection, and privacy and authentication
    d. Integration, in the sense of complete, end-to-end user/citizen experiences
5. A direction for combined industrial and academic research must be in the same line with this pilot research. Given the billions that are spent worldwide for Smart Cities services and application, it is strategic to anchor investments in direct interpretations of user perceptions
6. From a sustainability point of view, it is critical to continue the debate about how social inclusive economic growth and open democracy can be facilitated by Smart Cities applications.

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

Appendix A Our Research Tool

Smart City Technologies

Content Management Smart Urban Systems Cluster

- Open educational spaces (integration of Massive Open Online Courses in a simple access point)
- The Smart Open University as an open space of dialogue
- A Smart City MOOCs system integrated with social mining capabilities and analytics
- Social campaigns management run by active citizens
- A Smart Urban Learning Management System for Entrepreneurs
- A Smart system of Social Inclusion, Diversity and Equality
- Smart Services against victimization and harassment etc.

Smart City Document Management Systems Cluster

- Smart Urban applications for digital signatures issuing over distributed documents
- Advanced voice navigation and narration systems over published documents and websites in Smart City Context for advanced accessibility
- Smart wikis hub for ideas, opinion, and social mining.
- News and insights smart systems related to City Life (perceptions about quality of life, opinions and ideas for prosperity and response to critical social problems)
- Sophisticated content annotators for citizens public comments and shared ideas
- Customized smart city toolbars over browsers ("LoveMyCity") and rating systems to local services or resources in urban territory.
- A collaborative community-driven vocabulary, taxonomy and annotation schema for smart city services
- Supervising systems of systems capable of aggregating and routing all relevant documents across distributed procedures.
- Documents as web services in a smart city context
- A marketplace of smart documents
- An integrated Information System for smart city administrators, policymakers a d computer engineers, for workflow modeling towards new smart city services and prototype systems generation

Smart City Micro-content Services and Systems

- Governmental platform for discussion on planned reforms and feedback management.
- Advanced participatory democracy applications for the dynamic aggregations of converging opinions, groupings based on beliefs etc.
- Smart urban application for summarizing trending opinions and feeling of citizens related to their quality of living, or complaints they might have from local authorities.
- A supervising application for distribution blocking of fake news and a related toolbar helping the member of the smart urban design to tag news as fake and thus preventing others from harm.
- A fully annotated, searchable ecosystem of cultural blogs promoting the exciting things that happen in the city.
- Social networks of collaborating artists, or citizens promoting open art
- Automatic translation system with voice navigation to the cultural context

- Chatbots as a smart city assistant (e.g., a chat bot that provides support to citizens requesting the issuing of a digital certificate)

Smart City Collaboration Systems and Services

- A smart requests' aggregator application for flexible response to citizens inquiries.
- An advanced Question and Answering System with collaborative filtering and automatic suggestions
- An automated message exchanging system between different authorities and organizations in the smart city context, for automating the workflow of distributed processes affecting citizens perceptions about service and support.
- A school is driven peer-to-peer collaboration system for the development of meaningful learning stories over shared cultural content.
- A smart ontology annotation system, that scans the entire minutes of meetings in Mayor Hall Meetings and permits citizens to extract or the public interventions of a member of City Council.
- An automatic video annotator of Smart City executive meetings
- An advanced visualization system for analytics related to individual and group performances in the smart city.
- Advanced visualizations of smart city neighborhood social networks
- A visual interactive system for navigating to documents archives in smart urban designs.
- Open shared collaborative spaces for communities of practice in the context of smart cities.
- A system of systems interface that integrates through APIs public discussions in social media and constructs automatically consultation documents about critical social issues.
- An intelligent matching collaboration service that brings together groups based on their expertise or capacities for promoting greater collaboration.
- Aa micro-spatial application that enables the exchange of messages between people in the same neighborhood.
- An integrated complains management system over social networks.
- An automatic service selection system based on workflow automation
- A global smart urban network connecting research institutions all over the world for the promotion of a humanistic vision.

Networking Technologies for Smart Urban Systems Cluster

- A hotspot for micropayments or crowdfunding for smart services sustainability
- A peer-to-peer networking service for activism or open dialogue.
- An advanced networking system for the integration of patient records and advanced data mining value adding services
- An advanced cognitive computing-based healthcare system for diagnosis.
- A wide area network with distributed scientific committees and ongoing open source projects
- A volunteer-based scientific collaborative space with the provision of open projects for participation and delegation.
- A mobile application aiming to aggregate personal contributions about museum exhibits
- A supervising smart city system building dynamically profiles of citizens based on their interaction with several other value-adding systems related to their daily life and interaction with all the types of activities and services offered in the context of the smart city.
- A peer to peer application like MyCitySmartConnect for smartphones enabling the effective sharing of files, as well as opinions, ideas, etc.
- A supervising system for the dynamic allocation of network resources to different applications run in the smart urban design can secure an excellent quality of services.

Data Ware Houses and Distributed Systems for Smart Urban Applications

- A semi-automatic annotator of citizens records with a wide-spread scan of all the dispersed databases as a first basis for integration.
- Advanced notification services for status changes related to human activity
- A communication mechanism powered by Semantic Web Technologies aiming to orchestrate the integration of the various data marts with ontologies annotation.
- A big data platform for managing inquiries over medical data, for example, automatic planning of medical appointments or services supervising cost control in health expenditures are interesting applications.
- An Open Educational Big Data Archive of learning resources
- A business miner/insider of social opinions and beliefs through rating mechanisms of business services and quality of customer support.
- Open Architectures for community-based problem solving,
- Open Social Networking for collaboration.
- A smart city integral hub for businesses listing and collaboration
- The design of an Innovation hub, where innovators, individual or businesses, industrial partners and funding organization collaborate to build joint alliances.
- E-Marketplaces of skills and competencies dedicated to promoting the human capital of smart cities,
- E-marketplaces dedicated to local products, cultural artifacts or e-marketplaces related to the exchange economy of social business and entrepreneurship at a local or global scale.
- A secure payment service that can be used by any member of the smart city on demand for the design of export activity.
- A Value adding service between Smart Cities networks (e.g., the Smart City Lighthouses projects in Europe).
- The utilization of the smart city infrastructure for the enhancement of youth entrepreneurship or startups networks.
- Rating Systems over Big Data
- A cloud-based, a system for accessing and expanding the smart services

Analytics and Business Intelligence Smart Urban Systems Cluster

- A transparent ecosystem of open and distributed, publicly accessible analytics
- An application capable of visualizing profile elements not related to explicit knowledge, like beliefs, opinions and calculating the distance between citizens in terms of their personalities would be a case for this cluster.
- A recommender system promoting peers for potential collaboration for joint entrepreneurship.
- A system capable of integrating smart regions urban designs can serve as a hub of collaboration and prosperity.

Emerging Technologies Smart Urban Systems Cluster

- An Augmented Reality (AR) application in the historical centers of World Capitals enabling access to immersive scenarios of content explorations.
- An AR system supporting a Smart City Schools Distributed Open Laboratory of Life Sciences.
- An advanced accessibility application capable of customizing the interface of smart applications to disabled people
- A smart mobile application capable or recommending news alerts to citizens based on their opinions as they are expressed in social media.
- An open source coding lab for young students
- A Virtual Reality Laboratory System for advanced services e.g., realization of Prototypes of Services, Designs of User Experiences for Smart City Interaction.

- A Robotics Lab where showcases and experimentations can take place.
- An integrated system of Audio Sensors in urban areas detecting the noise and customizing policies for its management and protection of urban areas.
- An advanced sensor system with cameras and cognitive capabilities alarming authorities for abnormal behavior.
- An advanced IoT service for the fleet management of vehicles in smart urban designs for cost utilization and monitoring.

Smart City Innovation—Smart Urban Systems Cluster

- A smart application that brings together the most talented people in a city and through the exchange of ideas and joint efforts they design new services innovations and systems.
- An open dialogue platform that for the same problem aggregates the propositions of different scientific or social communities.
- An application where citizens and other stakeholders vision the City of 2050 or City of 2060 are good initiatives for minds and creativity. The collective wisdom should be exploited for good purposes.

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sustainability

Article

Smart City Development and Residents' Well-Being

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Abstract: The development of smart cities has greatly improved the living and working environment of urban residents, but whether it can enhance the happiness of urban residents is a controversial topic. In this study, we investigate residents' experiences of obtaining information, services and networks in smart cities from the aspects of safety, usefulness and convenience, and empirically explore their relationship with residents' subjective well-being (SWB). The results show that residents' safety, usefulness and convenience experiences of obtaining information, services and networks in smart cities all have positive impacts on their SWB, and the relationship between residents' safety experience and SWB is, to a certain extent, mediated by their usefulness and convenience experiences.

Keywords: smart city; usefulness experience; safety experience; convenience experience; SWB

1. Introduction

Since the concept of the smart city first appeared in the 1990s [1,2], the theoretical research dynamics and practical development status of smart cities have attracted the extensive attention of academic circles and industry internationally [3]. Anthopoulos [3] provides an "umbrella" definition of the smart city: new or existing cities or regions that use ICT (information and communication technology) and innovation as a means to achieve sustainability in economic, social and environmental terms, and to address several challenges dealing with six dimensions (people, economy, governance, mobility, environment and living). The ultimate goals of a smart city are convenience of public services; livability of the living environment; smartness of infrastructure; long-term effectiveness of network security; and strength of the economic outlook [4].

Smart infrastructure and smart services (SISS) are the core elements of a smart city [5]. Smart infrastructure includes hard infrastructure (all urban facilities and all ICT-based hardware) and soft infrastructure (individuals and groups of people living in the city, business processes, software applications and data), which are equipped with the latest ICT to provide corresponding smart services [3]. The International Standards Organization (ISO) has explained the types of smart services, including climate change adaptation, e-government, transport, logistics, healthcare, energy and resources, environmental protection, public safety, and community and household [4,6]. The technology in smart cities itself is not used to provide smart services [7]. Smart services use ICT and hard and soft infrastructure to provide "products, services and utilities" to stakeholders, so as to improve the quality of life and livability of the whole city [3,8].

The Chinese government attaches great importance to the development of smart cities, especially the construction of smart infrastructure. All construction investment is to improve the service level of government and social institutions to citizens [9]. According to the *New Smart City Development Report 2017*, intelligent infrastructure includes information infrastructure (sensing infrastructure, passive and active network facilities, user-side peripheral equipment) and intelligent municipal infrastructure (synthesis pipe gallery, the sponge city, municipal utility, big data platform and information network transmission), aiming at solving the problems of urban citizen service and municipal issues [9]. In China, information and services acquired by residents in smart cities are provided by smart infrastructure, including transportation, employment, government affairs, online education, urban supervision and management, social security, medical care, mobile internet life, city cards and wireless networks [9]. Hangzhou, one of the pilot smart cities in China, has been accelerating the development of smart city models since 2012, and has completed the construction of intelligent digital urban management systems and integrated command systems. As of the end of September 2016, the timely settlement rate of urban management issues in Hangzhou's urban management public cases increased from the initial 26.7% to 99.33%, and the construction effect was very significant [9].

Although theoretical research and practical construction have been effective, the field of the smart city is still in its infancy, and there is a certain gap between utopia and reality [5,10]. The development of smart cities costs a lot of money, but its initial basic goals have never been fully met [11]. Considering the complexity of the real situation, the urgent task for the development of smart cities is not to make multi-faceted investment with existing resources and funds, but to focus on the areas that are in shortage and in urgent need for improvement, so as to formulate a development strategy of smart cities [12]. The application of information technology has been deeply rooted in people's work and life, and the demand of residents to participate in urban management has increased significantly, and they require a higher level of public management and public service level [13]. Improving residents' sense of well-being has become the main driving force and ultimate goal of smart city construction in various countries [14], which is also listed as an important indicator of the smart city evaluation system [15].

Subjective well-being (SWB) measures quality of life and determines the importance of smart cities in people's lives [16]. Different countries and cities have different levels of development, and residents' experiences and demands for happiness are also at different levels [17,18]. At present, some scholars have begun to pay attention to the topic of well-being brought by the smart city to the residents [19]. The Dubai government has committed to applying the smart city's hardware and software technology to the improvement of happiness and proposed the ABCDE model of needs linked to SWB, namely, affective and emotional (A), basic (B), cognitive and evaluative (C), deeper and eudaimonic (D), and enabling (E) [20]. In South Korea, practical research on smart tourism technology (STT) has been shown to increase the happiness of tourists [21]. Vagnoli et al. [22] developed the SensorWebBike service framework by using the network information technology of a smart city, aiming at more effective monitoring of urban air quality and improving the living environment of urban residents.

Although the research process of the smart city has been in place for more than 20 years, current research on the smart city focuses more on its definition, practical application, commercial value and management [3], and rarely considers the direct feelings brought by the development of a smart city to its urban residents, and especially their SWB [23,24]. Our contribution lies in that, firstly, we focus on the subjective feelings of smart city development on urban residents' happiness, which enriches the theoretical research on smart city development. Secondly, safety experience, usefulness experience and convenience experience are introduced to empirically study the driving factors of residents' SWB in smart cities, and a theoretical model is constructed. Finally, it provides an experience-feedback-oriented research direction for the future development of smart cities.

Based on the above theoretical research basis, this paper explores the impact mechanism of intelligent infrastructure and intelligent services on the SWB of residents in smart cities from residents' perceptions. Through the use of questionnaire survey data from 247 residents in China's smart cities, we examine relevant research hypotheses and propose guidelines and strategies to promote the long-term development of smart cities.

2. Theoretical Background and Research Hypotheses

SWB is an important concept in the field of positive psychology and quality of life, and refers to an overall assessment of an individual's self-state and quality of life in a certain period of time, including life satisfaction, positive emotion, and negative emotion [17]. Positive and negative emotions are also generally considered as the perceptual dimension of SWB, which refers to individuals' perception of their own subjective emotions; life satisfaction is considered to be the cognitive dimension of SWB, which refers to individuals' perception and evaluation of their current living conditions [17]. With changes of the environment and the way of interaction between people and the environment, the individual's SWB also changes [25]. The introduction of SISS is the most important feature distinguishing a smart city from other urban concepts. This paper will explore the impact of this environmental change on residents' SWB.

In the marketing research field, experience becomes the third key element in attracting consumer attention to consume products and services beyond functionality and quality [26]. The experience stems from a series of complex interactions between customers and products [27]. Through the use of the product, customers can create their own unique experiences [28]. Pine and Gilmore [29] classify consumer experiences into four types based on the customer engagement and the desire or performance of customer access to the activity: entertainment (passive-absorption), educational (active-absorption), escapist (active-immersion), and esthetic (passive-immersion). Schmitt [30] defined the customer experience in five dimensions: sensory experiences (sense); affective experiences (feel); creative cognitive experiences (think); physical experiences, behaviors, and lifestyles (act); and social identity experiences. Gentile, Spiller and Noci [26] proposed six components of customer experience based on previous research, namely, sensorial, emotional, cognitive, pragmatic, lifestyle and relational. In recent years, the experience is increasingly recognized as a multi-dimensional and holistic evaluation applied to marketing and tourism, including all kinds of perceptions and cognitive evaluations of users in the process of consuming products and services [26,27]. In this paper, we portray the concept of experience in the marketing field to the development of smart cities, describing a variety of various functional perceptions and evaluations that urban residents bring in the process of using smart infrastructure and enjoying services. The information security of the system was a concern to the citizens participating in the project of a smart city [31], and the perceived usefulness and the perceived ease of use are the two main factors affecting users' acceptance and behavior when using the new system [32], as well as the drivers of urban residents' use of SISS. This paper portrays the functional experiences generated by urban residents using SISS with regard to three aspects: security, usefulness, and ease of use, and attempts to explore their impact on the SWB of urban residents.

Creating an effective user experience within a smart city is an important factor of success [33]. The Stimulus-Organism-Response (SOR) framework of environmental psychology argues that objective conditions such as atmosphere, design, and social factors stimulate consumer perceptions [34]. In smart cities, SISS, as a kind of artificially created activity scene, will inspire urban residents to participate actively or passively and produce various experiences. Residents' personal experiences of SISS may change their situations and paces of life, which may directly affect emotional changes, different levels of needs and cognitive attitudes [20]. In addition, experiential marketing can provide emotional and functional values through feel perception, think perception, and service quality to induce customer satisfaction in hotels and the tourism industry [35]. At the same time, self-determination theory argues that when a person's behavior satisfies the three basic psychological needs of ability, relationship, and autonomy, the individual's well-being increases [36]. Based on the above analysis, we believe that the three functional experiences brought about by urban residents using smart infrastructure and enjoying services can enhance the satisfaction of their three basic psychological needs, thus promoting their well-being.

2.1. Residents' Safety Experience and Their SWB in the Smart City

When urban residents use SISS, their personal information and activity trajectories will inevitably be recorded and preserved by relevant smart devices, and they will become a key resource for related operators of the smart city to provide intelligent and personalized services to residents [37]. According to exchange theory, this phenomenon can be understood as a kind of exchange of realism, that is, the exchange of individual privacy information for high-quality services [38]. Safety experience refers to the security residents feel when using SISS, especially the perception of personal information and that their behaviors are not disclosed and utilized [39]. In the process of information transmission and processing, whether information will be leaked will affect the user's psychological cognition and behavioral judgment [40,41]. Safety experience reflects residents' psychological cognition of the risk of information leakage caused by the use of SISS, and it has an important impact on their living and working conditions.

Although different countries' governments have different attitudes toward the privacy issue and have built different legislative systems, and users also have different ideas when private information are collected [42], the private information security of residents has always been the focus of smart city development. Li et al. [43] and Kansal [44] pointed out that a poor safety experience would make users confused and doubtful about the quality of the services provided online, and even fall into negative emotion in severe cases. The studies [45] on privacy concerns also pointed out that even if the user's private information was not revealed, the users' privacy concerns caused by enjoying online services would produce a feeling of anxiety that affected their emotions and quality of life. Hayes et al. [46], Dinev and Hart [47], and Hsiao and Hwang [37] found that, if certain commitments were given to residents on the information supervision platforms of a smart city, and residents were clearly told that their personal information was protected, they would be more confident of smart city development, especially SISS. The increased safety experience will reduce residents' privacy concerns, and raise their faith in SISS [47], which in turn will make them enjoy the pleasure and happiness in the use of SISS [48], and give rise to good SWB. Moreover, a safety experience can enable urban residents to show positive self-sense, which can bring a sense of control and emotional pleasure [49]. Moreover, urban residents will pay more attention to personal development and self-expression, which can promote their well-being by meeting basic psychological needs [50]. Based on this, Hypothesis 1 was proposed.

Hypothesis 1. *Residents' safety experience in a smart city is positively related to their SWB.*

2.2. Residents' Usefulness Experience and Their SWB in the Smart City

In the technology acceptance model (TAM), perceived usefulness is a key factor in explaining a user's acceptance of a new system. It refers to the user's perception of a particular system that contributes to improving their performance [32]. The usefulness experience broadens the application range of perceived usefulness and reflects the extent to which user needs are effectively met [51]. It is mainly used to describe urban residents' perception of the information and service they get by SISS that is beneficial for the improvement in the quality of their life and job.

According to the theory of self-determination, individuals have three basic psychological needs: autonomy need, competence need and relatedness need [52]. The competence need is individuals' self-confidence and efficacy perceived in their interaction with social environment [53]. When an individual's competence need is met, their well-being will rise [54]. A good usefulness experience means that the information and services that urban residents have access to through SISS can actually improve their quality of life and job performance [5]. This experience can enhance residents' self-efficacy, including better adaption to the social environment and accomplishing their tasks more efficiently [55]. That is, to some extent, their competence need is better met, which will lead to higher life satisfaction and more pleasure for urban residents. In addition, when urban residents have a good usefulness experience, they will strengthen their pursuit of a better life in the future [56,57], which will make residents produce positive emotions, such as optimism, and alleviate their negative emotions brought about by life and work stress, such as anxiety and tension [58]. Based on this, we propose Hypothesis 2.

Hypothesis 2. *Residents' usefulness experience in a smart city is positively related to their SWB.*

A good usefulness experience can bring positive emotions and inner satisfaction to urban residents [58], but they will feel hesitant if they need to sacrifice personal privacy [45]. Although some users are willing to provide more private information to obtain personalized services [59,60], self-protection awareness has prompted rejection and aversion to personal privacy breaches [44]. This means security, especially information security, is a prerequisite for residents to obtain the information and services they need through SISS. A good safety experience enables residents to generate trust in SISS. This trust not only allows urban residents to enjoy pleasure in the use of SISS and to be satisfied with the urban environment, but also allows them to better concentrate to accomplish specific tasks through SISS, which will enhance residents' usefulness experience. Therefore, we believe that safety experience not only directly affects residents' SWB, but also produces an indirect promotion by enhancing the usefulness experience of urban residents. Based on this, we propose Hypothesis 3.

Hypothesis 3. *Usefulness experience in a smart city mediates the impact of residents' safety experience on their SWB.*

2.3. Residents' Convenience Experience and Their SWB in a Smart City

Significant costs and energy consumption have been saved by efficiently using information and communication technologies (ICTs), which have improved service quality and brought convenience to residents' lives [61]. Convenience experience refers to the degree of convenience experienced by urban residents in the use of SISS, especially in terms of time and effort savings [62,63]. In the process of purchasing or consuming goods and services, the convenience of products or services will affect the users' mood and attitudes, and willingness to continue to use [64]. The convenience experience reflects residents' psychological cognition of the time and energy saved by the use of SISS. It not only determines their willingness to use the facilities and services, but also affects their attitude towards the working and living environment and their own emotions.

A good convenience experience means that urban residents can easily learn to use SISS, which will affect their SWB in the following two aspects. On the one hand, the mastery and rapid operation of SISS will bring them confidence and a sense of accomplishment, which will improve their self-efficacy and behavioral initiative by enhancing self-association [65,66]. In this way, residents' need for autonomy and competence will be better satisfied, and their happiness will be improved [67]. On the other hand, an effective convenience experience will help residents save time and effort in accessing information and services based on SISS [24,63,68], which allows them to have more time and energy to engage in social interactions and interpersonal communication than before. Moreover, self-determination theory believes that the satisfaction of individuals' relatedness need is related to social interaction and interpersonal relationships, which is beneficial to individuals' pursuit of meaningful happiness [50,69]. In addition, Colwell et al. [70] also pointed out that the more convenient it is for the user to enjoy the service, the higher their life satisfaction. Conversely, the more complex it is for the user to acquire the service, the more bored and disgusted the user is [71], which in turn creates some negative emotion and reduces their SWB [31]. Based on this, we propose Hypothesis 4.

Hypothesis 4. *Residents' convenience experience in a smart city is positively related to their subject well-being.*

As long as there are safety risks, such as the risk of private information leakage of residents, even if smart facilities and services are very easy to use, they will be questioned and distrusted by the residents of a smart city. The safety experience is the main focus of residents on smart city development, and is the basic premise for residents in deciding to use SISS [31]. A good safety experience means that when urban residents use SISS to obtain information and services, their safety, especially information security, can be effectively guaranteed. This guarantee for SISS is like the brand of the product, with value-added functions, which can bring praise to the convenience experience for SISS. At the same time, this safety experience will also alleviate residents' security concerns and allow them to focus more on the operational use of SISS for a better convenience experience [72–74]. Therefore, we believe that the safety experience not only directly affects residents' SWB, but also produces an indirect promotion by enhancing the convenience experience of urban residents. Based on this, we propose Hypothesis 5.

Hypothesis 5. *Residents' convenience experience mediates the impact of residents' safety experience and their SWB.*

Based on the above theoretical analysis, a conceptual model was proposed in this study, as shown in Figure 1.

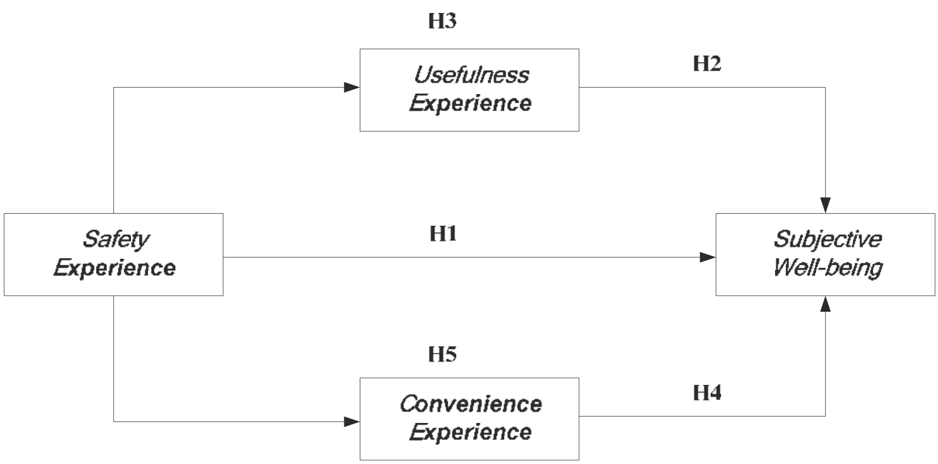

Figure 1. Conceptual model.

3. Methods

3.1. Questionnaire Design

This paper adopted a questionnaire to collect data, consisting of three parts. Firstly, the specification of the questionnaire explains the purpose of this study to the respondent, and promises that questionnaire responses will be anonymous that the data obtained will be used only for scientific research and is strictly confidential, and encourages the respondent to fill it out with confidence. The second part is the main content of the questionnaire, including the measurement of the safety experience, usefulness experience, convenience experience, and SWB. Each concept is clearly defined before each variable is measured to facilitate the correct understanding of the measurement item by the respondent. The third part comprises the demographic characteristic variables, which collects the basic information of the respondent, including basic information, such as gender, age, work, health, living city, and education.

3.2. Measurement

To ensure the validity and reliability of the measurement tool, the study utilized established scales to detect the core variables of the study. The Likert 6-point scale was used for this questionnaire (1 = completely disagree; 6 = completely agree). To ensure the effectiveness of the questionnaire, before the formalization of this research questionnaire and investigation, we conducted a small-scale pre-study of residents in Guangzhou, a representative smart city in China. After carefully listening to the respondents' opinions on the questionnaire, some statements were adjusted accordingly to minimize loopholes, such as unclear expressions and unreasonable design of the items. Finally, the content and number of items, and the wording of the questionnaire, were revised to form a final draft to guarantee the scientific and normative nature of the research tools. Measurement of key constructs can be found in Table A1 of Appendix A.

Security is one of the most important aspects of smart city concerns, involving the sustainable development of smart cities and the well-being of urban residents [39]. To measure residents' perception of their information and behaviors exposed in a smart city, the scale was modified from Hayes et al. [46] and includes three items: "The information is credible", "These services are of guaranteed quality", and "The process of obtaining such information or services is secure".

Usefulness experience measures the extent to which urban residents' needs for life are met, as well as the perceived degree of living standard and job performance. The concept of perceived usefulness in the TAM was combined with the measurement scale of Adams et al. [51] to obtain five items, namely, "The way this information or service is obtained is easy to learn and master", "The operation to obtain this information or service is simple", "The instructions for obtaining the information or service are clear and easy to understand", "It does not take much time to become an expert in accessing the information or services", and "These information or services can be accessed quickly in lots of ways".

Convenience experience measures the extent to which smart city residents spend time and effort on accessing services. This article uses the scale proposed by Seiders, Voss, Godfrey and Grewal [63] to measure the convenience experience, which comprises five items: "It makes me more efficient", "It improved my work performance", "It perfected my work environment", "It improved my quality of life" and "It makes my life more convenient".

SWB is an evaluation of people's affection and cognition, including the three dimensions of satisfaction with life, positive emotion and negative emotion [75]. For the measurement of satisfaction with life, this paper uses the scale proposed by Diener et al. [76] to determine how satisfied city residents are in the perception of SISS, including five items, such as "My living conditions are great". The measurement of positive emotion and negative emotion was performed using the scale of Watson et al. [77]. The items of positive emotion include "Active", "Enthusiastic", and "Happy". The five items of negative emotion include "Ashamed", "Sad", and "Afraid".

In addition, we also consider control variables that may affect SWB. Derdikman-Eiron et al. [78] and Kroll [79] have shown that men are more sensitive to emotional changes in happiness and women are happier. A study by Siedlecki et al. [80] indicates that there is a more complex link between residents' SWB and age. Shier et al. [81] argue that whether a user has a job also affects their cognitive judgment of happiness in life. A study by Lee and Browne [82] shows that people with physical and mental health are happier. In addition, people with good education have lower emotional distress, and higher SWB [83], since SISS are easier to understand and accept for people with higher education levels [84]. Therefore, this paper chooses gender, age, work, health and education as control variables.

3.3. Sample and Data Collection

The formal research of this study was conducted by urban residents of 220 new smart cities evaluated by the China Development and Reform Commission in 2017. The data collection work was conducted from March 2018 to the end of July 2018. Considering that the domain of the target of the questionnaire was too scattered, we used the third-party platform Questionnaire Star (China's largest questionnaire distribution platform) to produce an electronic questionnaire, and then distribute it randomly across the country. A total of 516 questionnaires were distributed, eliminating the questionnaires filled out by non-smart urban residents whose respondents had never used mobile payment (Alipay, WeChat, etc.) for purchase transactions, and those with more than 5% of the items not answered. Finally, 247 valid questionnaires were obtained, and the effective questionnaire recovery rate was 47.87%.

4. Analysis and Results

4.1. Reliability and Validity Analysis

We use the Cronbach's alpha value to test the reliability. As the results of Table 1 show, the Cronbach's alpha values of safety experience, usefulness experience, convenience experience, the satisfaction with life, positive emotion and negative emotion were, respectively, 0.865, 0.901, 0.920, 0.908, 0.934 and 0.885. All values exceeded the critical value of 0.7, indicating that the study scale had good internal consistency.

Table 1. The measurement model.

Measurement Item	Factor Loading	CA (Cronbach's Alpha)	AVE (Average Variance Extracted)
SE 1	0.828		
SE 2	0.895	0.865	0.683
SE 3	0.749		
UE 1	0.820		
UE 2	0.771		
UE 3	0.781	0.901	0.646
UE 4	0.866		
UE 5	0.778		
CE 1	0.839		
CE 2	0.892		
CE 3	0.871	0.920	0.699
CE 4	0.814		
CE 5	0.756		
TSWL 1	0.681		
TSWL 2	0.848		
TSWL 3	0.853	0.908	0.666
TSWL 4	0.846		
TSWL 5	0.840		
PA 1	0.810		
PA 2	0.871		
PA 3	0.870	0.934	0.740
PA 4	0.896		
PA 5	0.851		
NA 1	0.687		
NA 2	0.826		
NA 3	0.868	0.885	0.609
NA 4	0.815		
NA 5	0.687		

Note: extraction method: principal component analysis. $N = 247$. SE = safety experience, UE = usefulness experience, CE = convenience experience, TSWL = the satisfaction with life, PA = positive emotion, NA = negative emotion.

The measurement items in this study are from maturity scales of various variable fields, which guarantees the content validity of the scale. Furthermore, the use of confirmatory factor analysis (CFA) measures the aggregate validity of each scale. The results show that the fitting index of the overall measurement model is within the acceptable range ($\chi^2/df = 2.005$; CFI = 0.935; TLI = 0.926; IFI = 0.935; RMR = 0.062). As shown in Table 1, the factor load values of each index are greater than 0.6 and highly significant on the corresponding latent variables. The composite reliability (CR) of each variable is above 0.7, and the average variance extracted value (AVE) of each variable is greater than 0.6, which indicates that the data has a high degree of aggregation validity.

Because measurement items were answered completely by self-reporting of residents, there may be common method variance (CMV). We used the Harman's single-factor test to determine the range of CMV to reduce its impact on the results of the study. The results showed that principal component analysis extracted six factors with a total variance of 71.78%. There was no single factor, and the first factor accounted for only 37.29% of the interpretation variance. Therefore, this study largely controls the common method variance.

4.2. Descriptive Statistics of the Latent Constructs

The correlation coefficients between the variables and the mean and standard deviation of the respective variables can be seen in Table 2. Safety experience is significantly positively correlated with useful experience (r = 0.632, $p < 0.01$), and has a significant positive correlation with convenience experience (r = 0.695, $p < 0.01$). As for the correlations between the three experiences and SWB, safety experience has a significant positive correlation with SWB (r = 0.436, $p < 0.01$), usefulness experience has a significant positive correlation with SWB (r = 0.419, $p < 0.01$), and convenience experience has a significant positive correlation with SWB (r = 0.447, $p < 0.01$). These results formed the basis of subsequent regression analysis.

Table 2. Descriptive statistics and correlation analysis.

Variables	1	2	3	4	5	6	7	8	9
1. Gender	-	-	-	-	-	-	-	-	-
2. Age	−0.003	-	-	-	-	-	-	-	-
3. Work	−0.076	−0.086	-	-	-	-	-	-	-
4. Health	0.029	0.022	0.055	-	-	-	-	-	-
5. Education	−0.082	−0.056	−0.086	0.068	-	-	-	-	-
6. Safety experience	−0.061	0.215 **	0.101	0.051	−0.015	-	-	-	-
7. Usefulness experience	−0.116	0.200 **	0.087	0.018	−0.008	0.632 **	-	-	-
8. Convenience experience	−0.104	0.296 **	0.075	0.092	−0.104	0.695 **	0.651 **	-	-
9. SWB	−0.050	0.166 **	−0.041	0.141 *	−0.028	0.436 **	0.419 **	0.447 **	-
M	0.380	2.160	0.760	2.780	1.940	4.211	4.320	3.948	3.546
SD	0.487	1.136	0.430	0.627	0.733	1.057	0.978	1.175	0.708

Note: $N = 247$. SWB = subjective well-being. Significance levels shown are two-tailed for hypothesis testing and control variable. * $p < 0.05$, ** $p < 0.01$.

4.3. Hierarchical Regression Analysis

Our hypotheses were tested by using hierarchical linear regression analysis and the results are shown in Table 3. Model 1 (M1), Model 3 (M3), and Model 5 (M5) represent benchmark models for different dependent variables (M1 for UE; M3 for CE; M5 for SWE) with controlled variables, and examined the effects of gender, age, work, health, and education. Models 6 (M6), 7 (M7), and 8 (M8) were used to verify the impact of resident's safety experience, usefulness experience and convenience experience in a smart city on their SWB, respectively. We used Model 2 (M2), 4 (M4), 9 (M9) and 10 (M10) to examine the mediation effect of the useful experience and convenience of smart city residents on their relationship between safety experience and SWB. Model 11 (M11) is used to test the stability of the relationship between variables. The variance inflation factor of all models was less than 10, indicating that the model did not suffer from multicollinearity and the results were reliable.

Table 3. Results of hierarchical regression analysis.

Variables	UE		CE			SWB					
	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
Gender	−0.11	−0.08	−0.110	−0.07	−0.06	−0.04	−0.02	−0.01	−0.02	−0.02	−0.010
Age	0.21 **	0.07	0.300 ***	0.15 **	0.16 *	0.06	0.07	0.03	0.04	0.02	0.020
Work	0.10	0.03	0.080	0.01	−0.04 *	−0.09 *	−0.08	−0.08	−0.10 +	−0.09	−0.100 +
Health	0.01	−0.01	0.090	0.06	0.14	0.13	0.14 *	0.11 +	0.13 *	0.11 +	0.120 *
Education	0.01	0.02	−0.100	−0.10 *	−0.04	−0.04	−0.04	0.01	−0.04	−0.01	−0.020
SE		0.61 ***		0.65 ***		0.42 ***			0.28 ***	0.26 **	0.200 *
UE							0.41 ***		0.24 **		0.180 *
CE								0.43 ***		0.26 **	0.180 *
R^2	0.06	0.41	0.123	0.52	0.05	0.22	0.21	0.22	0.25	0.25	0.270
ΔR^2		0.35		0.40		0.17	0.19	0.2	0.20	0.20	0.014
F	3.23 **	27.92 ***	6.760 ***	43.68 ***	2.65 *	11.25 ***	10.46 ***	11.08 ***	11.55 ***	11.41 ***	10.800 ***
ΔF		141.95 ***		200.37 ***		51.51 ***	46.97 ***	50.51 ***	32.10 ***	31.65 ***	4.420 *

Note: $N = 247$. SE = safety experience, UE = usefulness experience, CE = convenience experience, SWB = subjective well-being. Significance levels shown are two-tailed for hypothesis testing and control variable. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Firstly, we tested the effect of resident's safety experience in a smart city on their SWB. Compared to Model 5, adding safety experience in Model 6 contributes 17% of the variance ($\Delta R^2 = 0.17$, $p < 0.001$). Residents' safety experience significantly affected their SWB ($\beta = 0.42$, $p < 0.001$); thus, Hypothesis 1 was verified. In the process of using SISS, residents are very concerned about information security and personal information privacy [37]. Furthermore, the above result shows that the better the residents' safety experience, the stronger their SWB will be. This result supported Hayes's [46] view that, through monitoring and protecting personal privacy information in related service platforms of a smart city, a safe social atmosphere was created in which residents become more confident in SISS, and get more satisfaction and happiness by using them.

Secondly, we tested the effect of residents' usefulness experience in a smart city on their SWB. Compared to Model 5, adding usefulness experience in Model 7 contributes 19% of the variance ($\Delta R^2 = 0.19$, $p < 0.001$). Usefulness experience of residents significantly positively affects SWB ($\beta = 0.41$, $p < 0.001$); thus, Hypothesis 2 was verified. The outcome demonstrated that residents' usefulness experience of SISS can predict their SWB in a smart city, and the government as a designer and promoter of a smart city should pay more attention to residents' usefulness experience and information security. Furthermore, the mediation of residents' usefulness experience in the smart city between their safety experience and SWB was analyzed using the procedure recommended by Baron and Kenny [85]. Comparing Model 2 with Model 1, 35% of the variance was explained in Model 2 ($\Delta R^2 = 0.35$, $p < 0.001$). In addition, it can be seen that the residents' safety experience significantly positively affects their usefulness experience ($\beta = 0.61$, $p < 0.001$). Apart from this, adding the mediating variable (usefulness experience) in Model 9 compared to Model 6 contributes 3% of the variance ($\Delta R^2 = 0.03$, $p < 0.01$). Specifically, the results indicated the positive effect of residents' safety experience on their SWB decreased (β dropped from 0.42 to 0.28), which indicates that usefulness experience partially mediates the relationship between residents' safety experience and their SWB. Hypothesis 3 was supported, meaning that residents' usefulness experience can not only directly enhance their SWB, but also serves as a bridge between the impact of security experience on SWB.

Furthermore, we tested the effects of residents' convenience experience in a smart city on their SWB. Compared to Model 5, adding convenience experience in Model 8 contributes 20% of the variance ($\Delta R^2 = 0.20$, $p < 0.001$). Residents' convenience experience had a significant positive impact on their SWB ($\beta = 0.43$, $p < 0.001$); thus, Hypothesis 4 was confirmed. This result complements the view of Hayat [61]. Through the use of SISS, residents save time and cost in their daily lives and work, and enjoy more convenience, which can encourage them to maintain a pleasant mood and an optimistic attitude. Similarly, we further tested the mediating effect of residents' convenience experience. Comparing Model 4 with Model 3, 40% of the variance was explained in Model 4 ($\Delta R^2 = 0.40$, $p < 0.001$). In addition, it can be seen that residents' safety experience significantly positively affected their convenience experience ($\beta = 0.65$, $p < 0.001$). It can be seen from the above results that the better the residents' information and trajectory on the related platforms of a smart city are protected, the better the convenience experience they enjoy. Additionally, adding the mediating variable (convenience experience) in Model 10 compared to Model 6, contributes 3.1% of the variance ($\Delta R^2 = 0.031$, $p < 0.01$). In addition, the positive effect of residents' safety experience on their SWB decreased (β dropped from 0.42 to 0.26), which indicates that convenience experience partially mediates the relationship between residents' safety experience and their SWB. Hypothesis 5 was supported, indicating that residents' convenience experience cannot only directly enhance their SWB, but also indirectly plays a bridge role in the influence of safety experience on SWB. In Model 11, we can also find that resident's safety, usefulness and convenience experience all significantly positively affected their SWB ($\beta = 0.2$, $p < 0.05$; $\beta = 0.18$, $p < 0.05$; $\beta = 0.18$, $p < 0.05$), which again supports above research hypothesis.

5. Conclusions

From the perspective of security, usefulness and convenience, we investigated the impact of residents' experience on their SWB. Through the empirical analysis of questionnaire data of 247 urban residents in Chinese smart cities, the relationship between residents' experience and their SWB was explored. First, we found that residents' safety experience not only played a positive role in their usefulness experience and convenience experience, but also had a positive effect on their SWB. This reveals that the safety experience is the basis for residents to obtain happiness from the use of SISS. In particular, if the safety experience is not guaranteed, the residents' usefulness experience and convenience experience will be greatly reduced. Second, residents' usefulness experience and convenience experience not only play a positive role in their SWB, but also mediate the positive impact of residents' safety experience on their SWB. This shows that the roles of safety experience, usefulness experience and convenience experience are different in affecting residents' SWB. In summary, with consideration of residents' experience of SISS, these results supported the views of Anthopoulos [3], Visvizi and Lytras [24], and Lytras and Visvizi [39] regarding the relationship of smart city construction and residents' well-being: safety, usefulness and convenience are three key characteristics of residents' experience in SISS influencing their SWB. In addition, we incorporated residents' experience into smart city construction, which expanded the research scope of the smart city from urban planning and technological progress to a humanistic perspective, and promoted user orientation in smart city construction.

Our findings have important managerial implications for smart city construction. Firstly, the development of smart cities relies on ICT, and increasing individual behavioral information is actively or passively entered into the smart city network. The storage and transmission of such information requires a high degree of security and confidentiality, and the perception of the residential network security environment is the basis for improving the usefulness experience, convenience experience and SWB. Second, there are differences between individuals, who are always pursuing services that meet their needs and maximize their own interests. The experience is concerned with the willingness and behavior of urban residents to participate, directly affecting their happiness. Therefore, the development of smart cities not only pays attention to the general needs of urban residents, but also satisfies their personalized needs, which is one of the important factors to improve the well-being of smart cities in the future. Finally, intelligent services meet the needs of people through the construction of intelligent infrastructure, which emphasizes that SISS is targeted at people. This also reminds governments, enterprises and relevant institutions to avoid blindness in the construction of smart cities (for example, economic development and government stimulating domestic demand and improving enterprise performance).

We acknowledge several limitations of this study, which also point to possible future research directions. First, we utilized a self-reported survey and a convenient sample research approach to collect the data. Future research may expand the geographical scope of the sample. Second, safety experience, usefulness experience and convenience experience are just three experiences that affect residents' SWB in a smart city. The experiences of residents are complex and changeable, and there may be other dimensions of residents' experiences that affect their SWB in a smart city, which is subject to further research and further exploration. Third, in this paper, the control variables have no substantial effect on subjective well-being. More control variables that may have a substantial impact on subjective well-being, such as marriage, personality traits, beliefs, etc., should be considered in the follow-up studies. In addition, regional culture and specific life events will also affect individuals' perceptions and attitudes towards life and work. Future research can also take them into account and conduct detailed research. They can also be considered in the future to explore the possible differences between long-term factors and sudden factors.

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Appendix A

Table A1. Measurement of key constructs.

Construct		Measurement Items
Safety experience		The information is credible. These services are of guaranteed quality. The process of obtaining such information or services is secure.
Convenience experience		The way these information or services are obtained is easy to learn and master. The operation to obtain this information or service is simple. The instructions for obtaining the information or service are clear and easy to understand. It does not take much time to become an expert in accessing the information or services. These information or services can be accessed quickly in lots of ways.
Usefulness experience		It makes me more efficient. It improved my work performance. It perfected my work environment. It improved my quality of life. It makes my life more convenient.
SWB	The satisfaction with life	In most ways, my life is close to my ideal. My living conditions are great. I'm happy with my life. So far, I've gained the important things I want in life. If I could start my life over, I would change almost nothing.
	Positive emotion	Active Enthusiastic Happy Elated Excited
	Negative emotion	Ashamed Sad Afraid Nervous Horrified

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Analysis of Social Networking Service Data for Smart Urban Planning

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Abstract: New technologies are changing the channels of communication between people, creating an interconnected society in which information flows. Social networks are a good example of the evolution of citizens' communication habits. The user-generated data that these networks collect can be analyzed to generate new useful information for developing citizen-centered smart services and policy making. The aim of this paper is to investigate the possibilities offered by social networks in the field of sport to aid city management. As the novelty of this research, a systematic method is described to know the popular areas for sport and how the management of this knowledge enables the decision-making process of urban planning. Some case studies of useful actions to make inclusive cities for sport are described and the benefits of making sustainable cities are discussed.

Keywords: Smart Cities; social networks; ambient behavioral analysis; urban planning; decision making; sustainability; accessibility

1. Introduction

Information and data have become a new working tools in the area of informational urbanism. From the access to information emerges the new urban paradigm that spreads to other disciplines such as cybernetics, information theory, self-organization, or systems theory, giving rise to a new urban model based on flexibility, uncertainty, and open and self-organized systems. The incorporation of these concepts into the field of urban planning is currently a process with great development potential. The traditional tools urgently need to be complemented by new tools based on information, which help to understand the increasing complexity of cities and their continuous evolution and transformation.

Thus, we are witnessing a slow reformulation of the urban planning paradigm [1,2]. The image of urban planning has gone from being static to a reality in motion, where the environment and the citizens themselves in continuous evolution are important sources of data, constantly providing relevant information for better urban planning, adapted to the real changing needs of the city, and the real requirements and preferences of citizens. To this end, the inference of information on city services usage and citizens habits is of great help to design smart urban planning actions and to improve city management [3].

The development of new Information and Communication Technologies (ICT) has led to major changes in society in recent times. Today, the proliferation of smart devices and mobile communication in the hands of users has enabled the creation of new applications and services aimed at improving the lives of citizens. This development is altering people's communication habits, their relationship with the environment and with others, creating an interconnected society in which information flows. ICT is affecting the growth and structure of the cities and can be used to make them more sustainable [4].

Social networks are a good example of this evolution in the citizens' communication habits. In general terms, a Social Networks Site (SNS) or Social Networking Site can be defined as a service (web-based or through a mobile App) that allow users to share a personal profile and make contacts with other users [5]. In this way, a SNS is a platform where users can spread information about themselves, their preferences, their tastes, their hobbies, their creations, or their professional activities.

The great acceptance in many sectors of society, and especially among the young population, has generated dizzying growth and ensures a promising future with many social implications. Currently, we can find the presence of social networks in many areas of society, such as social communication, education, or employment [6]. They have become a fundamental part of our lives [7]. SNS contain explicit and implicit information about social structure and almost any aspect of the daily life of citizens such as practices, preferences, pictures, etc.

The information collected into these communication spaces can be analyzed to generate new useful knowledge [8,9]. The applications of this source of data are very broad since it comes directly from users in the development of their daily activities. Thus, for example, there are previous works of analysis in the fields of education [10–12], social interaction [13], and labor [14].

Social networks are also a powerful tool to obtain knowledge about a city. Currently, they are one of the main sources of information available to urban planners in order to find out how users of the city use public space. Knowing the real uses that citizens make of urban public space is fundamental for the planning and smart design of cities.

Nowadays, governance must take advantage of new opportunities and the possibilities of the internet age [15]. New technologies enable citizens to participate in a direct way in the decision-making process. Administrations have evolved towards citizen-centric management where government and citizens can work together in designing better cities. This trend is shaping the concept of the Smart City, which is mainly characterized by the use of ICT for increasing the quality of life of its citizens [16].

This research is aimed at taking this opportunity by analyzing social network services. Specifically, this work is focused on the analysis of SNSs in the field of sport, in which users provide information related to their activity, as well as the scores, times, and routes through which they practice sport.

This work extends a preliminary approach presented at Urban Growth '18 conference [17]. In that work, the feasibility of the approach was presented through a simple analysis but no suggestions for policy-makers were proposed. Once the idea has been validated, a more detailed analysis and broader understanding of the data inferred from sporting SNS have been undertaken in this work.

In short, the main objective of this new research is to study the information retrieved from SNS on sport activities and its potential for improving urban planning of the city, that is, to design better infrastructure based on where and when it is used. As a secondary objective, this work aims to analyze the most popular areas of the coast side of the Alicante city to check its suitability for sporting activities.

The major contribution comes from the methodology used to identify the common places of the city where sport is practiced, as well as the systematic analysis performed on the retrieved data from the SNSs. Other contributions are the identification of common issues along the city and the proposals for making the urban space more inclusive, taking the City of Alicante as an example.

These contributions are also the main novelty in relation to the previous research. As will be described in the related work section, existing investigations (including our previous one) are focused on the potential of data from 'big app' companies to conduct research focused on georeferenced-point data but not specific urban actuation.

In this way, the information from sport SNSs allow implementation of policies for transforming the city into an inclusive, accessible, and usable urban space.

To address the above issues, we first conducted a review of the related work on the analysis of social network data as a source of information, and how they can be used for improving city management; next, in Section 3, we explain the possibilities offered by user-generated data retrieved from sport SNS; Section 4 describes an application scenario where some urban actions are proposed; and finally, conclusions and some future research lines are described in Section 5.

2. Related Work

The following text briefly describes the current state of knowledge on the different aspects of this research. The conclusions of related studies are also summarized below.

2.1. New Tools for Enabling Informational Urbanism

The emergence of new data processing technologies has provided powerful tools for informational urbanism. Big data, data mining, or data analytics are able to provide valuable knowledge about the city dynamics [18,19]. Recently, frameworks have been proposed to handle big-data analytics for smart city environments with advantages in comparison to traditional knowledge discovery approaches [20]. It aims to bring advanced analytics and intelligence into different domains of the city.

These techniques work in a complementary way with technologies for sensing the city. That is, to acquire the raw data about any interesting aspect to be analyzed. To this end, the Internet of Things (IoT) paradigm is revolutionizing how information can be acquired and communicated to a central server to be further processed. In this regard, researchers have studied how to develop embedded systems and devices able to read the relevant data, and how it can be transmitted over the Internet. As a result, there is a clear connection between IoT and Smart City development where government, public administrations, firms, and other stakeholders are implementing many initiatives within the city's ecosystem [21,22]. Indeed, the leveraging of new technologies and their assimilation into initiatives in the scope of informational urbanism needs to integrate different types of information and to develop capabilities for smart city managers, such as knowledge management and ICT capabilities [22].

There are many works that take advantage of the combination of big-data and the IoT for designing urban planning actions. In this line, several architectures to build all the processes involved in a smart-city project have been proposed [23,24]. In these architectures, the datasets are generated by the IoT layer in connection with the physical world. For example, the data can be produced by smart homes, weather stations along the city, meter sensors, surveillance objects, etc. In most of these studies, the urban planning actions are extensively preferred as they connect several regulations and have a visible effect on the life of individuals such as smart transportation, smart parking, smart travel card data, etc.

However, IoT deployment for city sensing can be very expensive and also needs additional technology infrastructure, such as base stations, gateways, Internet hotspots, etc. Instead, social networks can be also used to acquire data generated by human responses and to know their behavior. This approach will be discussed in the following subsections.

2.2. Analysis of Social Network Sites

Social networks have always existed among us: group of friends, families, employers of a company, etc. In some way, they are part of the human nature. However, technology and new ways of communication have enhanced this phenomenon as never before. Now, social networks are broader, more specific, and enriched with multimedia data.

The area of social network analysis is experiencing intense research activity, as evidenced by the number of recent works found. This discipline requires the contributions of different sciences (sociology, psychology, mathematics, statistics, computer science, etc.) to understand human relational phenomena and behavior, and for analyzing the data.

The analysis of SNS can be studied from two perspectives: (a) human relations and (b) the content itself being published and exchanged.

(a) From a human relations point of view, the analysis of social networks is a methodological and theoretical approach that emphasizes the study of relationships between people, organizations, countries, or things [25,26]. This analysis of social structures is usually made by applying graph theory methods [27]. These methods provide broad outcomes and indicators of a diverse nature. The outcomes are social structures that exist among interacting people, such as cohesion of groups, subgroups, predominant participants or influencers, interactions within an organization [28], etc. Discovering who does the most to connect with fellows and who is going to act as a knowledge diffuser is very helpful to focus the communication efforts [29]. These results can be of great help for many social-oriented issues, such as management improvement [30], effective marketing communications [31], or improving social media operation strategies of public administrations [32].

(b) Regarding SNS content analysis, big-data techniques have significantly enhanced the knowledge generation from social networks [33,34]. The main strength of this approach is the synergy between network and content to provide valuable knowledge for many purposes [35].

Currently, there is a lot of multimedia data available online through SNSs. It is basically composed of text, pictures, and videos. In most cases, this data has been posted by citizens during their daily activities. In this case, it is known as social media data. One reason for the popularity of social media is the ease of receiving, creating, and sharing information at low cost and ubiquitously [36] through the mobile devices of citizens. In this regard, democratization of smart phones among populations has highly encouraged the enormous growth of social media. Some social media networks such as Instagram, Twitter, and Facebook have become very popular with billions of users around the world. This data has increasingly interested companies in their business decision-making [37]. In this way, user's opinions on their consumer satisfaction or experience can help firms to improve their products and to offer a better service according to the characteristics, preferences, and interests of their customers.

2.3. Analysis of Social Network Sites for Informational Urbanism

In the area of informational urbanism, public administrations are also very interested in obtaining citizens' preferences and opinions about the city. In this way, the citizens' participation in public decision-making processes and governmental activities becomes possible because citizens can now post opinions and requirements through social networks [38].

However, the role of social networks is still an open issue for smart city purposes [39]. Big data technologies have generated new challenges in the area of analysis of social networks. These include how data can be processed and used to acquire valuable knowledge on citizens and city operation. New proposals and frameworks are appearing for analyzing SNSs in order to obtain valuable information for city managers [40,41]. In this line, big data analytics enables governments to build prediction models, to discover behavior patterns, and to assess citizen satisfaction [42], and also for advancing urban sustainability research and planning [43].

Some of the recent research generally aims to understand the link between people and places, and the dynamics of using the urban spaces, that is, to identify which places in the city are preferred, used, and livable [44,45]. There is some empirical research in relation to how the use of social networks might relate to citizens' behavior. These studies propose different methodologies to generate this information. For example, the work conducted by Martí et al. [46] aimed to identify successful public areas in the city through the location-based application "Foursquare". This is a SNS that enriches consumer experiences through a deep understanding of the location of the consumer. Other proposals are focused on discovering popular tourist attractions within the urban areas through geo-tagged images posted in Flickr [47] or Panoramio [48]. These platforms are SNSs where users can share, organize, and find multimedia content composed mainly of pictures [49,50].

One of the most analysed platforms is Twitter, due to the large amount of data produced daily by messages from its users. For example, it is used to depict urban boundaries with geo-located messages [51]; to analyze the relationships between factors affecting human outdoor activity in cities, such as weather conditions and traffic congestion [52]; to enrich sensor data for environmental monitoring with those generated by citizens exploiting social network paradigm [53]; to infer coordination patters among population in a nationwide social system [54]; or to obtain socio-spatial relations in the city by analyzing the everyday activities of different groups. This SNS has been also used to analyze the network of different social issues, such as opinion propagation [55], urban emotions [56,57], and even human sentiments from social messages posted by users [58].

Other studies focus on how the visualization of social network data can be used to explore the relationship between citizens' movements and activity distributions. For example, the work by Zeng et al. [59] identifies some points of interest throughout the city where a high density occurs; and the research conducted by Wu et al. [60] proposed a graphical representation to characterize the spatial and temporal mobility of the citizens.

In the case of social networks for sport, there are recent initiatives that study how this data can be exploited to make better cities [34,61–63]. These analyses are mainly focused on taking advantage of the available georeferenced-data taken by the citizens' GPS devices during their sport activity and voluntarily uploaded to SNSs. These works are focused on cycling activity but not on pedestrian sports. The outcomes include some information of interest about the use of the city's infrastructure, such as origin and destination areas of the city, popular or avoided routes, or intersection wait times.

However, much remains to be done. Firstly, to transform this information into useful knowledge that improves urban planning processes; and secondly, to provide urban planners with new planning tools.

On the one hand, from the continuous interaction with the environment and the users of the city, a new understanding of urban capacities and opportunities emerges that makes a new urbanism possible that is more human and flexible, where the citizen is a participant and not a mere observer [64]. On the other hand, it is in this context of the new urban model based on the paradigm of smart cities where it is necessary to reformulate the paradigm of urban planning, which necessarily involves considering people at the centre of planning and which requires new tools to be put into effect [65,66].

Therefore, the latest ICTs and SNSs have transformed the traditional meaning of citizen participation. This new understanding of citizen participation has important implications for the planning and design of cities of the future. City planning has gone from being the responsibility of planners to representing a collective challenge which involves both governments and citizens [67,68].

2.4. Findings

After reviewing the main related works, we can draw the following issues that justify and summarize our contributions in this field:

1. Informational urbanism needs to be fed by valuable knowledge to be useful for designing smart urban planning actions. Big data technology and the IoT play a vital role in providing it, but they need to integrate different data sources and have deployment costs.
2. The analysis of SNSs is a growing research discipline that has important implications in many areas of society. This analysis can be done from a human relation point of view, or from a content perspective. As a result, valuable information of the preferences, habits, and behaviors of citizens can be obtained.
3. Using data from SNSs opens new possibilities to identify the real uses of urban spaces. This information contributes to the construction of the informational urbanism concept and opens new management possibilities to perform urban planning actions taking into account the dynamics of the city.

Based on the above, this work identifies two research gaps: first, to find out if valuable knowledge for pedestrian urban planning can be also obtained from data of SNSs, and secondly, how these data can be used to derive urban actions to integrate sport within the city.

The work described in this paper addresses the abovementioned two points by developing a method for analyzing the data from SNSs for sport. It aims to demonstrate the value added by knowledge generated by these SNSs which enables the design of citizen-centric policies for smart urban planning. In addition to the results of other works in this area, the step forward of this research lies in proposing specific urban planning actions as an example of the progress in making more inclusive cities.

3. Analysis of Social Networking Services for Sport

Recently, the news headlines have informed people that American soldiers and their secret bases around the world were revealed due to a sport application [69]. The owner of this App has published a heat map with all its users' activities, including military who use this 'App' for sport and training [70]. The map also shows the intensity of the movements. It is, according to its designers of the 'App', "a live view of worldwide network of athletes.

New Social Media are the communication channel of the new generations, especially those who use the internet as a source of information [71]. Among the many SNSs for sport, this work has explored a variety of sites with the aim of learning about their diversity and the variability of the information available. Table 1 describes some of most common SNSs for sport.

Table 1. Social Networks Sites for Sport Activities.

Social Network	Web Site
ATLETO	http://www.atletosports.com/ This is a is a sports social network to connects athletes with each other to facilitate games or other athletic activities
STRAVA	https://www.strava.com/ Social network to share activities with a broad social community of registered users
MAPMYRUN	http://www.mapmyrun.com/ Social network to share the sports activity linked to the sports products company Under Armor
runtastic	https://www.runtastic.com/ Social network to track and manage health and fitness data
RunKeeper	https://runkeeper.com/ It is a top social network that helps people get out the door and stick with running.
SPORTS TRACKER	https://www.sports-tracker.com/ Social network where sports enthusiasts can access to public workouts, every day
GOTZAM	https://www.gotzam.com/ Social network to share sport events and activities among users

On these platforms, users provide information on the development of their activity and they post data on scores, times, and routes where they do their sport. Data on these aspects are introduced by users themselves on a voluntary basis with the aim of sharing their experiences and comparing their marks with other users.

The process of data generation and communication to the SNS is usually done automatically through the users' mobile devices, such as smart watches, phones, and other wearable devices with Global Positioning System (GPS) functionality. After that, the route of the sport activity made by the user can be drawn easily on a map.

3.1. Data Visualization

All the sites analyzed provide information on the routes followed by users in the practice of their sport for each city where the social network is used. These routes can be viewed directly through a web-based interface for a desktop browser or through a mobile device application for a smartwatch or smartphone. The interfaces of these applications are very useful and intuitive, and include searching tools to find the sport activity, for example, time duration, length, type of sport, city, region or country, etc. Furthermore, they usually provide the best marks and the users that have followed each race. In addition, they offer premium services for registered users that include additional features such as the creation of training plans, advanced sports performance statistics, health guides, and access to personal trainers.

Figure 1 shows an example of the interface centered on the city of Alicante (Spain) of one of the most popular SNSs studied.

Figure 1. Example of the interface centered on the city of Alicante. Retrieved from the Strava social network on 28 October 2018. Orange lines represent the routes uploaded by users. Each marker has a number with the route identifier in the application.

A set of routes drawn on the map can be observed in Figure 1. Each of these routes has been covered by at least one user. For each of them, a lot of information can be obtained. This detail includes, for example, distance travelled, time spent, average slope, and estimated calories burned. Figure 2 shows the details of a route provided by one of the most popular social networks. As shown, this example route has been run by 3973 citizens doing sports in the city. Using the search tools of the SNS studied, it is possible to identify the existing routes in a city or geographical area.

In addition, the data can be filtered by dates in order to retrieve information on when and where the sport practice is done. Thus, valuable information for urban planning can be obtained from the knowledge on where and when each sport is actually performed by citizens.

Apart from the web platforms of these SNSs, Geographic Information Systems can be used for applying advanced visualization techniques and further analysis.

Figure 2. Route details of the "Alicante beach" route. Data retrieved from the Strava social network on 28 October 2018. Markers show the origin, middle, and destination points of the route.

3.2. Data Download

The routes stored in the sport SNSs are generated by the users thought their mobile devices or wearables when they are practicing sport. Usually, these devices are equipped with a GPS device which tracks the sport activity. Once the sport activity has finished, the mobile devices or wearables upload the activity features to the SNSs by themselves. Millions of GPS-tracked activities are uploaded to these platforms every week [34].

These routes can be easily downloaded from the platform for analysis. There are several commonly used structured geopositioning formats in which the routes can be codified for further processing. These formats are generally based on the XML schema. Table 2 lists the most common geopositioning formats.

Table 2. Common geopositioning formats

Format	Description
KML (Keyhole Markup Language)	Designed by Google for representing geographic data in three dimensions. It is used by Google Earth (https://developers.google.com/kml/schema/kml21.xsd)
GPX (GPS eXchange Format)	It is an open standard for the interchange of GPS data between applications and Web services (https://www.topografix.com/GPX/1/1/gpx.xsd)
TCX (Training Center XML)	Designed by Garmin and used to track an sport activity with a mobile device (https://www8.garmin.com/xmlschemas/TrainingCenterDatabasev2.xsd)
GTM (GPS TrackMaker)	Designed by TrackMaker for creating routes and detailed maps from GPS information (https://www.trackmaker.com/)
GeoJSON	Open format based on JavaScript Object Notation (JSON) for encoding a variety of geographic data structures (https://tools.ietf.org/html/rfc7946)
GML (Geography Markup Language)	Designed by Open Geospatial Consortium for representing geographic information (http://www.opengeospatial.org/standards/gml)

As an example of content structure, Figure 3 illustrates the path shown in Figure 2 both in KML and GPX formats. As shown in Figure 3, these file formats represent each route by means of the set of individual points that compose it. Each point is a special location defined by a single geodetic longitude, geodetic latitude, and (optional) altitude coordinate tuple. Other information such as the device used to register the route is stored. The proliferation of wearables and smart watches has definitely contributed to promoting the social interaction of athletes.


```
  <?xml version="1.0"?>
- <kml xmlns="http://www.opengis.net/kml/2.2">
  - <Document>
    - <Style id="kmlLineStyle">
      - <LineStyle>
          <color> 7f0000ff </color>
          <width> 4 </width>
        </LineStyle>
      </Style>
    - <Placemark>
      - <name>
        - <![CDATA[
            Route from GARMIN 2413 (2018-02-03 07:43:00+00:00)
          ]]>
        </name>
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      - <LineString>
          <altitudeMode> clampToGround </altitudeMode>
          <tessellate> 1 </tessellate>
          <coordinates> -0.4836653173,38.3472299762,0 -0.4836731125,38.3472044114,0 -0.4836651497,38.34718
            -0.4836106673,38.3470817003,0 -0.4835989326,38.3470538724,0 -0.4836102482,38.347029984,0 -0.
            -0.4835983459,38.3469113801,0 -0.4834920634,38.3467258886,0 -0.4834734555,38.3466977254,0 -(
             ...
            -0.4760338459,38.34703275,0 -0.4761941917,38.3471858874,0 -0.4763018154,38.3473048266,0 -0.4
        </LineString>
      </Placemark>
    - <Style id="Kilometer_1">
      - <IconStyle>
        - <Icon>
          - <href>
            - <![CDATA[
                http://api.mapmyfitness.com/vx/map_marker_image/0/?format=png&txt=1
              ]]>
            </href>
          </Icon>
        </IconStyle>
      </Style>
    + <Placemark>
    + <Style id="start_marker">
    + <Placemark>
    + <Style id="finish_marker">
    - <Placemark>
        <styleUrl> #finish_marker </styleUrl>
      - <Point>
          <coordinates> -0.476301061,38.3473293018,0 </coordinates>
        </Point>
        <name> Route from GARMIN 2413 (2018-02-03 07:43:00+00:00) </name>
      </Placemark>
    </Document>
  </kml>
```


(**a**)


```
  <?xml version="1.0" encoding="UTF-8"?>
- <gpx xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:gpxx="http://www.garmin.com/xmlschemas/GpxExtensions/v3"
  xmlns:gpxtpx="http://www.garmin.com/xmlschemas/TrackPointExtension/v1"
  xmlns="http://www.topografix.com/GPX/1/1"
  xsi:schemaLocation="http://www.topografix.com/GPX/1/1
  http://www.topografix.com/GPX/1/1/gpx.xsd
  http://www.garmin.com/xmlschemas/GpxExtensions/v3
  http://www.garmin.com/xmlschemas/GpxExtensionsv3.xsd
  http://www.garmin.com/xmlschemas/TrackPointExtension/v1
  http://www.garmin.com/xmlschemas/TrackPointExtensionv1.xsd" creator="Exported from Strava
  via extension e-ivanov.ru" version="1.1">
  - <metadata>
    - <link href="http://e-ivanov.ru/projects/strava-export-gpx/">
        <text>Strava gpx export</text>
      </link>
      <time>2018-10-28T19:46:04.380Z</time>
    </metadata>
  - <trk>
      <name>0,6 km de Segmento de carrera en Alicante, Valencian Community, Spain en
        Strava</name>
    - <trkseg>
      + <trkpt lat="38.348372" lon="-0.473763">
      + <trkpt lat="38.348296" lon="-0.473946">
      ...
      + <trkpt lat="38.34488" lon="-0.478509">
      + <trkpt lat="38.34476" lon="-0.478693">
      + <trkpt lat="38.344648" lon="-0.478844">
      </trkseg>
    </trk>
  </gpx>
```


(**b**)

Figure 3. “Alicante beach” route file example. (**a**) KML format; (**b**) GPX format.

In order to obtain useful information in an effective way, it is necessary to perform an automated analysis of a route's information. The use of massive analysis techniques is required to download the routes and process them. The social networks studied provide computer tools that allow applications based on the information they contain to be developed. To this end, they have a specific Application Programming Interface (API) to access the services they offer, such as: Strava (https://developers.strava.com/); Mapmyrun (https://developer.underarmour.com/), and Runtastic (https://github.com/runtastic). The first two tools also offer a RESTful web service delivery architecture with structured data exchange communication in JavaScript Object Notation (JSON).

The social network Strava provides a service for data aggregation oriented to departments of transportation and city planning groups (https://metro.strava.com/). In order to maintain the privacy of users, data downloaded from SNS are anonymized by removing all personal data of each route. Among the operations they provide is the query of available route sets according to established search criteria, including the geolocation of the area of interest and the radius of action. In this way, collections of routes can be obtained for mass analysis of any given city.

The analysis of this information makes it possible to determine the date, recording time, and the places in the city where each activity has been carried out. This provides accurate information on citizens' actual sports habits and their evolution over time, and therefore is a useful tool for knowledge generation about the real uses of urban spaces.

4. Smart Urban Planning

New free ways of using public space are constantly emerging in cities at the initiative of citizens without having been previously thought or planned. These are new uses or new ways of understanding public space that are quickly disseminated and shared among the users of a city and among different cities. A good representative example of the current situation is the use of urban public space for sports-related activities. Increasingly, citizens share information on social networks about new routes or places where, due to their appropriate characteristics, they choose to carry out their daily sporting activity. It is evident that this information on the use that citizens make of public space, on their needs and preferences, understanding the fact of voluntarily sharing this information in SNSs as a current form of public participation in the organization of the city, cannot be left out of the decision-making process about the right urban planning actions to design smart today's cities.

The research question can be defined in general terms as how these technological advances make it possible to incorporate this information into the planning process to recognize the capacity and right of citizens to make decisions about the city. In this sense, the management of this knowledge aids the decision-making processes of urban planning.

In this work, we have focused on studying routes of citizens that only include pedestrian sport activities such as walking, hiking, and running. Other sports practiced in city environments, such as cycling or skating, can also be analyzed in the same way.

4.1. Methodology

In this section, a case study is conducted for the city of Alicante. Alicante is a Spanish city of medium size (coordinates: 38°20′43″ N 0°28′59″ W; area: 201.27 km^2; population: 328,648) located at the east of the country on the Mediterranean coast. This application scenario has good potential for analysis since this is a very touristic place, visited by around 2.2 million tourists per year [72].

The methodology used for this scenario is empirical, and it is based on the results of some case studies. A methodology based on analysis of case studies can be appropriate when researching "how" or "why" questions about contemporary phenomena over which the investigator has little or no control [73,74]. This is especially suitable for studies in real-life contexts where this type of analysis can provide better understanding of the context where the study is developed, including city and regional planning research [74]. From the case study strategy, new hypotheses and research questions can arise from the results.

The case studies described in this work are not the full set of issues and proposals, indeed, we have found some other issues in the city regarding where and when usually citizens do sport. Nevertheless, we have carried out an information-oriented selection of the study cases [75]. We look for paradigmatic cases for our context, that is, we have carefully chosen the study cases to be representative of what may be found throughout the city, and to consider them as illustrative examples of the decisions and urban planning actions that can be carried out for addressing them.

The method for obtaining the common places of the city where sport is practiced is described by the following steps:

In first place, the city area is selected. To this end, the web-based interfaces of the SNSs are visited to observe the aggregated data and visualize spatial distributions of routes. This information allows one to know at first glance the sport habits, atypical locations, or frequent places and streets where sport is practiced. From this observation, the interest area of the city is selected for route downloading. In this research, we have mainly focused on the coast side of the city, where the seafront promenade and the beach are, because these are very touristic places. This is a little part of the city, but it is a representative sample of the results of the analysis. For this area, we have retrieved the routes from the three most used SNSs: Strava, Mapmyrun, and Runtastic. As mentioned in the previous section, the routes are codified in structured data formats such as those depicted in Figure 3.

Secondly, the places of the city under study are characterized. That is, the geo-codification of each place, such as the street, square, promenade, or road of the city. This codification consists of representing these places by a polygon with georeferenced vertices. The places can be defined totally or partially according to the required precision. For example, a long street can be divided into several pieces.

Finally, identification of the places through which the sport routes pass is conducted. This procedure is made by comparing each route point-by-point with the characterized places of the previous step.

For example, Figure 4 shows an overview of this procedure for a square of the city. This comparison can extract the places where routes pass.

Figure 4. Example of identification of places through which each route passes.

The list of the common places frequented by citizens when they practice sport is generated as a result of the comparison process on a set of selected routes. Figure 5 illustrates this process for an example route.

Having information about which places are preferred and used by citizens to practice sport in the city is an essential tool for city managers. In this sense, the analysis of the routes stored in the SNSs allows us to identify the urban areas and infrastructures where the users' sports activities are practiced.

Figure 5. Route example matching. Data retrieved from the Mapmyrun social network on 30 October 2018. Markers represent the identified points along the route. Each of them corresponds to a known place of the city.

4.2. Analysis and Proposals

The generation of knowledge about the city is the result of this analysis step. The analytical technique used consists of building an explanation of each case [74]. That is, to describe the issues from an urban planning point of view that cause unsuitable conditions for doing pedestrian sport and potential actions to solve them. In this sense, this analysis is mainly explanatory.

As mentioned, the search through the web interface of the SNSs provides us with the map of where the routes occur. Figure 6 illustrates several routes for the common transit areas observed. A detailed search shows that these are popular places for running in Alicante. Figure 7 shows the high density of routes found in these areas.

It seems that it is more fun to run around the city than in sport centers, and after a preliminary analysis, the coast side of the city is one of the more popular areas. This preference creates the challenge to make inclusive cities where the sport activities can be part of daily city life. That is, runners can be integrated with pedestrians. A priori, this seems difficult when there are many crossroads or people on the streets. However, addressing this challenge could encourage more people to do sport and to make a better use of public spaces.

Some ideas based on the following examples can be proposed for decision-making processes of urban planning to make more inclusive and accessible cities for sport. The study cases have been illustrated with pictures from Google Maps and Street View applications. For the areas of the city under study, and based on the effective routes acquired from social networks, the following issues and proposals for addressing them are pointed out:

(i) Address the unexpected consequences in the operation of urban environments. There are many inefficiencies in the operation of urban infrastructure that make it difficult to do sport and lower the city's accessibility in general [76]. For example, the installation of public furniture, street lamps or traffic lights in the sidewalks. In the analyzed area there are many obstacles of this kind. For example, in Figure 8, besides the palm trees, there are many bins and lamps in the middle of the sidewalk. These obstacles might be removed or shifted to one side. In addition, some other actions, such as making broader sidewalks, should be studied, even if it means reducing the space for vehicles.

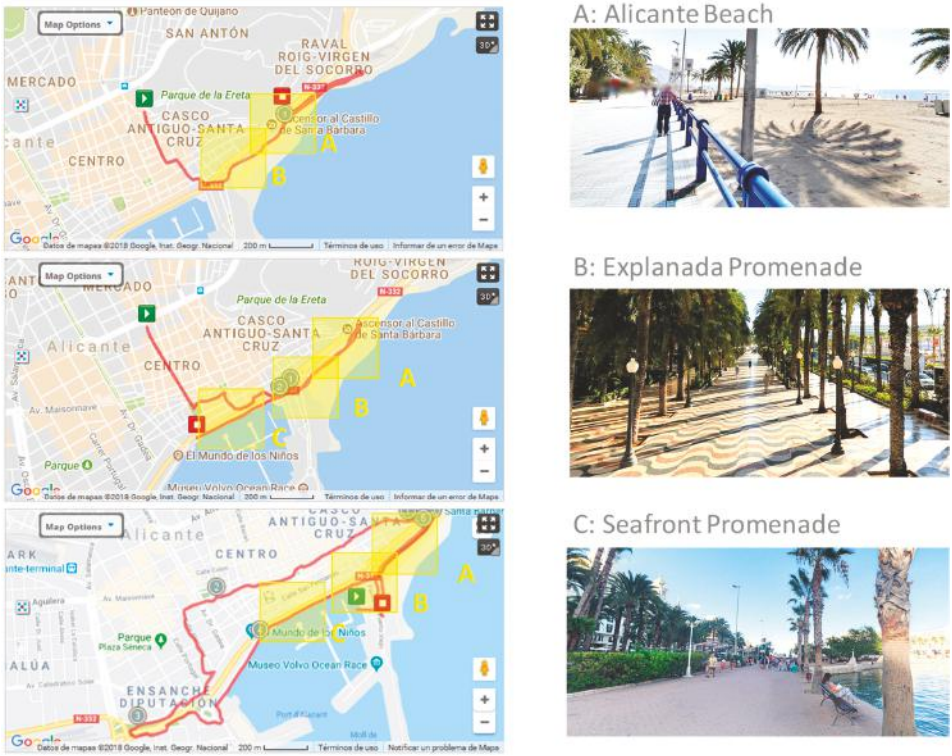
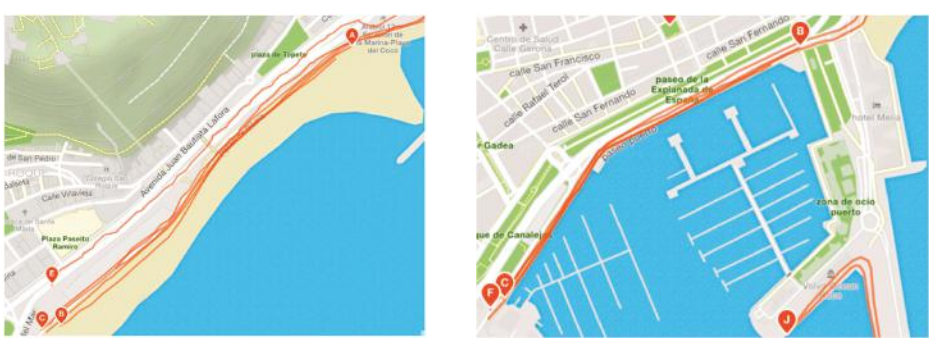


Figure 6. Common routes across Alicante city. Data retrieved from Mapmyrun social network on 26 October 2018. Red lines represent the routes uploaded by users. The tagged yellow areas (**A**–**C**) in the maps correspond to the photographed places through which the route passes.



(**a**) (**b**)

Figure 7. Density of routes. (**a**) Alicante Beach; (**b**) Explanada and Seafront promenade. Data retrieved from the Strava social network on 30 October 2018. Orange lines represent the routes uploaded by users.

Figure 8. Alicante urban planning examples. (i) Unexpected consequences. Pink marker indicates the place in the map that corresponds with the picture on the left.

(ii) One issue for runners is having to stop at traffic lights or crossroads frequently. Therefore, city intersections could be minimized where urban sport is practiced. For example, by designing overpasses and underpasses to the road. Within the area analyzed, there are two conflictive crossroads, for both runners and pedestrians. Figure 9a shows a widely used crossroad between 'Explanada' and Seafront promenade where it could be beneficial to consider an overpass. Indeed, this solution has been already implemented 558 m further along in the same road (Figure 9b).

(**a**) (**b**)

Figure 9. Alicante urban planning examples. (ii) City intersections: (**a**) populated crossroad; (**b**) existing infrastructure. Pink markers indicate the places in the map that correspond with the pictures on the left.

(iii) Special lanes could be waymarked to delimit the space for runners, similar to what is done for cyclists. In addition, other marks could be included, such as distance indicators or alternative paths. Figure 10 shows an example that could be implemented to this end. These special lanes could be available for sport for only some hours a day, according to the habits of runners or avoiding the times with the most pedestrians. In this case, the social networks provide useful information to make decisions on this issue.

Two major lifestyle components are physical activity and nutrition [77]. Moreover, the connection between doing sport and living a healthy lifestyle is unquestionable. In this sense, some of the behavioral indicators used for measuring the quality of life of the city include participation in sports and the amount of walking and bicycling activities in the city [78].

Traditionally, city managers build sports facilities in the city (sport centres, running tracks, etc.) to promote sport and healthy lifestyles. However, transportation for exercise is becoming less common, especially among young people [79]. New habits of urban life suggest that many citizens do sport within the city using the standard infrastructure. Knowledge generated from sport social networks not only verifies this trend, it also provides information of when and where sport is practiced. Hence, carrying out urban planning actions for making inclusive sport activities in the city could increase the quality of life of citizens, and enhance their interest in sustainable forms of movement in the city.

Figure 10. Alicante urban planning examples. (iii) Space for runners. Pink marker indicates the place on the map that corresponds with the picture on the left.

In addition, making suitable infrastructure for sport provides other kinds of social benefit for the city. Social interactions are enhanced by sporting activities. In this way, urban spaces become a new method for creating possibilities of interaction among citizens [80].

Another issue is the management of this knowledge, since social networks are dynamic systems. This feature could also enable agile urban planning and policy-making.

5. Conclusions

Doing outdoor physical activity around cities is a new trend of urban citizens. There are many synergies between physical activity and health. Policy makers and urban planners should take this into account in order to promote sport activities and make more inclusive and sustainable cities.

A set of measures consists of adapting city infrastructure to the citizens' needs. To this end, there are new ICT tools able to aid in urban decision-making. These tools are part of the knowledge-related infrastructure block of the conceptual framework of informational urbanism [16]. In this way, social networks for sport provide useful information about how city infrastructure is used, what actions are required, and where they are needed. Through all these networks, valuable knowledge can be obtained by applying simple techniques to the data voluntarily generated by users.

In this work the most relevant SNSs for sport have been studied in order to assess the suitability of urban infrastructure for pedestrian sport activities. By analyzing the data from SNSs, we can infer the popular areas of the city for doing sport. As a result, we have found that sport is practiced more within the city than in sport-dedicated infrastructure, such as sport centers, athletics tracks, or sports halls.

This knowledge is very important to improve the urban planning and design process of the city. In response to the questions raised in this work, we have identified some typical issues along the popular areas of the Alicante city where citizens frequently do pedestrian sport. Taking them as case studies, a proposal has been done for each of them in order to make the city more inclusive and to promote sport among the population.

The limitations of this study are common to other analyses of human preferences using data from social networks, that is, the representativeness of the sample. Not all citizens who do sport in the city are users of these SNSs. Nevertheless, these SNSs have a growing number of users and cover heterogeneous areas around the world. In addition, the described cases are not exhaustive, but they may be regarded as typical samples of how the information from SNSs can be used for improving the urban planning process for citizens. In this regard, the findings could rely too much on specific phenomena.

In the future, we plan to extend this study to the entire city of Alicante in order to further characterize sport-related issues. To this end, we will conduct a large-scale analysis of the urban physical activities stored in the Strava Metro information system. In addition, we plan to enhance the inference of the citizens' needs and urban requirements by applying advanced big-data techniques to the information processing.

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Exploring a Stakeholder Based Urban Densification and Greening Agenda for Rotterdam Inner City—Accelerating the Transition to a Liveable Low Carbon City

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Abstract: Work on a liveable low carbon city has often been approached in a technocratic way, not linking to other disciplines and urban practices at a large scale. This paper explores a stakeholder based urban agenda for a more liveable low carbon city by densifying and greening with the case study of Rotterdam inner city. Rotterdam presents a unique European case with a modernistic inner city. Like many North American cities, the inner city for a long time mainly served as a business or shopping district with few inhabitants and few synergetic links between flows, urban functions, and areas. In line with other cities, Rotterdam aims to reduce carbon emissions and provide a high quality of life. To address this, the hypothesis 'densifying and greening leads to a more sustainable inner city', was tested and applied with stakeholders using transition management combined with urban data, modelling, and design. With sustainability indicators, geographic information system (GIS) mapping, and urban models, a baseline study was completed and expected outcomes were described and, where possible, validated in reality. The outcomes confirmed the stated hypothesis and showed that linking design, GIS mapping, and city data to transition management proved successful.

Keywords: synergetic urban landscape planning; low carbon cities; densification; liveability; greening; sustainable urban development; urban planning

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1. Introduction

1.1. Densification and Greening in an Urban Quality of Life, Liveable Low Carbon Context

Uncertainty and impacts of demographic changes, multiculturalism, globalisation of trade, environmental degradation, as well as climate change are pressing forces, which urban planning has to consider when drafting a liveability and low-carbon agenda for the short-term and long-term action of a city.

At the start of the low carbon city agenda presented by the city of Rotterdam in 2007, many projects on a low-carbon city were approached in a technocratic way, resulting in the first years in available technical solutions which did not find their way quickly into urban practices or projects. At the same time, there was a lot of knowledge developed, and is still developing, on how to work on a transition towards a low carbon city, addressing social, economic, as well as environmental issues [1–3]. Bringing together these issues was an obvious step to be taken and lead to this study. This paper explores a stakeholder-based urban agenda for a more sustainable low-carbon city that improves the quality of life/liveability of the area as well as its sustainability performance. How can this be measured and enhanced using urban data?

The low-carbon focus is on the built environment, for which simulation models are used, based on design strategies. The outcomes presented in this paper will be mainly descriptive (based on data of the existing models) rather than quantitative.

Rotterdam presents a unique European case with a post-World War II modernistic inner city. Like many North American cities, for a long time the inner city mainly served as a business or shopping district with few inhabitants and few synergetic links between processes, urban functions, and spatial patterns. In line with many other cities, Rotterdam's long-term vision consists of issues such as reduction of carbon emissions, becoming more sustainable, and providing a high quality of life. To address these goals as well as to create synergetic links between them, they need to be applied in projects.

One of the bigger project ideas at hand is the densification and greening of the inner city.

The International Architecture Biennale Rotterdam 2012 (IABR2012) named 'Making City' and the European INTERREG IVB project Music (Mitigation in Urban Areas Solutions for Innovative Cities) served as a platform for this project idea as well as its actual application [4]. Right now, the topic of densification and greening in a sustainable way is very relevant since a new urgency has emerged and many cities in the world have to densify to accommodate new inhabitants. CPB, Centraal Planbureau, Netherlands Bureau for Economic Policy Analysis and PBL, Planbureau voor de Leefomgeving, Netherlands Environmental Assessment Agency (2015) [5] presented two scenarios: a high and low one; both expect population growth as well as growth of housing need. This varies from 250,000 to more than 1 million houses for the Randstad area till 2030. This means that cities like Rotterdam need to add tens of thousands of new houses in the coming decade. The outcomes of this study can help in all these tasks.

To bridge the gap with the technocratic approach applied in the city until then, a governance approach, namely transition management [3], was used and enriched using urban data, modelling, and design throughout the process.

A set of sustainability indicators is used in a baseline study, geographic information system (GIS) mapping and urban simulation models, to predict expected outcomes of the presented plans.

1.2. Government as a Stakeholder: From 'Blueprint' Planning to Facilitating

The urge to create a more sustainable city that offers a high quality of life, a city where actively engaged inhabitants are required, showed that 'blue print' or top-down planning alone, could not be used as a model as it was too strict and left little space for experiments and bottom-up initiatives. As such, the role of the government's planning approach is under study. Which strategy should be followed? How to act? In order to build a stakeholder-based urban agenda for the Rotterdam inner city, challenges and opportunities need to be defined, also taking the historical context into account.

1.3. Concise History of the Rotterdam Inner City

Until 1940 the centre was a bustling city. However, after 1945 it was characterised by functionality. The bombing of 1940 unwillingly led to the fulfilment of another cherished desire, which was to become a new modern city. A complete new centre with modern architecture was introduced. However, this was accompanied by an almost anti-urban experiment with the separation of functions, based on a typical model of society at that time: the city as a sum of separate functional clusters, which had nothing to do with each other. As a result, new housing was not part of the inner city and was planned outside the city in one of the new-green-neighbourhoods. Essential for the city was also the vibrant, cultural (night) life that was gone. It turned out that the new 'functionalism' approach did not offer a good breeding ground for this. In the 1970s and 1980s, the gloss of modernity, so typical of the period of reconstruction after the war, was gone. The ever so modern Lijnbaan shopping mall in the centre of the city had become outdated. There were large bare spots in the city centre and in the evening the streets were deserted. Since 1985, more housing has been planned in the inner city area. The famous cube houses of Piet Blom were built in those days (Figure 1).

Apartment buildings were built and in the following years high rises were permitted as well. In a few years' time the Rotterdam skyline changed. A high-rise policy was implemented. Slowly, the city regained some allure. In fact, in the Netherlands, it was nicknamed 'Manhattan on the Maas'. However, this didn't change much at street level at first. It was only after the city implemented a public space strategy with a lot of attention at street level, that public life in the streets started to emerge faster. Instead of skyscraper, this strategy was called 'groundscraper' [6].

The idea that the inner city was mainly for business and shopping and not so much for living was left in the late seventies, but only banned in the past twenty years. At the moment, there is a very clear idea that to become a successful sustainable city, the city also needs an attractive heart, and that includes inner city living. The modernistic separation of urban functions from the reconstruction period after World War II is still present in the inner city. Due to the efforts of the last twenty years, the glass is half full, but there is still a backlog in critical mass, amenities, child friendliness, good public space, and green. That is why it is vital for Rotterdam to continue to densify the inner city. It might take another two decades to reach the population density of an average Dutch city, but those parts of the city that are already densely densified, such as the Scheepvaartkwartier and the Laurenskwartier, show a buzz of urban life. For example, the Veerhaven and surroundings and De Meent are an attractive entertainment area.

Figure 1. Piet Blom's 'cubic houses' in Rotterdam built in the 1980s (photo Ossip van Duivenbode, www.rotterdambrandingtoolkit.nl).

1.4. A Facilitating Government

The Rotterdam inner city has the scale of a district or neighbourhood. These scales are crucial as they are the best scales for realising sustainability ambitions in a city: small enough to take quick action and large enough to make an impact.

There has, however, been a shift in approach for urban-area development: a shift from a strong focus on top-down planning and master plans towards bottom-up approaches accompanied by room for initiatives. "The question is how to combine the step towards a sustainable world with the exploitation of forces in an energetic city. This is not about top-heavy committees that launch proposals of the likes of the Delta Works, but about an administration that attempts to channel social energy in the right direction" [7].

Rotterdam left behind its long-cherished, post-war reconstruction mentality. The municipality has been moving towards a facilitating role. With that, a new way of working is introduced in which frameworks play an important role. Defining frameworks is a first step. Another crucial aspect is the competence required for their application, such as regulations. Regulation is an extremely complicated exercise of equilibrium. "Too much regulation will put a check on things. Too little may lead to derailment. Moreover, regulation can be interpreted wrongly or inadequately supervised, and thus miss its goal. The conclusion is that cooperation or this way of working requires socially intelligent civil servants" [8]. This change within the municipality could provide opportunities for a multitude of initiatives from inhabitants and businesses.

1.5. Challenges and Aims

1.5.1. Challenges: Underperformance and Lack of Synergies

Urban regions are the engine of our economy, with inner cities playing a leading role in this. In the history of the Rotterdam inner city, the background of the main challenge was described: increase urban living in a modernistic inner city where for a long time the focus was on businesses, offices, and shopping, where housing was not a priority. In this context, the Municipality of Rotterdam is expected to set priorities and the inner city is at the top of the list. As yet, the potential of Rotterdam's inner city has not been fully exploited. This is in large part a consequence of the relatively small number of inhabitants the inner city currently accommodates. A confident inner city is vital for the quality of life of the city as a whole. Synergy is an important aspect in this: synergy between the enterprising inhabitants of inner cities and employment, and culture and, for example, culinary meeting points [9]. This is why the Municipality of Rotterdam values inner-city densification with more dwellings and apartments.

1.5.2. Aims

To get from a project idea of densification and greening to realisation, politicians and policymakers had to be convinced of its values as well as its potential of realistic realisation. The question is also if it will lead to a more sustainable city, as Florida (2010) and Glaeser (2011) and other authors suggest [10–13].

Densification is usually a step-by-step process. Rotterdam has already shown that densification can contribute to creating a successful city; the Laurenskwartier district is an example of this where more inhabitants fuelled amenities and good street life. When comparing the inner city of Amsterdam to Rotterdam, twice as many people live on the same surface area in Amsterdam as in Rotterdam. Would it be possible to house twice as many people in Rotterdam's inner city and increase its population from 30,000 to 60,000? To give insight if this is a realistic number within the Rotterdam context, but also to study if this could improve quality of life, small scale densification studies were done.

To follow up on this, the research question is: What are potential densification and greening strategies and a stakeholder based urban agenda, which improves the quality of life/liveability of the area as well as its sustainability performance? How can this be measured and enhanced using urban data?

Within this context, the objectives of this paper are:

1. To test if densification and greening of the inner city of Rotterdam can lead to a more sustainable city with a higher quality of life.
2. To present the outcome of a transition management process as realised in the city of Rotterdam from the problem delineation to agenda setting.

3. To determine how to measure sustainability in a sustainability profile. What is the baseline and what are expected results?
4. To determine how these data can be used in transition management and a stakeholder environment to explore potential synergies and vision making.

2. Materials and Methods: A Stakeholder-Based Urban Densification and Greening Agenda and Building a Validation Tool

2.1. Organisation and Planning

IABR 2012, the International Architecture Biennale Rotterdam which served as a platform for this study, describes that 'by linking urban issues, political decision making and design in an interactive and direct way, it promoted more flexible forms of cooperation and alliances, design instruments and governance' [14]. These are the ingredients of the methodology of this paper (Figure 2).

2.2. Inventory, Pre-Studies, and Stakeholder Analysis

The first part of the study is an inventory, background, and history of the area. This is also useful for knowing more about the urban challenges in the area related to social, economic, or spatial structures. Next is a system analysis, studying facts and figures about the urban challenges ahead. A last step is a first link to exploring synergies using design. Design is used to show stakeholders potential solutions to one or more challenges, what it can look like if it fits and if it evokes a positive or negative experience. In a fast changing world, there is a big need for information and data, but also participation. To help strengthen the inventory phase, but also to have an overview of which stakeholders to select for a good embeddedness to make the transition happen, a range of stakeholders were selected in meetings. From bottom-up to top-down, from government to business. In this process, three *focus group meetings* were organised with stakeholders in the city. The first group were the (future) inhabitants. As the topic is densification and greening, the main focus was what kind of city (future) inhabitants wished to have; who were the clients who would live there? The future inhabitants were identified through housing brokers and their clients in the city. This was a mix of young families living in neighbouring cities but working in Rotterdam, graduating students, former immigrants making a career, and pensioners. A second group was a mix of shopkeepers, business people, and designers such as (landscape) architects. These people were all connected or members of the 'van der Leeuwkring', an organization concerned about the quality of the public space of the inner city. The third group were market parties and inhabitants who were already setting up initiatives and doing things themselves.

2.3. GIS Analysis and Transition Management

Transition management depends in part on the role of the participants in the process, as well as on good, detailed information.

The development of GIS tools such as urban energy maps provided the participating stakeholders in the transition management workshops with valuable information on, for instance, CO_2 reduction potentials. These tools also allowed for measuring energy consumption and the outputs of the actions that were formulated in the transition management action plan. The stakeholders, therefore, acquire a good insight in the real impact of their actions and pilots, and will be able to compare them with alternatives. The GIS maps and data feed the stakeholder process. A stakeholder process without accurate data and mapping allows for some stakeholders to take the over in a discussion or for incorrect assumptions to be incorporated in a discussion. A stakeholder process with accurate data and maps levels the playing field better and can quickly check disputable assumptions. Of course, this depends strongly on the accessibility of the data and maps and requires a good discussion leader and data specialists. There are also other low-tech ways to collect data such as fieldwork with observing situations and interviewing locals. Either way, this way of working has additional values when combined with GIS technologies as it gives extra information and knowledge.

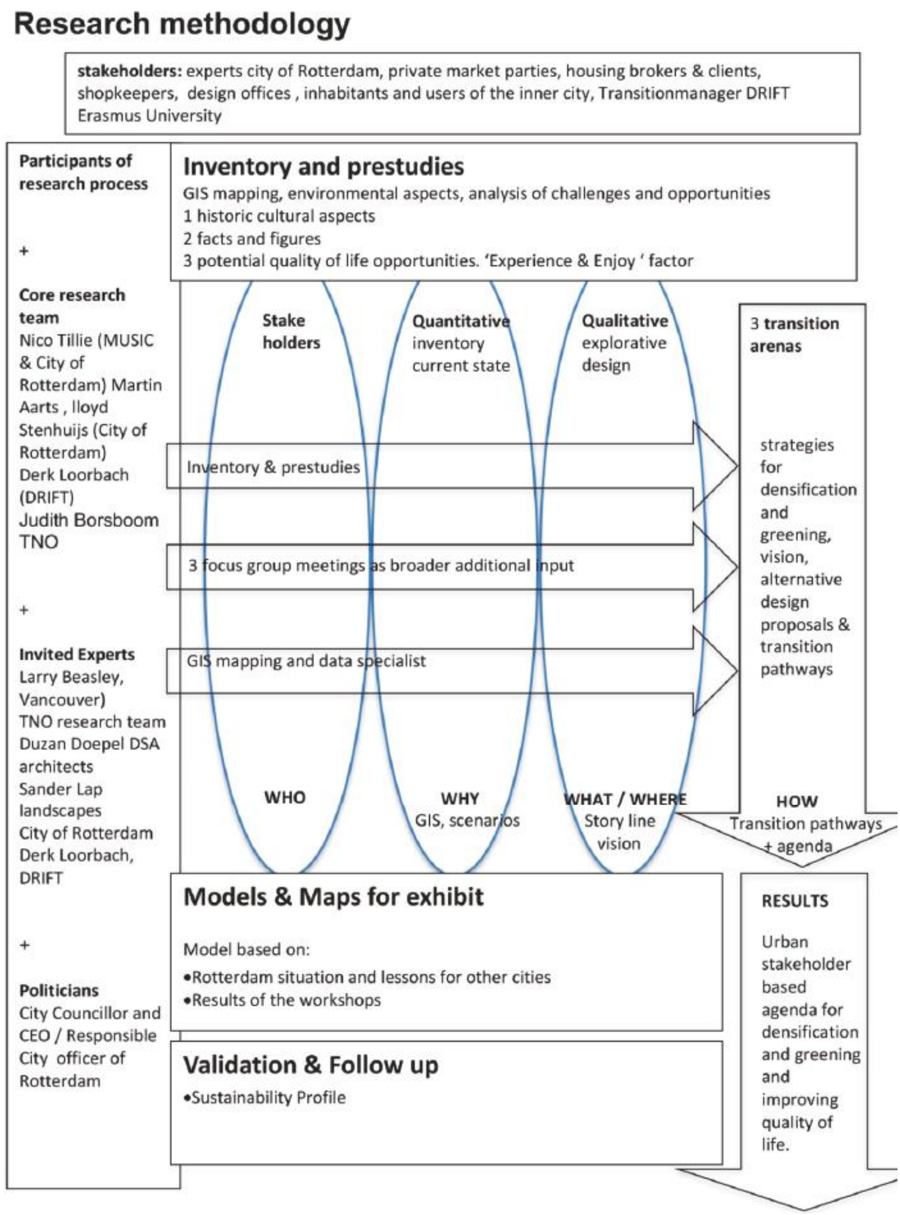


Figure 2. Research methodology for building a stakeholder-based urban densification agenda linking quality of life, liveability and sustainability performance. GIS = geographic information system; MUSIC = Mitigation in Urban Areas Solutions for Innovative Cities; CEO = Chief Executive Officer; TNO = toegepast-natuurwetenschappelijk Onderzoek; DRIFT = Dutch Research Institute For Transitions.

2.4. Transition Arenas

As a start, interviews were held with various stakeholders to find out who as engaged inhabitants and entrepreneurs wished to participate (or should be invited) in giving form to Rotterdam's future inner city. Trend-setters among this group, along with cultural leaders and trend-setters from the Municipality of Rotterdam, participated in transition arenas. Ideas, initiatives, obstacles, and problems were debated at these meetings with the aim of reaching consensus on a common vision.

In transition arenas, the urban challenge of densification plus greening in a sustainable way is discussed, elaborated, designed, altered, and finally put into a long-term vision with an agenda of actions. The transition arenas were organised to build the densification and greening agenda from vision to implementation.

Three components fed the transition arenas. Firstly, the pre-studies such as historical background, challenges, and opportunities. Secondly, the three focus group meetings with housing brokers, clients, shopkeepers, entrepreneurs, and designers. Thirdly, an important extra component, as explained earlier, was the use of information coming from GIS maps and the city to give direct feedback to (wrong or right) assumptions. In this way, the proposed change can be based on facts (quantitative), wishes, opportunities, stories, and design (qualitatively). Stakeholders can see and understand different scenarios or transition paths and choose accordingly. This way the transition strategy and agenda was formed posing for long-term ambitions and short-term innovative actions to go hand in hand.

2.5. Validation Tool, Sustainability Profile for Measuring

The concept of sustainability is often criticised for its lack of clarity and expressiveness. Sustainability can be explicit though. Data, software tools, and sound theoretical context are put to use in order to present condensed analyses of important selected sustainability aspects that are related to this case of densification and greening.

The concept of sustainability originally stems from ecology, where it refers to ecological and environmental boundaries that should be respected to ensure preservation of stock of fish and forests for future generations [15]. In 1987 the Brundtland report, "Our Common Future" [16], broadened the concept of sustainability to socio-economic aspects and the balanced development of social, economic, and environmental factors; later it was rephrased as people, planet, profit (prosperity).

In this chapter, the impact of densification of the inner city of Rotterdam on sustainability is investigated with the help of a newly developed sustainability profile.

As a first step, a framework consisting of 35 indicators was built for eight chosen themes. Figure 3 shows an overview of the different themes and indicators. These themes were seen as priority issues by the city at the time. The themes distinguished cover a broad definition of sustainability, and thus include social and economic aspects as well as ecological and environmental ones (people, planet, prosperity). The subdivision into themes and indicators is based on earlier studies of TNO (toegepast-natuurwetenschappelijk onderzoek; the Netherlands organisation for applied scientific research), with sustainability measuring at the regional level. In this case, the benchmark of the province of Utrecht for its new spatial vision and a visualisation of chances for more sustainability for the province of Overijssel was used [17].

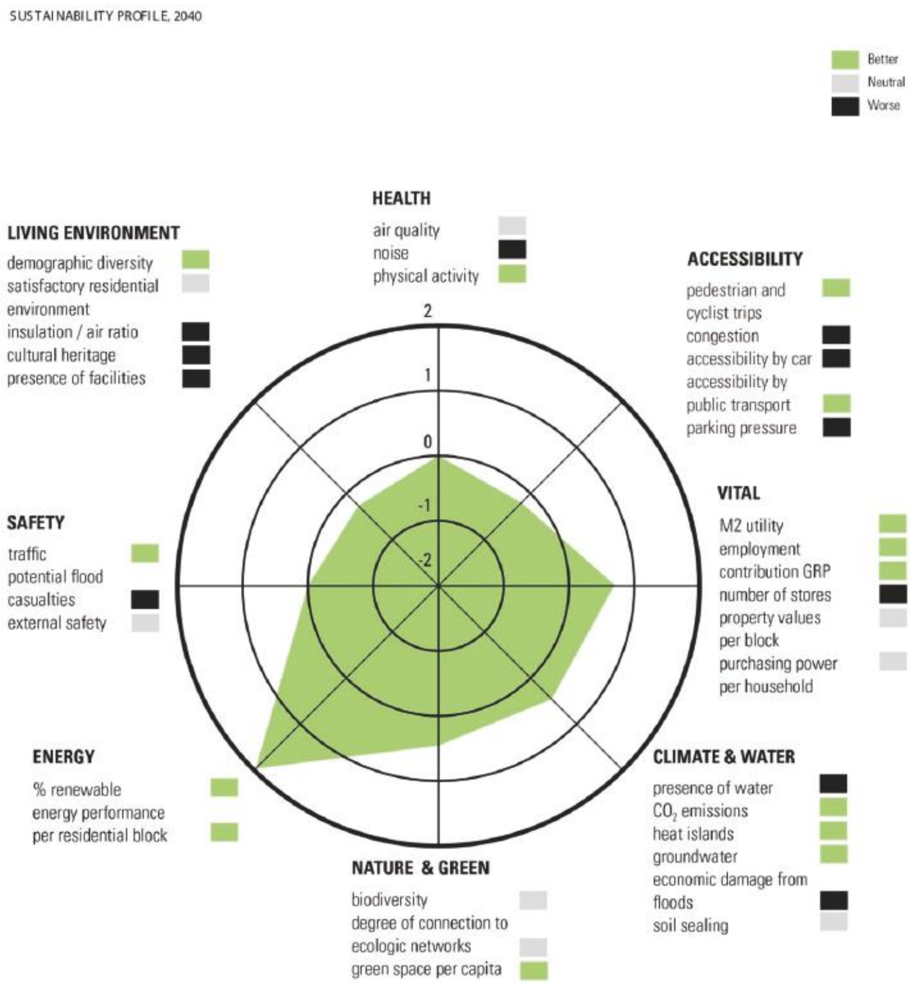


Figure 3. Sustainability profile outcome of the densification and greening strategy of the Rotterdam inner city (image by Doepel Strijkers Architects, Rotterdam).

Indicator Selection

The selection of indicators was based on priority issues formulated by the city, their relation with urban densification, and on the availability of data. Subsequently, a baseline of the Sustainability Profile was set for these themes in the inner city. Following this, the densification strategies and designs were imported into the model Urban strategy [18] and GIS; the values of the 35 indicators were calculated for 2040 or for the moment the proposed densification and greening is completed. To assess the impact of the proposed densification, the outcomes were interpreted qualitatively by visual comparison, and quantitatively by summarising results and making additional calculations. After that, the values of the individual indicators were combined for all distinguished themes. The outcomes were presented in a spider diagram which was called The Sustainability Profile.

The Urban Strategy model provided the energy, traffic as well as the noise and air pollution modules [19] to assess the impact of the densification proposals on eight sustainability themes.

Other models were used in addition: Regina, the regional economic model [20], SOLWEIG (Solar and Longwave Environmental Irradiance Geometry Model), the heat stress model [21], as well as the 'Hoogwater Informatie Systeem' or Flooding information system [22].

3. Results

3.1. Focus Group Meetings and Transition Arena Objectives

The first focus group meeting was for framing challenges and exploring potential synergies with stakeholders. The launch of a research project was a stakeholder meeting to search for possibilities as well as requirements for densification of Rotterdam's inner city. A common belief among the 20 stakeholders was the crucial role of the quality of life of the (future) inhabitants.

Furthermore, it was emphasised that creating attractive conditions for families is important, even if they only form a small percentage of the total number of inhabitants. It was expected that families would make up 20% of the inhabitants (after densification). Several architects presented their work. In addition to the existing high-rise strategy, what also emerged was that there are at least six alternative densification strategies to be distinguished for this group of enterprising inner-city inhabitants. A follow-up issue that arose from the stakeholder meeting, as former director of planning of the city of Vancouver, Larry Beasley described it, was to find out whether these bottom-up initiatives would also contribute significantly to the desired numbers as well as attractiveness of the inner city. To avoid the inner city becoming very "stony", greening strategies were developed together with the densification strategies.

The City Councillor for urban development chaired the second focus group meeting with the 'Van der Leeuwkring', an organisation concerned with the quality of public space.

During the third meeting, the new ideas as well as existing and built plans were shared among each other to show a possible end goal.

After these focus group meetings, the transition arenas took place, during which a transition vision was created.

Table 1 shows an overview of the different topics addressed. Figure 4, shows the proposition or vision for densification and greening. In this long-term vision, densification and greening strategies are defined.

Table 1. Overview of the outcomes of the transition arenas [23].

From	Towards
1. no-connected places (loose beads)	1. connected inner city (a necklace of beads)
2. open festival area, gates and cleaning up	2. everything is allowed provided its fits within a future proof structure (create your own dream world)
3. various communities going their own way in the city: little interaction or collaboration	3.community feeling in which the public realm is the meeting place
4. municipality/companies make the city	4. Rotterdam inhabitants make the city
5. alienation from outdoor space	5. feeling at home, outdoor space becomes a living room
6.playing hide-and-seek	6. making interests, places and existing energy visible

(**a**)

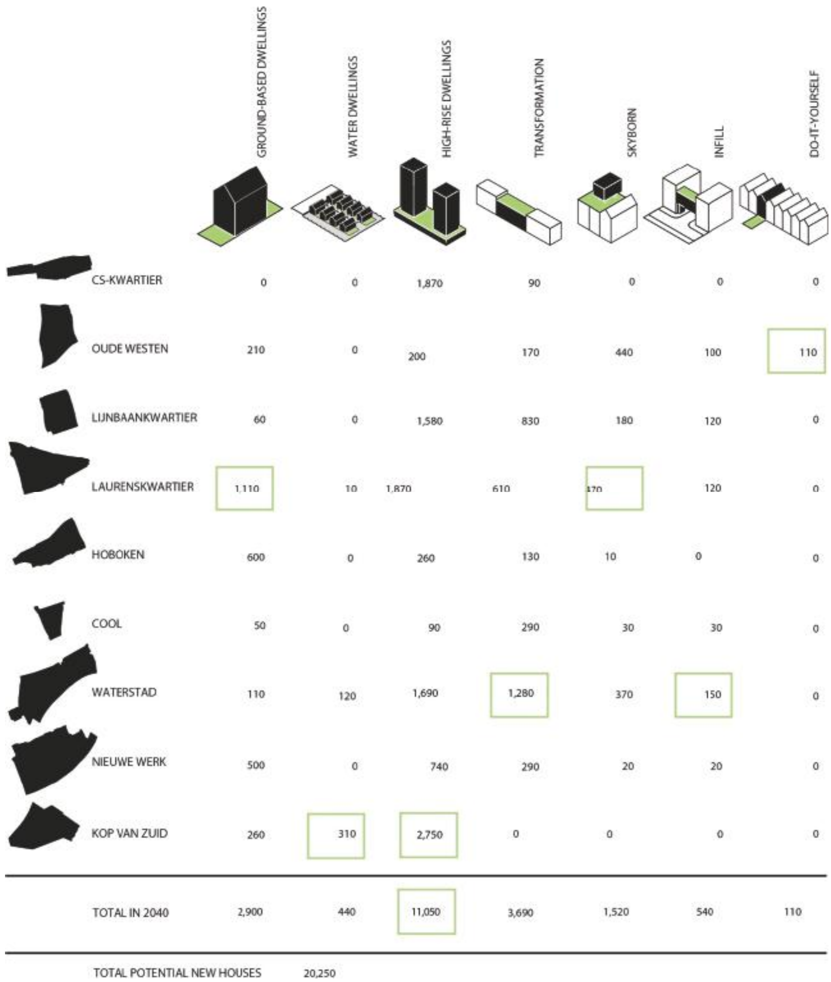
(**b**)

Figure 4. (**a**) Reconstruction plan after World War II (courtesy City of Rotterdam). (**b**) Green densified inner-city plan as the built vision: city as a forest (image by Doepel Strijkers Architects, Rotterdam). This new vision gives a more central role to greening strategies.

3.2. Densification and Synergies

For this research, seven densification strategies, which were identified during the stakeholder sessions, have been explored in terms of their spatial potentials. The ambition of this exploration is not to generate a master plan for densification of the nine neighbourhoods in the inner city (Figure 5); rather, the intention is to demonstrate that there is more available space in the inner city than one may think, and that, in theory, doubling the number of inner-city inhabitants is spatially realistic without diminishing the existing quality of life. To use realistic data for this research on densification, housing typologies characteristic for certain areas in Rotterdam were used. People tend to live were other people of their own peer group live. An example is that people with children want to live where already other people with children are living [24]. So, the strategy was to start with successful areas which were already present. Below in Figure 6, the densification strategies are listed in a matrix. For each strategy, the number of potential units are listed per neighbourhood in the inner city district.

Figure 5. Overview of the nine neighbourhoods studied for densification and greening (image by Doepel Strijkers Architects, Rotterdam).



	GROUND-BASED DWELLINGS	WATER DWELLINGS	HIGH-RISE DWELLINGS	TRANSFORMATION	SKYBORN	INFILL	DO-IT-YOURSELF
CS-KWARTIER	0	0	1,870	90	0	0	0
OUDE WESTEN	210	0	200	170	440	100	110
LIJNBAANKWARTIER	60	0	1,580	830	180	120	0
LAURENSKWARTIER	1,110	10	1,870	610	170	120	0
HOBOKEN	600	0	260	130	10	0	0
COOL	50	0	90	290	30	30	0
WATERSTAD	110	120	1,690	1,280	370	150	0
NIEUWE WERK	500	0	740	290	20	20	0
KOP VAN ZUID	260	310	2,750	0	0	0	0
TOTAL IN 2040	2,900	440	11,050	3,690	1,520	540	110
TOTAL POTENTIAL NEW HOUSES	20,250						

Figure 6. Calculations per neighbourhood of potential new housing per densification strategy, which totals 20,250 (image by Doepel Strijkers Architects, Rotterdam). A short description is given per strategy.

3.2.1. Ground-Based Dwellings

Access at ground level makes street-facing, ground-based housing particularly attractive, not only because it contributes to the individual dwelling, but also since it increases the liveability of a neighbourhood. Undeveloped plots of land and large public outdoor spaces are useful for this form of densification. A garden and access at street level is what makes this densification strategy particularly attractive for families.

3.2.2. Water Dwellings

There are two sites that form natural, potential locations for water-based housing: the old and the former harbours. Not hindered by zoning of land and existing building lines, a multitude of different dwelling types are possible: quay blocks at the interface of city and water, jetty dwellings, pole houses, and floating housing make optimal use of this dynamic environment.

3.2.3. High-Rise Dwellings

The potential for high-rise dwellings can be realised where regulations and ground conditions allow for it. This should be fully in line with the Rotterdam skyline strategy. These dwellings are situated in the most urbanised areas (high-rise zones), the inhabitants of such dwellings benefit from the proximity of amenities. At ground level, the human scale of the building is important and should be carefully designed. In Rotterdam, the term 'groundscraper' was introduced to plan for a good relation between buildings and public space.

Transformations of the inner city's offices were mapped by Zandbelt and van den Berg. There are a lot of short- and long-term term vacancies all over the city, with a concentration in the post-war office areas. As housing is less sensitive to economic conditions, a mix of dwellings with offices could provide a more stable backbone for an attractive inner city.

3.2.4. Skyborn

This is a strategy where existing buildings with a solid construction are suitable for densification by "topping-up" (Figure 7). This is mostly done with houses built after 1950, as they have a concrete or steel structure and flat roofs. The skyborn densification strategy optimally exploits the proximity of urban amenities and green infrastructure. Since new dwellings need to adapt to existing substructures, this strategy encompasses a large diversity of building typologies: from roof villages with a communal character, to individual penthouses. Collective green outdoor space can be created at roof level, with additional private outdoor areas in the form of large balconies or patios. In time, the green roofs, sloping buildings, and bridges will create a new layer in the city.

Figure 7. Skyborn densification strategy, Didden Village in Middelland Rotterdam, by MVRDV (photo courtesy of Forgemind ArchiMedia, via https://www.flickr.com/photos/eager/15771369594/sizes/l www.creativecommons.org/licenses/by/2.0/).

3.2.5. Infill

Infill housing is fit in with great precision (Figure 8). Gaps above narrow delivery streets, undeveloped plots of land, and large courtyards can be filled in with dwellings that cross the street like a bridge. Especially around the so-called 'WWII Fire Boundary', where the border between old and new city is most apparent, infill is a valuable strategy. In doing so, the identity of the urban fabric can be strengthened, increasing the diversity and attractiveness of a neighbourhood.

(**a**) (**b**)

Figure 8. (**a**) Mauritsstraat, Cool, infill densification strategy, by Kühne en Co. (Rotterdam, The Netherlands); (**b**) Boomgaardstraat, Cool, Kühne en Co. (photos by Nico Tillie).

3.2.6. Do-It-Yourself (DIY)

DIY-housing is part of the nineteenth century housing stock with their characteristic facades. These houses appeal to a large group of buyers. Often in a poor state of repair, and way too small to meet current spatial demands, houses of this type can be adapted to suit the lifestyles of young professionals and families. This best practice is now also used in other cities and old apartment blocks. Sometimes it is not about densification in terms of square metres, but rather about the adaptation of building blocks to house more inhabitants. In other areas of the city, housing associations or developers ensure that the foundations are stable and the roof is watertight, while the new home owners are responsible for an interior structure that suits their individual lifestyle. These dwellings are extremely suitable for young families.

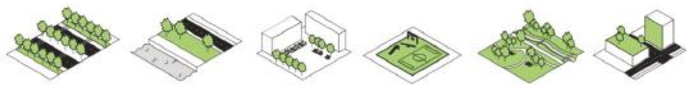
In Figure 9, a mapped overview is given of all the densification strategies discussed.

Figure 9. Mapped overview of potential new dwellings per neighbourhood (image by Doepel Strijkers Architects, Rotterdam).

3.3. Greening and Synergies

The city's wish to attract more inhabitants and visitors to its city centre will only work if the city offers a pleasant living environment that develops along with the densification. The public realm plays an important role in this. Research has shown that an attractive public realm, one in which green amenities are the essence, is an important prerequisite for city life, in terms of day-to-day living and for the work and leisure environment [25]. The more attractive this public realm, the more people would like to spend time there. In this research hypothesis, 5000 new trees should be added and along with other green covering will cover a total area of 150 football pitches (90 ha).

The Municipality of Rotterdam [26,27] notes that more green space in the inner city is desired, as well as greater diversity in the green space and a better quality of green design and management. This implies that the construction of new dwellings should be accompanied by the provision of extra high-quality urban green, to compensate for previously unmet or future demand. In any case, to welcome the inhabitants that come with new dwellings, as well as for people living there already, more and better quality urban green is needed. An attractive green infrastructure in the inner city is conditional to the popularity of living in the inner city. The current green infrastructure needs to be expanded and complemented with new qualities. Below in Figure 10, the greening strategies are listed in a matrix. For each strategy, the number of potential m^2 of green is listed per neighbourhood in the inner city district.



	BOULEVARDS	QUAYS	SQUARES	PLAYGROUNDS	PARKS	GREEN ROOFS & FACADES
CS-KWARTIER	10,400	0	34,900	2,500	0	39,500
OUDE WESTEN	13,600	0	0	0	0	172,600
LIJNBAANKWARTIER	7,700	0	21,300	4,500	2,300	119,300
LAURENSKWARTIER	35,900	48.900	42,700	4,500	5,100	155,200
HOBOKEN	6,500	11,900	6,000	0	0	113,200
COOL	8,300	0	4,600	4,500	7,000	41,200
WATERSTAD	30,000	26,300	0	0	25,800	122,900
NIEUWE WERK	11,300	59,100	0	2,500	0	59,900
KOP VAN ZUID	6,700	64,400	3,000	6,000	29,000	46,500
TOTAL IN 2040	130,400	210,600	112,500	24,500	69,200	870,300
TOTAL POTENTIAL NEW GREEN	1,417,500 M²/ 141,7 ha					

Figure 10. Calculations per neighbourhood of potential new green per greening strategy that totals 141.7 ha. (image by Doepel Strijkers Architects, Rotterdam). A short description is given per strategy.

3.3.1. Boulevard

The boulevard strategy aims to complete the tree structure along main roads. The diversification in tree stock creates more variety and reduces vulnerability for species-specific diseases and aging. Trees and grass on roadsides and alongside and in-between tram tracks make roads and streets more attractive and improves the microclimate of the city. Green streets and roads invite people to walk and cycle and provide routes leading to green areas a high-quality flowscape.

3.3.2. Quay

The quay strategy aims to transform the riverbanks and stony quays into an attractively connected, green recreational landscape. This is all about a new perception of the river Maas, the old river mouths, and old harbours. Getting rid of car parking on the quays wherever possible and designing new green spaces will create a continuous walking and cycling route along the river with connections in the direction of the inner harbours and the areas beyond them. The city is once again connected with the water.

3.3.3. Square

The square strategy aims to give each square, in a way, its own character with various uses: a palette of different squares. Squares function best when surrounded by buildings with mixed programmes at street level and amenities in the form of terraces or attractively decorated public places [28]. Trees and attractive green in the form of scented flowering bushes and plants attracting insects can play an important role in providing a square with a pleasant ambiance, as well as contributing to its identity and character. Sculptures and playing facilities also play an important role in this. Flexible use of space can also provide opportunities for inhabitants to have a barbecue, a children's party, or have other events.

3.3.4. Parks

Concerning parks, the inner city has no more room for a large metropolitan park at ground level, but many small parks can also green the inner city. The park strategy aims to have a park within walking distance (250 m) of every home. The parks will differ from each other in form and use. Existing qualities in parks should be maintained and reinforced as much as possible. The west side of the city has a continuous network of good parks, which can contribute to the perception of green in the entire inner city, provided they are well connected. Some of these parks are improved or redesigned such as the Museumpark (Figure 11).

In a densifying city, parks and greenways on rooftops are not only an option but probably a necessity.

Figure 11. Greening strategy of strengthening existing qualities, such as the Museumpark Rotterdam. Redesign of the Museumpark by Chris van Duijn OMA (Office for Metropolitan Architecture, Petra Blaisse Inside Outside and Nico Tillie (Delft University of Technology/City of Rotterdam).

3.3.5. Playgrounds

The Municipality of Rotterdam intends to create lively oases for children: squares, parks, and gardens that encourage children to play with sufficient places to sit. The Speeldernis or 'play wilderness' is a great example of playing and discovering nature (Figure 12). Child-friendliness entails more than just creating a few playgrounds; it encompasses the entire design of the public realm. Broad sidewalks, slow-traffic routes, and speed-bump zones play an important role. Broad sidewalks provide informal space for games. Speed-bump zones create transitional areas between the private domain and public space, where children can play in a safe, protected environment. In North American town planning, the Dutch 'Woonerf' is making a revival.

(**a**) (**b**)

Figure 12. Greening strategy of playgrounds: (**a**) Speeldernis or 'Play Wilderness' and (**b**) Green roof and green facades in the urban fabric in Singapore as examples (photos Nico Tillie).

3.3.6. Green Roofs and Facades

Green roofs and facades provide extra ecological quality, capture fine particles, and can provide green scenery and green recreational (sitting and playing) environments (Figure 12). Moreover, they have a positive effect on the densified inner-city climate and function as water buffers, thus contributing to urban water management. Green roofs and facades also provide excellent locations for realising urban agriculture. Combinations of building functions (e.g., restaurants and schools) and agricultural activities on roofs and facades also have social and economic value.

Furthermore, this can all be combined with installing solar panels. In the MUSIC project, the online Rotterdam energy atlas was produced for inhabitants to see the potential for solar energy on their roof.

3.3.7. Glamourous Green

Glamourous Green or outdoor space of excellent quality is needed for the busiest and most characteristic places in town. The design of this public realm is decisive for the atmosphere, tempting people to dwell longer and, finally, to feel more connected with the city.

In Figure 13, a mapped overview is given of all the greening strategies discussed.

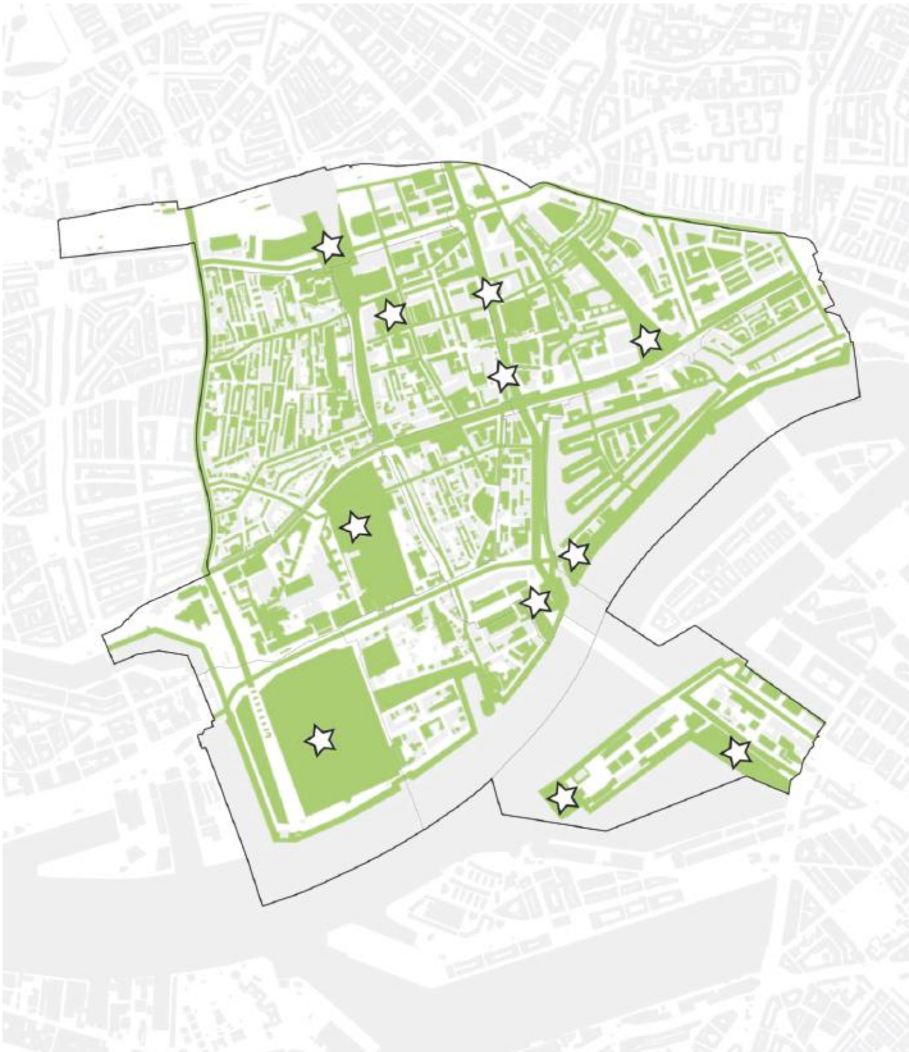


Figure 13. Mapped overview of existing and potential green per neighbourhood (image by Doepel Strijkers Architects, Rotterdam).

3.4. Validation Results

The densification and greening proposal resulted in quantifiable outcomes such as number of houses and trees. This was direct input in the scenario models, which then resulted in, for example, energy use. When this was not possible, a consensus of expert opinions and views were used, combined with sources of geographical data. The results were analysed with geographical information systems (GIS). For each of the eight themes in Figure 11, the outcomes of one or more indicators are explained below.

3.4.1. Energy

Energy use: Doubling the number of dwellings will strongly help to decrease the average energy consumption per dwelling of the inner city area.

Average use of energy per dwelling will decrease because new housing will have to meet stricter standards of energy efficiency. New buildings will have to be energy neutral after 2020. However, substantial efforts will be needed to upgrade the energy efficiency of the existing housing stock. Ideally, upgrading could be carried out while densification strategies are being realised. Densification has the added benefit of contributing to a more compact urban form; more clustering within the urban morphology leads to more energy efficiency as well. Furthermore, existing district energy networks will become more efficient and profitable because they will supply energy to a greater number of buildings; also, heat exchange between buildings will become possible [29]. Lastly, a compact urban form also has a favourable effect on energy consumption by urban transport such as public transport, walking, and cycling that are all forms of low carbon transport.

Renewables: The growth of renewable energy production within the city can be expected. Solar photovoltaic units can be installed on many flat roofs, either alone or combined with green roofs. In urban transport, the combination of less car use and more frequent use of public transport, walking, and cycling, in combination with more energy-efficient vehicles, will largely compensate for the additional use of energy.

3.4.2. Climate and Water

CO_2 emissions—low carbon: Since all the new houses will comply with new energy regulations, 44 tonnes of CO_2 emissions will be avoided on a yearly basis, compared to a business as usual scenario, i.e., 18% of the current residential CO_2 emission of houses in Rotterdam. Of course, as long as new buildings are not energy neutral, adding new buildings will increase carbon emissions of the built environment. New buildings will have to comply with stricter norms on energy performance as from 2020. This means that all new buildings will be nearly carbon neutral. Apart from decreasing energy consumption for buildings and transport, the energy mix for the inner city should change to make it carbon neutral. Heating and cooling should either shift from natural gas to zero carbon electric or district heating and cooling systems, and the electricity should come from renewables off grid or form a zero-carbon grid. Scenario studies in GRIP (Greenhouse Gas Regional Inventory Project) [30] for Rotterdam have shown that this is possible. CO_2 emissions avoided in new buildings has been defined in comparison with business as usual. However, for future studies, it would be interesting to know more about avoided CO_2 emissions when comparing living in a densified neighbourhood to an alternative, for instance living in a suburban neighbourhood. Similarly, for the GAP indicator (green area preserved) [31], it would be interesting to compare not building outside, but inside the city.

Heat stress: The increase in urban heat island effects by adding building mass to the inner city is compensated by adding urban green and shadow cast of high building blocks.

The densification strategies as described in Section 3.2 are accompanied by ambitious urban greening strategies. Higher buildings lead to more prominent heat island effects. However, higher buildings also create more shade, which compensates for increased urban heat island effects. Also, development of more urban green mitigates these heat island effects even further. As a result, heat stress does not increase significantly compared to the existing situation. Several parts of the city that warm up during summer were mapped; the greener the area, the smaller the chance that during a warm period the critical radiation heat will exceed 55 °C. Note that radiative heat is not the same as air temperature; radiative heat is usually much higher than air temperature.

Soil sealing, flooding, and economic risk: Soil sealing and flooding risks remain at the same level. Economic risks increase as a result of potential flooding, not because flooding occurs more frequently, but because the total economic value of real estate is higher as the inner city grows.

3.4.3. Health

Physical activity factor. In this example, higher density stimulates walking and cycling. With more inhabitants living in densely built-up areas, walking and cycling can be promoted, particularly so because car use becomes less attractive as a result of a limited supply of parking spaces and an urban design attuned to cycling and walking. Ambitious urban green development induces physically active behaviour. More playgrounds will be created through strategies for urban greening and existing playgrounds can be used more intensively. A high-quality flowscape for pedestrians and cyclists depends on the quality of the urban design of the densification strategies. Examples of relevant elements in a successful urban design may include lanes with separate walkways and cycle paths, the establishment of attractive green areas, and the reduction of barriers by providing extra connections such as bridges for slow traffic or simply zones where pedestrians and cyclists have right of way. On the other hand, new blocks of buildings could limit the possibilities for physical activity around the city. Improvement of physical activities occurs when new green areas and infrastructure is developed, while decline takes place when blocks of buildings are added. It is clear that the new city structure includes some blocks for which it is less inviting to venture out on the streets, because there is little urban green or barriers to walking and cycling are present. Additional analyses of the combined effect of physical activity, air pollution, and traffic safety show that extending the possibilities for physical activity leads to extra years of healthy living.

Noise pollution will increase slightly due to more automobile traffic on a few thoroughfare roads. Effects of busier traffic are countered by buildings that act as acoustic screens. However, more than half of the new inhabitants will experience noise levels above the strict future norms. After the realisation of the densification strategies, about 18,000 of the new inhabitants will experience noise levels greater than 48 dB at the outer walls of their dwellings. This is primarily due to an increase in the number of cars. The policy limit of 48 dB anticipates new, stricter policy norms in the future; 55 dB is the current norm. Very few houses are expected to experience noise levels above the current norm of 55 dB. Noise levels above 50 dB are mainly confined to roads; noise levels at the facades of homes are mostly below 50 dB.

As for congestion, few changes occur between the old and new situation. There are few places where an increase of more than 5 dB will take place. In contrast, many places show a decrease of noise hindrance due to the assumed higher importance of public transport, walking, and cycling as means of transport. Although densification will not as such substantially aggravate noise levels in the inner city as compared to current standards, action (e.g., reduction of car traffic) must be taken to comply with future norms.

Air quality: It is expected that air quality will improve. By 2016, heavy polluting vehicles were not allowed to enter the inner-city anymore, with air quality improvement as a result. As a consequence of densification, more people will be exposed to the existing levels of air pollution. At the same time, adults and children will have more possibilities for physical activity, which in combination with relatively less car use can lead to two more years of healthy living according to the models.

3.4.4. Vital City

Employment: Densification leads to a significant increase in employment in service activities.

A denser inner city leads to a higher demand for services, such as shops, restaurants, hairdressers, and the financial and administrative services that in turn support these companies. Employment and added value per square meter will increase as a result of urban densification and the resulting increase in inner city inhabitants.

Market value of new houses: Although the average current market value of houses per city block is known, it is difficult to accurately predict the future value of houses since there are too many variables that influence their future price. We can nevertheless give a first indication of price developments based on observed correlations between the number of new homes and the development of housing prices, assuming that all other factors stay the same. These correlations show that if up to ten houses are added to a residential area, house prices will rise only slightly. This is because a small investment indicates a small scale of improvement of an urban area that has been already developed. If more than just a few houses are added, the data show that prices will drop. This can be explained by the simple mechanism of supply and demand: the more apartments or family homes in a certain building block, the less new owners are likely to pay more for them. Indication of the relative change in house prices in Rotterdam per city block were studied, as well as the current average values per block before and after densification. However, a strong reservation should be made about the outcome, since it is only based on the number of homes; other factors determining house prices such as location, house type, and number of rooms have not been researched. Differences can be seen between the north-western and north-eastern parts of the inner city. Unfortunately, data is missing for some city blocks.

3.4.5. Nature and Green

Biodiversity: The current initiatives to improve biodiversity will compensate for a more intensive use of the inner city area. The amount of urban green is expected to increase significantly. Also, there is more diversity of green such as green roofs, sloping roofs linking street level to a roof network, and green walls. Nevertheless, it will be used by more people, so the area of urban green per inhabitant slightly decreases.

Ecological networks and green space per capital: The availability of urban green improves, but it will be used more intensively. An expansion of urban green will be realised, although the increase in number of inhabitants is relatively larger than the volume of urban green added. In this analysis, urban green available for daily activities (within a range of 250 m of the dwelling), such as recreational walking and cycling, was distinguished from urban green available for weekend activities (within a range of 500 m of the dwelling). It appears that the total amount of urban green per inhabitant decreases somewhat in spite of ambitious strategies for urban greening. However, the good news is that for many inhabitants, their proximity to urban green is significantly closer, especially for those who live in existing buildings. Less urban green per inhabitant will lead to more intensive use of the urban green in place. This can result in "cosy crowdedness" and "more eyes on the street" (Jane Jacobs). The presence of people attracts other people. The quality and characteristics of urban green is important as these influence how green areas are used, because there are more factors such as access and linkage, safety, sociability, and activities [25,28,32]. Although the quantity of urban green decreases per inhabitant after densification, from 37 to 34 m^2 per inhabitant, green space of high quality can partly compensate for this and thus contribute to creating a satisfying living environment.

3.4.6. Living Environment

Facilities: In the search for new housing locations, the number of leisure facilities and services available often play a minor role. Nevertheless, in order to maintain an adequate service level, places need to be identified where leisure facilities and services should be added or expanded. All stakeholders should be aware of the needs of entrepreneurs and organisations at an early stage. Diversity and flexibility of space for leisure facilities and services should allow for easy adaptation to actual needs in future. The location of bars, restaurants, hotels, theatres, galleries, museums, and other cultural points of interest per city block were mapped. Also, the anticipated increase in the number of new facilities needed in relation to the location of new dwellings and new inhabitants after densification were studied. Especially, the areas around the railway station and the Kop van Zuid district need a boost in leisure facilities.

Demographic diversity: More demographic diversity due to the settlement of families contributes to greater satisfaction with the living environment. Measures to design child-friendly neighbourhoods, such as routes and continuing pavement, have a positive effect on safety and well-being, not just for children but also for elderly people.

3.4.7. Accessibility

Accessibility in the inner city appears to be largely dominated by the voluminous traffic flows of commuters and visitors rather than the doubling of the number of its inhabitants, so the effect of densification is relatively small. Besides, for the inner city, the limited supply of parking places (0.48 parking place per dwelling 2012, and shrinking) and increasing numbers of other means of transport, such as public transport, walking, and cycling, will lead to reduced use of cars. Although the Urban Strategy model predicted for congestion to get worse on a few thoroughfare roads as a result of higher traffic intensities outside the area studied.

However, when interviewing the traffic department in Rotterdam, it turns out that congestion in the inner city overall has not increased in the past four years. In fact, some roads show a decline in car use and car traffic.

3.4.8. Safety

In terms of safety, the results show that traffic safety improves due to relatively less car use. In the past years there is a downward trend for car use in the city. Also, design solutions for a child friendly city improve traffic safety.

Safety from flooding remains the same; the risks do not increase, although the number of potential casualties is higher.

3.5. Results Outside the City Itself

3.5.1. Densification

Real life projects are not the results of the last few years only. During the third stakeholder meeting, the trend-setters were already demonstrating how they were already practising various initiatives. Sometimes the Municipality of Rotterdam was the initiator, as in the case of some DIY houses. Surveys among inhabitants and potential dwellers/buyers clearly indicate that this initiative is very much appreciated by enterprising inhabitants because they have an opportunity to satisfy their individual wishes and needs. Entrepreneurship is key to such developments, as demonstrated by Joost Kühne, spokesman for a group of initiators who develop small new housing projects as urban infill, financed in advance by market parties, which demonstrate how small interventions can have great impact on a neighbourhood. Another built example comes from ERA Contour, with 'block city', or the housing corporation Woonstad by selling houses, destined to be DIY houses in the district of Het Oude Westen. The DIY ideas were awarded with a European prize and are now applied in many other cities. Also, the recent renovation of the Bijlmermeer in Amsterdam was very successful using a similar approach.

Transformation of vacant office buildings and municipal real estate is also an issue high on everyone's agenda. This is why the Municipality started inviting creative entrepreneurs to come forward with plans to exploit the opportunities provided by vacant (municipal) real estate.

Also in 2017, new areas came to life regarding facilities such as bars and restaurants. Places that were not developed well a few years ago are now hot, such as the area near the central station, the former office of Nationale Nederlanden (sandwich bars and coffee), Kop van Zuid, and 'Onder de Bogen'. This area developed very fast as a result of the 'Luchtsingel', a crowdfunding initiative from the Rotterdam office of ZUS (Zones Urbaines Sensibles) linking different parts of the city by building a wooden bridge over the railway. This was also one of the IABR2012 projects.

The year 2014 proved to be a turning point for the popularity of the inner-city with new developments such as the new Market hall, Central Station, and the multifunctional Rotterdam Building near the Erasmus bridge.

3.5.2. Greening

The greening strategies in Figure 10 show that a significant expansion of urban green space is possible under densification. Green roofs and Quays form the biggest part of this. A number of plans have already been built, such as the green quays at Leuvehoofd. This was designed by Piet Oudolf. New developments go further and in some areas tidal parks are built at the river. As such, the whole riverfront can be seen as a (potential) metropolitan park.

With the greening strategies it is important that, in addition to the municipality's involvement, private parties and developers can also contribute. For example, private initiatives such as the urban agriculture garden on the Müllerpier or former garden in Delfshaven near the roof park have already contributed to the green space. Existing green roofs, facade gardens, and other urban agriculture initiatives are also contributing to the city's green. The number of initiatives has grown. Extrapolation of the effect of densification and greening strategies indicates that there is sufficient space to extend these approaches on a larger scale and increase the involvement of inhabitants, and as such reinforce the vitality of the city.

In terms of transition management and stakeholder follow ups, over the years, stakeholders got more involved in different processes. Over the past four years, the so-called city conference or 'stadscongres' was organised. This is basically a yearly conference of one week, where the city officials present their new plans and ideas for input and where city plans as well as local initiatives link up with each other and other organisations. There are hands-on work sessions to prepare short-term actions in a long-term vision. As such, it is a kind of big dating event where people and organisations who like to improve the city get together.

A newer initiative is the 'wijkraden' or neighbourhood boards. Each neighbourhood has a group of active inhabitants or organisations that are involved in making a better city. As such, the transition arena group of the IABR2012 can be seen as an early neighbourhood board.

Another but older initiative that ran for four years is the city competition. Politicians agreed that for four years, inhabitants of the city could vote each year for the best initiative they wanted to be built in the city. The winner would be granted a few million euros for the project to be built. Actually, the 'Luchtsingel' described earlier as the wooden bridge was one of these projects. One of the positive side effects was that many people got involved in many initiatives. Even if their plan did not win, it created a lot of positive energy and ideas that were often realised later on.

4. Discussion

4.1. Synergies

In Sections 3.2 and 3.3 many synergies were listed with the densification and greening strategies. The strategies are implemented in such a way that synergies occur. The synergies comply with other urban agendas in many cities, such as climate adaptiveness, child friendliness, good quality biking, and so on. By planning for synergies, the densification and greening agenda in cities relates directly to local broader social, environmental, and quality of life issues. In a follow-up study, this could be compared and linked to, for instance, ISO37120 standard on city services and quality of life and the United Nation's Sustainable Development Goals.

4.2. GIS and City Data Information

An important component to adapt the stakeholder sessions and transition arenas to local context and needs was the use of GIS maps and city data in the transition arenas to give direct feedback to (wrong or right) assumptions. Using a third party (TNO) to test alternatives and future plans was crucial as they are an independent party in the process; a city testing and valuing its own plans would be less credible.

The outcomes showed that linking GIS mapping and city data to the stakeholder process and transition management proved extremely valuable.

The outcomes of the process also showed positive results for the densification and greening hypothesis in order to improve the sustainability of the city. It also showed that it is a very delicate process were stakeholder involvement is crucial to get things right. 'People make the inner city' was a phrase coined in this context.

Using the Sustainability Profile was very helpful, although at a practical level the themes and indicators did not match existing indicators at neighbourhood and city level. Follow up research should take this into account.

5. Conclusions

Densification and greening of the inner city of Rotterdam can lead to a more sustainable city with a higher quality of life. In this study, ambitious concepts and strategies for providing low-carbon urban transport are a side effect (walking, biking, and public transport). Electric cars and sustainable distribution of goods are strategies that have not been explored in this study. The hypothesis stated earlier is, therefore, only partly verified; low-carbon transport strategies are missing and still need to be articulated better. For specific conclusions on the different themes in Figure 11, Sections 3.4 and 3.5 describe the outcomes of this research.

The outcomes of the transition management process from problem delineation to agenda setting were successfully presented. In this case, the focus groups as well as the use of GIS mapping and a data specialist were new.

Although the Sustainability Profile served as a good baseline to measure improvements, it was difficult to (re)use for the employees of the city administration as they used slightly different indicators. In the follow-up process, the indicators were adapted to the ones used by the city administration (the Sustainability Profile was renamed into Smart City Planner).

These data were used in transition management and can be used in any a stakeholder environment to explore potential synergies and vision making.

The overall conclusion to be made is that the densification and greening strategies can contribute to a higher level of urban sustainability.

The research results also made clear that densification and increase of urban green need to go hand in hand with good parking solutions and an ambitious mobility strategy. The inner city has evolved into a pilot project for finding out which measures will succeed in turning the entire city of Rotterdam into a sustainable, vital one. This approach can also be copied to other cities.

Author Contributions: N.T. wrote the paper and was the initiator of this project and was responsible for the project and research outline. He also worked on different aspects from data, to greening and densification as well as stakeholder sessions where the different strategies and agenda were formed. He was first author of the project publication and was with M.A. also responsible for arranging the financial resources for this project. J.B.-v.B. was responsible for studying the impact of the proposed strategies and developed with TNO the sustainability profile. D.D. was responsible for the upscaling of the densification and greening studies in the city. He also provided maps and designs. M.A. was co-initiator of the project and was responsible for contacts with the city councillor and was crucial in developing the project strategy. He organised and guided many stakeholder sessions. During the process, all work was discussed on a weekly basis so all authors added to each aspect in this study. Also, all authors wrote or contributed to preprints of this paper.

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sustainability

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Article

The Impact of the Comprehensive Rural Village Development Program on Rural Sustainability in Korea

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Abstract: An imperative challenge emerges from the demand to apply the scientific method in the assessment of recent agricultural and rural policies throughout the world. The objective of the present study was to conduct an ex-post quantitative evaluation of the Comprehensive Rural Village Development Program (CRVDP), a representative rural development policy operated by the Ministry of Agriculture, Food and Rural Affairs, a central government agency in South Korea. The primary purpose of this program is to ensure sustainable rural society. This study found a moderate but significant positive impact of the policy in enhancing the standard of living in rural areas. The present paper concludes with suggesting some policy implications, limitations and future directions of policy evaluation studies.

Keywords: policy evaluation; sustainable rural policy; spatial econometrics model; decomposition method; South Korea

1. Introduction

The rapid economic development in South Korea (hereafter "Korea") over the past six decades has been deservedly hailed as globally unmatched. Concomitant with this national economic growth has come an increase in both agricultural production and farmer's income. However, the rural and agricultural environment in Korea has undergone rapid change over the past fifty years. In particular, the trend toward urbanization, which has been accelerating since the mid-1970s, has resulted in decreasing relative competitiveness of agricultural land use in Korea's rural areas, which today suffer disproportionately from such problems as an aging population, the collapse of basic industries and a lack of social overhead capital, which adversely affect the living conditions of rural residents.

In response, the Korean government has implemented a number of initiatives to revitalize rural areas and to guarantee a sustainable rural society. The initiatives could be a necessary and legitimate redress of the historical siphoning of wealth from rural areas to urban areas. The initiatives by diverse levels of government are key factors to revitalize rural economy for both developed and developing countries [1]. Even so, there is growing concern rooted in changes in popular opinion regarding the massive government investment in resolving such rural problems. Some critics insist that there is a moral hazard in expanding government support for rural residents. However, assigning and assessing values that are associated with such investment involve investigating how the program has affected the values and philosophies constituting Korean society. At the very least, social demand that policy be improved in the interests of promoting greater efficiency and competitiveness in rural areas has increased.

As is well known, policy evaluation can facilitate more successful policy development through a feedback process. With this in mind, the Korean government implemented diverse policy evaluation instruments to improve the overall effectiveness of government policies with regard to rural revitalization and sustainability. However, few studies have been conducted that draw extensively from and inquire deeply into the implications offered by quantitative schema. Moreover, in the case of rural policies, policymakers place more emphasis on policymaking itself than on its objective evaluation. As a result, very few assessments use objective and quantitative techniques to evaluate the impacts of policy, and, in turn, the lack of such evaluation has undermined the credibility of existing assessments, consequently lowering the level of public confidence in policies produced by the Korean government.

The objective of the present study is to conduct an ex-post quantitative evaluation of a representative rural development program operated by the central government in Korea. This study selects a rural development program called the "Comprehensive Rural Village Development Program" (CRVDP) as a subject for an objective evaluation of the impact of rural policies in Korea. The main objective of the CRVDP is to ensure the sustainability of rural society by establishing forward-looking rural communities in which living conditions and livelihoods are in harmony by intensively supporting several key villages in a *eup/myeon*-unit rural area. The *eup/myeon*-unit is the lowest level of administrative unit in Korea. The present study constructed a three-step econometrics model incorporating a factor analysis, a spatial econometrics model and a decomposition model, to evaluate the impact of the rural development program on rural sustainability.

Why does the evaluation of values from the CRVDP have to be conducted using a quantitative approach to an ex-post design? By clarifying the factors of success or failure and then analyzing the sustainability of outputs and impacts through objective and retrospective perspective, the evaluation results are able to provide implications for policy-making processes in the future. In addition, this evaluation not only examines the newly formulated policy paradigm for agricultural and rural development but also contributes to balanced urban–rural development policies and social cohesion in Korea from a long-term perspective.

The present study was primarily concerned with formulating a robust quantitative evaluation of the impacts of government policies in rural areas to help resolve the debate and inform continued planning for rural revitalization policies. The remainder of the paper proceeds as follows. Section 2 presents the background of this study. Section 3 addresses and explains relevant methodologies. Section 4 discusses the data and variables taken into account. Section 5 demonstrates the statistical results of this study. Section 6 summarizes our findings and outlines the limitations and policy implications of this study.

2. Rural Policies and Evaluation in Korea

2.1. The Evaluation of Rural Policies

The current rural policy discourse has converted into a viewpoint that emphasizes the spatial value of rural areas by putting rural areas on a par with the agricultural sector [2–4]. This policy also transforms functions of the space from rural areas that are limited to food production to areas that attract experience- and leisure-oriented external consumers. However, although the increase in governmental investment can be justified by the multi-functionality of rural places, the limited budget and duality of rural policies require an objective and ex-post evaluation of the agricultural and rural policies [5–7]. (Lee and Yun [5] suggested that rural policy has a duality in matching the financial resource providers and the direct beneficiaries of the policy, especially from the urban–rural dichotomous perception.) In addition, when policy effects are demonstrated through ex-post policy evaluation, it is possible to consolidate the validity of political investments.

Nevertheless, agricultural and rural policies have been relatively free from rigorous evaluation measurements, with an emphasis on characteristics of the public property of agriculture and rural places. For these reasons, although not incorporated into the policy evaluation process, these characteristics have expanded only the appearance of the policy without verifying the logic and the effectiveness of the policy. Some groups raise the moral hazard problem, distrust the policies [8] and even draw questions about the effectiveness of the policies [9].

While investigating the relationship between government performance and evaluation has a deep research background [10], consideration of evaluation in rural policy is timely and imminent. OECD [11] shows that policy objectives in member countries have focused more on such rural issues as improving rural competitiveness, enhancing human and social capital, developing niche markets for rural goods and services, diversifying economic activities and so on. However, marked differences in the policies among the member countries exist. Exploring the differences of rural development policy between the EU and the US, Shortall and Warner [12] argued that the EU focused more on the social cohesion that underpins rural development policy due to an emphasis on "Europeanization" that can lessen territorial disparities and guarantee cultural diversity, while the US emphasized market competitiveness as a rationale for rural development, perceiving market mechanisms as the primary instruments for achieving equality.

Incorporating a dualistic construct, Bjorkhaug and Richards [13] contrasted the impacts of market-oriented versus market-protected agricultural policy on agricultural diversity to achieve the goal of sustainable rural development. They found that the market-protected regime was better at sustaining such endogenous goals of multifunctional agriculture as preserving rural space and cultural landscape, maintaining farming livelihoods and ensuring food safety. However, the market-protected approach is highly reliant on government subsidies. Two imperative issues related to this reliance on subsidies are the tighter budget constraints and skepticism regarding the effectiveness of stimulus packages for the spatially targeted interventions [14–16]. A strong claim to construct a credible scientific schema that enables researchers to evaluate agricultural and rural policies has been presented from a diverse array of academic disciplines [7,17–19]. However, identifying the precise impacts on the intended targets is a complex and challenging task.

One popular approach is the application of an ex-ante design [20]. Considerable efforts have been made in constructing such ex-ante economic models as SAM, I/O and CGE for policy evaluation in both the EU and the US [21]. The ex-ante design determines the possible benefits or pitfalls of a policy through diverse simulation mechanisms and attempts to predict the outcomes of intended policy intervention with given assumptions regarding individuals and circumstances. However, the ex-ante design is subjective and predictive in nature and possesses fundamental limitations to compensate for deviances in real empirical settings. Policies that appear promising before implementation often fail to generate expected outputs. Shumway [22] argued that, regardless of the specific technique used, the ex-ante approach often fails to meet the normative standard of scientific societies.

Due to the litany of ill-conceived and costly rural-development policies and initiatives, examples of successful rural policies are quite rare [11]. Olfert and Patridge [15] suggested that development efforts targeting rural areas require rigorous empirical evidence. Winters et al. [23] and Esposti and Sotte [17] urged that higher standards should be imposed for accurate discernment of the conditions under which rural development policies are justified and how they succeed. Despite the existence of a well-constructed body of literature on policy impacts, little attention has been paid to applying ex-post impact studies to agricultural and rural policies.

An imperative challenge emerges from the demand to incorporate an ex-post empirical approach and quantitative methods to recent rural policies. Walker et al. [7] stressed that pure impact or cost-effectiveness evaluations of agricultural and rural policies should be conducted by adopting an ex-post design that can distinguish the effectiveness of the policies. The ex-post approach overcomes the deficiencies of the ex-ante design because the ex-post approach measures the actual impacts of the policy. A well-designed ex-post evaluation can have substantial spillover effects that link concurrent and future impact evaluations of relevant government policies [6,24].

2.2. Experiences in Korea

Korea's economic success is best characterized as an example of a latecomer's high growth rate, compressing the longer developmental history of developed countries in the world into a shorter time period. In 1960, Korea had a per capita gross national product of $80 USD a year, a figure placing it on roughly the same level as Ghana and Sudan and a bit behind India. Since that time Korea's economy has rapidly advanced and is now consistently near the top of global growth charts, with forty years of growth averaging more than 8% a year until the late-1990s, doubling repeatedly in an exponential explosion of economic expansion. With the exception of neighboring Taiwan, this sustained boom has no historical parallel—not even in postwar Japan. The rapid economic development has lifted Korea's per capita income from one-third the OECD average in the mid-1980s, to the top quarter of OECD members at present [25].

To modernize its economy, Korea adopted an unbalanced industrial growth strategy. Anticipated imbalances soon became apparent in many areas, such as between urban and rural development, large-scale and small-scale businesses and export-oriented and domestic industries. As a result, although the standard of life of the nation's population increased substantially, the effect of the benefits has been largely concentrated in only a few regions. Because the economic efficiency-focused development model was widely supported, upholding the so-called "growth pole" strategy, preference was given to a few predetermined industrial policies concentrated within specific urban locations.

This urban-centered strategy has resulted in the speedy collapse of traditional rural communities, best reflected in the shrinking population size and deteriorating economic conditions. In 2010, farm households made up approximately 6.3% (~3.1 million individuals) of the total population, far less than a quarter of the 1970 level. In 2010, 35.6% of rural residents were 65 years of age or older, whereas the national average was approximately 11.8%. Agriculture accounted for approximately 26% of Korea's GDP in 1970, dropping to 2.4% in 2010. In addition, approximately 26% of GDP and 50.4% of the total labor force were accounted for by agriculture in 1970, whereas, in 2010, these figures were 2.4% and 6.6%, respectively. Rural households are having increasing difficulty in maintaining economic parity with urban households, and the gap in income between farm and urban households should be of grave concern to policy makers. The average income of farm households was higher (111%) than that of urban households in 1975, and average farm household income was comparable to that of urban households until the early 1990s. In 2010, however, farm household income was 66.7% of urban household income (all statistics in this paragraph come from the Korean Statistical Information Service [26]). To lessen this disparity, the Korean government introduced diverse rural policies planned and implemented since the early 1990s, when the gap between rural and urban areas was on the rise.

Rural policy in Korea is more inclined toward the European model, although the political, territorial and cultural contexts of the two domains differ markedly from one another. While planners and policy makers recognize the market failures in rural Korea, they seek to construct a policy of market planning that tries to make rural market systems function. (Market planning is well understood in the management science perspective implying the process of analyzing one or more potentially interesting marketplaces to determine how a business can optimally compete in them. Here, the hybrid concept comes mainly from urban planning and regional science perspective (cf. the online journal, Planning & Market, http://www-pam.usc.edu).) This approach incorporates two seemingly contradictory strategies: planned government interventions and a laissez-faire market system. While the policy posits the explicit pursuit of the construction of laissez-faire market systems in rural areas, the strategic contents of the rural policy are more often aligned with those of the Common Agricultural Policy (CAP) of the EU.

In parallel with the developed economies in the OECD countries, rural policy was synonymous with agricultural policy in Korea until the 1990s. In the 1990s, emphasis shifted to structural adjustment to enhance agricultural competitiveness in the global market. Beginning in 1998, the second phase of the structural adjustment plan to strengthen the agricultural sector and rural development was initiated. In 2004, the Korean government launched a comprehensive plan on agriculture and rural communities and established the "Ten-Year Mid and Long-Term Policy Framework on Agriculture and Rural Communities".

In each phase, massive investments have been made to achieve the specific goals (Table 1), with 42 trillion Korean Won ($47 billion USD) and 45 trillion Korean Won ($37 billion USD) being invested in the first and second phases of the plan, respectively. The third phase will invest 119 trillion Korean Won ($104 billion USD). These expenditures increased the share of the budget set-aside for agriculture in the total national budget to 13–15% during the 1994–2013 fiscal periods, an increase from 9% in 1993. (Part of the reason is the political power of farmers in Korea. Farmers are enormously influential in the legislative and the executive branches of central government, even though their numbers comprise a very small percentage of the total population. Although the percentage is decreasing every year, they still retain political clout that far exceeds their numbers.)

Table 1. Agricultural and rural investment plans in Korea, 1991 to 2017.

Phases	Titles	Period	Major Objective	Budget
1'st	Agricultural and Rural Structure Improvement Plan	1991–1996	- Strengthening the competitiveness of the agricultural sector	42 Trillion Korean Won (47 Billion USD)
2'nd	Agricultural and Rural Structure Adjustment Plan	1997–2003	- Strengthening the competitiveness of the agricultural sector and rural areas	45 Trillion Korean Won (37 Billion USD)
3'rd	Comprehensive Plan on Agriculture and Rural Communities	2004–2017	- Development of agri-food sector - Enhancing the competitiveness of the agricultural sector - Enhancing the quality of life in rural areas	119 Trillion Korean Won (104 Billion USD)

The agricultural and rural policies to revitalize rural societies in Korea have come under harsh criticism. The major concern of the government investment on agricultural policy is rate of return of the policy. Questions have been raised about the effectiveness of the policies [27] and the moral hazard problem, while many distrust the policies [8,28]. The financial effectiveness of agricultural and rural policies is a global concern, too [19,29]. With a huge investment on agricultural development over the past two decades [11,30], policy makers encounter increased skepticism regarding the efficiency of policy interventions in rural areas [16]. Evidence on the effect of vanity projects in rural areas is found throughout the world [2,31].

As one of the best rural development programs targeting the objective of "enhancing the quality of life in rural areas" in the third phase, the CRVDP is by far the largest program in terms of monetary investment at the village-level undertaken in Korea. The program selects hub villages that have the potential to become rural centers, with the expectation that the benefits these hubs gain will spillover to neighboring rural communities. Hub villages can receive government support of 4–7 billion Korean Won (4 to 7 million USD) for three years. Under this program, a total of 290 hub villages were selected by 2009, with plans to increase the number of hub villages to 1000 by 2017.

While the rural development policy in the third phase constructs a broader set of goals, the CRVDP is based on clear objectives. The four specific objectives of the program are enhancement of farmers' income, improvement of the residential environment, improving accessibility, and modernization of housing facilities. The investment portfolio of each CRVDP proposed by each local autonomy should be allocated to meet criteria of the four objectives [32]. Before 2010, the CRVDP was designed and initiated at the central government level; however, since then. it has been implemented at lower levels, typically by the local autonomy, that is, the county and some cities encompassing rural areas. While government intervention to resolve rural problems in Korea is warranted, evaluating government policies toward rural development for their effectiveness remains imperative. The following section proposes a methodology for modeling the effectiveness of the rural policy, which, we believe, is immediately transferrable to other cases and countries.

3. Methodology

The policy evaluation that policy-making groups expect could include causal analysis of input to output. How can the impacts of a policy be assessed with limited variables? Identifying causal effect through a quasi-experimental method is one possible alternative [33,34]. In this sense, the present study conducts an econometric analysis and simulations between an experimental group and a comparison group by using spatial econometrics model and decomposition method. To clarify the exact implication of the term in this study, this study used "evaluation" to refer only to the ex-post review of the government action. In this study, the evaluation was performed at the program level, but it could also be performed system-wide or by particular project.

This study offers a novel way to evaluate the impact of rural policies on standards of living in rural Korea. The process of evaluating policy impacts can be separated into three steps: (1) establishing policy goals; (2) implementing various actions to fulfill the goals; and (3) estimating the extent of policy impacts. Each step was converted into quantitative steps for our evaluation model. The relationship between the policy steps and the quantitative steps are shown in Figure 1.

In the first step, we identified goals of the CRVDP and converted them into quantitative indicators known as an evaluation index, as suggested by many previous studies [33,35–40]. If the policy objectives are too comprehensive to extract explicit indicators explaining the goal, it is recommended that additional work be performed to create a simple and objective index. As explained in the previous section, because the policy goal of the CRVDP targets the four different objectives, construction of a composite index that reflects the policy goal is essential.

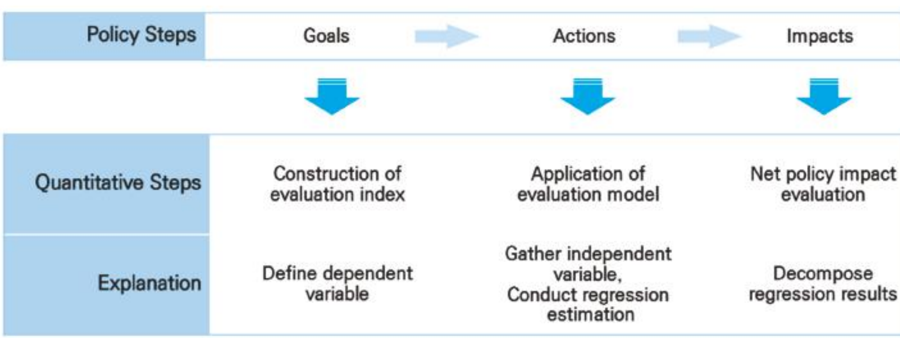

Figure 1. Relationship between policy steps and quantitative steps (Source: Lee and Kim [41].)

A composite index is made up of two or more variables or measures that are highly related to one another theoretically or statistically. Weighting is an important element in constructing the composite index [42]. From among the diverse weighting methods [43], we chose factor analysis because the weightings can be constructed using the data from the current study. This method is appropriate for constructing the composite variables that are linear combinations of the original variables [44,45]. The composite index in this study is most simply described as the weighted averages of various areal characteristics related to the objectives of the CRVDP. The composite index, which is a summary statistic of a set of area variables, can be fairly described as an objective measure of the living environment in rural areas. In a case such as this study, factor analysis is beneficial because it can be used to analyze how multiple variables are interlinked and enables extracting a common index to incorporate all of the variables related to the policy goal.

The next step was to establish a policy impact evaluation model. The present study adopted three types of spatial econometrics models because the basic unit of our data is aggregated by rural areas and dependent upon spatial characteristics. Unawareness of spatial dependence and spatial heterogeneity can produce statistical bias, as suggested by Anselin [46] and LeSage [47]. Lastly, we applied the decomposition method to identify policy effects, as explained by Oaxaca [48] and Blinder [49]. The advantage of this method for evaluating policy impacts is that it can be used to analyze different groups over the same period of time or the same group over different time periods [50].

3.1. Spatial Econometrics Model

In this study, we applied spatial econometrics models to estimate causal relationship between policy goals and the effect of the policy in areas where it is implemented. Anselin [46] noted that applying an ordinary least-square model to spatially aggregated data may introduce statistical bias due to the spatial dependency and/or spatial heterogeneity of error terms. To overcome such statistical bias, Anselin [51] suggested several spatial econometrics models, such as the spatial autoregressive model (SAR), which assumes that observations that are adjacent should reflect a greater degree of spatial dependence than those more distant from each other [47], expressed as:

$$Y = \rho W(Y) + X\beta + \varepsilon, \varepsilon \sim N(0, \sigma^2 I), \tag{1}$$

where Y is an $n \times 1$ vector of dependent variables; X represents an $n \times k$ matrix of explanatory variables; W represents a spatial weight matrix containing contiguity relations or functions of distance; the scalar ρ represents a coefficient on the spatially lagged dependent variable; and β denotes a parameter vector estimated from the explanatory variables.

The second model we utilized is the spatial autoregressive error model (SEM), which is based on the assumption that disturbances exhibit spatial dependence and is expressed as:

$$Y = X\beta + u,\ u = \lambda W u + \varepsilon,\ \varepsilon \sim N(0,\ \sigma^2 I), \tag{2}$$

where the scalar λ represents a coefficient of the spatially correlated errors.

The last model we used in this study is the general spatial model (SAC), which includes both a spatial lag term and a spatially correlated error term. This is expressed as:

$$Y = \rho W(Y) + X\beta + u,\ u = \lambda W u + \varepsilon,\ \varepsilon \sim N(0, \sigma^2 I), \tag{3}$$

where the W matrix shown in Models (1)–(3) represents the spatial weight matrix, containing contiguity relations or functions of distance. To reflect spatial dependence between adjacent regions, the W matrix may contain regional information, such as latitude and longitude:

$$W_{ij} = \frac{d_{ij}}{\sum_{j=1}^{n} d_{ij}}, \tag{4}$$

where W is the $n \times n$ spatial weight matrix and d_{ij} is the distance between region i and region j.

The correct interpretation of the estimated coefficients in the SAR and SAC models involves a computation of direct, indirect and total effects. These computations were extensively explained by LeSage and Pace (2009), so we do not reiterate these points here. The direct effect characterizes the average impact of a change in the explanatory variables on the dependent variable at the same location, whereas the indirect effect characterizes the average impact of a change in the explanatory variables on the dependent variable in different locations. The total effect represents the sum of the direct and indirect effects.

The SAR model expressed in Equation (1) can be rewritten to its reduced form in Equation (5) through which the direct and indirect effects can be calculated. It should also be noted that the SAC model shares the same direct and spillover effect properties with the SAR model.

$$Y = (I - \rho W)^{-1} X\beta + (I - \rho W)^{-1} \tag{5}$$

The matrix of partial derivatives of the Equation (5) of Y, E(Y) with respect to the *k*th explanatory variable of X can be calculated by:

$$\left[\frac{\partial E(Y)}{\partial x_{ik}} \cdots \frac{\partial E(Y)}{\partial x_{nk}}\right] = (I - \rho W)^{-1} \beta_k \tag{6}$$

The diagonal elements of Equation (6) represent direct effects, while the off-diagonal elements represent the indirect effects. Accordingly, the direct and indirect effects can be calculated as:

$$\begin{array}{c} \text{Direct effect}: \frac{\partial y_i}{\partial x_{ik}} = S_k(W)_{ii} \\ \text{Indirect effect}: \frac{\partial y_i}{\partial x_{ik}} = S_k(W)_{ji}, \ \forall i \neq j, \end{array} \tag{7}$$

where $S_k(W) = (I - \rho W)^{-1} \beta_k$ acting as a "multiplier" matrix that applies higher-order neighboring relations to X_k.

3.2. Decomposition Method

Identifying the underlying causes of group and area differences has been the focus of a large amount of research in diverse social-science fields since Blinder [49] and Oaxaca [48] first published their seminal papers four decades ago. For example, Fairlie [50] noted that, "Attesting to the wide use of the Blinder-Oaxaca decomposition technique, more than 1000 citations to these two articles were found in the Social Science Citation Index." The technique is especially useful for quantifying the different contributions of group differences in factors such as education, experience, marital status and location, as well as group and area gaps in outcomes. The technique is also useful for identifying the causes of geographical, temporal or other categorical differences in outcomes [50]. The decomposition method can be presented formally as follows.

For simplicity, we use Equation (1), but exclude the weight matrix *W* and the error term, as an example for applying the decomposition method. To identify the net policy impact evaluation using the decomposition method, Equation (1) is divided into two separate equations, as shown below.

$$\text{Group (A)}: E(Y_A) = \sum_{j=1}^{k} \beta_j^A \overline{X}_j^A \tag{8}$$

$$\text{Group (B)}: E(Y_B) = \sum_{j=1}^{k} \beta_j^B \overline{X}_j^B \tag{9}$$

In a cross-sectional analysis, as shown in Figure 2, Equation (8) applies to the area (A) where the policy has been implemented (treatment group) and Equation (9) applies to the area (B) where the policy has not been implemented (control group). Because Equations (8) and (9) are defined as forms of the expected value, the expected difference between two groups can be directly compared. The theoretical background of the comparison is based on determining the difference between "Do Something" and "Do Nothing"; however, in this study, the estimation of the policy effect contains pair-wise counterfactual simulations beyond the one-dimensional comparison. This estimation is mathematically explained as follows:

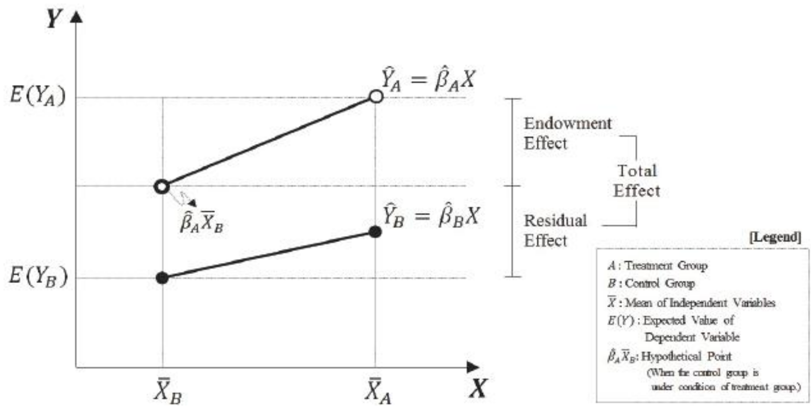

Figure 2. Graphical expression of decomposition technique (Source: Hwang and Lee [4]).

The left-hand side of Equation (10) denotes the difference in the policy impact between Group (a) and Group (b). The first part of the right-hand side of Equation (11) is the effect that is explained by the difference in independent variables between two groups, known as the endowment effect. The second part of this formula is the residual effect, which is not clarified by the endowment effect. The total effect is the summation of the endowment and residual effects. Equation (11) shows that the residual effect can be separated into the constant effect and the coefficient effect, where the constant effect represents a direct effect because it indicates the difference between policy implementation and non-implementation, which is not described by effects of independent variables, while the coefficient effect, in contrast, is regarded as an indirect effect. This effect implies what is explained by the difference in the influence of independent variables between the two groups. (It is possible that residual effect may contain unintentional but side–side effects of any potentially important variables other than the effect of CRVDP such as accessibility conditions, industrial structure and other policy impacts. However, the problem of the omitted variables is empirical, and there is little empirical evidence about the error rates when using the Korean Agricultural Census to model the effect of the CRVDP. The limitation is equally applied to other empirical studies that apply the decomposition method [50,52,53].) From a cross-sectional perspective, the treatment group is policy-implemented areas in 2010 and the control group is non-implemented areas in 2010.

$$E(Y_A) - E(Y_B) = \sum_{j=1}^{k} \beta_j^A \overline{X}_j^A - \sum_{j=1}^{k} \beta_j^B \overline{X}_j^B$$

$$= \sum_{j=1}^{k} \beta_j^A (\overline{X}_j^A - \overline{X}_j^B) + \sum_{j=1}^{k} \overline{X}_j^B (\beta_j^A - \beta_j^B) \quad (10)$$

$$= \sum_{j=1}^{k} \beta_j^A (\overline{X}_j^A - \overline{X}_j^B) + \left(\beta_1^A - \beta_1^B\right) + \sum_{j=2}^{k} \overline{X}_j^B (\beta_j^A - \beta_j^B) \quad (11)$$

Results of applying decomposition methods are represented as forms of simulated effects, such as the endowment, constant and coefficient effects, the results from which policy impacts can be evaluated. At first, the endowment effect increases with the differences in independent variables between two groups in the same time period. In addition, independent variables for assessing policy impacts may consist of variables such as social, demographic or spatial characteristics, which are not directly related to policy impacts. Therefore, the endowment effect should be excluded when evaluating policy impacts.

The residual effect, on the other hand, indicates that the difference in the policy effect occurs as a result of factors other than the difference in the independent variables between two groups over the same time period. Thus, net policy impacts are only evaluated by residual effect not controlled in Equations (8) or (9). As mentioned above, it is differentiated into a constant effect and a coefficient effect. Combinations of each of the effects can be diverse and may result in the following three cases: Case (1), when signs of both the constant and coefficient effects are positive, which implies that the overall policy impact is positive; Case (2), when signs of both the constant and coefficient effects are negative, implying that the overall policy impact is negative; and Case (3), when one effect is positive and the other negative, in which case the overall policy impact is judged by the total effect (the sum of the two effects).

4. Data and Variables

The main purpose of the CRVDP is to establish sustainable rural communities in which the living environment and income are in harmony by intensively supporting key villages of a *eup*/*myeon*-unit rural area. The *myeon* is the lowest administrative unit and where the local administration office is located in Korea. Along with the *eup*, a *myeon* is one of the sub-divisions of a county and some cities with a population less than 500,000. A *myeon* has a smaller population (about 3000–6000 people) than a *eup* (approximately 20,000 people) and represents the rural areas of a county. Applications of the CRVDP have mainly been focused on *myeon* areas. Designed by the central government, the initial CRVDP was implemented in 290 *eup*/*myeon* units (treatment group) during the period of 2004–2009. (Although the program maintains its original goals, project periods and government investments in the program have been changed since 2010. Now, with financial support from the central government, the program is mainly designed and operated by the local autonomy that enables the local government to be "more accountable and responsive" to the local demand [54].) Because Korea had 1388 *eup*/*myeon* administrative units in 2010, the remaining 1098 units are classified as the non-implemented areas (control group). To evaluate the impact of the CRVDP on improving residential environments at the *eup*/*myeon* level, data about the administrative units is required. Utilizing the 2010 Agricultural Census Data from Statistics Korea, we constructed aggregated data from the 1388 *eup/myeon* administrative units, from which we identified 290 units where at least one CRVDP had been implemented between 2004 and 2009.

Table 2 presents variables for analyzing the impacts of the CRVDP as represented by Equations (1)–(3). (We tried to construct as many aggregated independent variables as possible from the census data avoiding the endogenous problem. The statistical problem may arise from our dependent variable (composite index) that was created from the same data with the application of 12 independent variables in factor analysis.) The dependent variable (FACT) was derived by factor analysis. As discussed before, the goals of the CRVDP to enhance standard of living is composed of four primary categories: income enhancement, improvement of the residential environment, improving accessibility and modernization of housing facilities. The dependent variable derived from the factor analysis was designed to reflect these four characteristics, incorporating 12 area characteristics. As the results derived from the factor analysis are not the core focus of the present study, their outputs are listed in Appendix A. The dependent variable should be positively associated with the standard of living in an area; that is, a higher value is indicative of a higher standard of living for a given rural area.

We selected the probable determinants of living standards in rural areas based on the literature and on information available in the census. Because the population of an area may reflect its attractiveness and economy of scale [55,56], we expect that larger populations (POP) in a given rural area are indicative of a higher standard of living in the area. The aging population prevalent in rural areas may lead to negative impacts on community organization and sustainability, such as school closures or consolidations, inter-local cooperation, sharing of administrative functions and so forth [57,58]. Thus, the proportion of elderly people (OLD) may be negatively associated with the level of living conditions in a given rural area. Agriculture is a major source of economic capital in rural areas [59], and its role as an enduring emblem of rural areas is still evident in most developed economies [2,60].

Thus, the proportion of the number of farmers (FARM) should be positively correlated to a better living environment in an area.

Table 2. Explanation of variables for spatial econometrics models.

Variables	Explanation
Dependent variable (FACT)	Log (factor scores derived from factor analysis)
Demographic independent variables	
POP	Log (total population)
OLD	Proportion of over 65 aged people (%)
FARM	Proportion of farmers (%)
Spatial independent variables	
AGSALE	Log (average sales of agricultural products) (10 USD)
AGLAND	Proportion of farming land (%)
TYPE1	Proportion of vegetable and upland crops (%)
TYPE2	Proportion of fruit, special crop, flower (%)
Spatial lag matrix	
W	Spatial weight matrix (inverse distance)

Source: 2010 Agricultural Census, Statistics Korea.

Agricultural land is a major economic asset in rural areas [61], and an increase in agricultural land is assumed to result in a rise in the agricultural production of an area [62]. Thus, we expect that the larger the proportion of farmland (AGLAND), the better the economic environment of the area. Agricultural productivity represented by total agricultural sales (AGSALES) in a rural area is directly related to the level of gentrification in the area [56,63], so standard of living in an area should be positively associated with this independent variable. Farm type is an important determinant to obtain agricultural income [62,63] and agricultural income is, on average, high for such crops as vegetables, upland crops (Type 1) and fruit and special crops and flowers (Type 2) in Korea [4,41]. Thus, the standard of living in a rural area is much higher for areas where the majority of farmers cultivate profitable crops than in areas where farmers predominately grow non-profitable crops, such as rice. Among the diverse construction schema of weight matrixes for our spatial econometrics analysis, we apply an inverse distance structure (W) among spatial units that best matched our data characteristics.

5. Results

5.1. Regression Results

To apply spatial econometrics models with statistical validity, a spatial autocorrelation test should be carried out beforehand. We chose to use Moran's I statistic for our spatial data [64]. The results of Moran's I indicated that there is spatial dependency in our data at a 99% or higher level, as shown in Table 3. Based on the results of the Moran's I analysis, regression analyses for the three spatial econometric models explained in Equations (1)–(3) were conducted, the results of which are presented in Appendix B.

Table 3. Results of Moran's I.

Implemented Area		Non-Implemented Area	
Moran's I	*p*-value	Moran's I	*p*-value
0.1644	0.0000	0.2638	0.0000

Tables A5 and A6 in Appendix B list the results of the regression analysis of the three econometrics models for the policy implemented areas and the non-implemented areas, respectively. The results show that both the hypothesis of no spatially lagged dependent variable and the hypothesis of no spatially autocorrelated error term should be rejected at the highest significance level at $p < 0.01$. The results of a spatially lagged dependent variable and a spatially autocorrelated disturbance prove to be statistically significant effects in all three econometrics models for both areas. SAR and SEM show statistically significant effects for the spatially lagged dependent variable (*rho*) and the spatially autocorrelated disturbance (*lambda*) and both spatial dependency variables are statistically significant in the SAC model. The explanatory power is slightly higher in the models of the policy implemented area (55–66%) than those of the non-implemented area (36–46%). Among the three spatial econometrics models, SAC displays the highest explanatory power ($\overline{R}^2$ = adjusted R^2) (cf. Appendix B). Therefore, we decide to use the SAC model in the application of the decomposition method for evaluating the CRVDP.

Table 4 presents the estimation results of the SAC model for both areas. The explanatory powers of two areas represented by the adjusted R-squares are 0.46 for the implemented-areas and 0.66 for the non-implemented areas. Considering the cross-sectional characteristics of our data with eight degrees of freedom, the explanatory power of both areas is acceptable for the investigation of individual parameters. The application of the SAC model reveals some interesting results with regard to the determinants of the standard of living in an area, not all of which were expected a priori.

Table 4. Results of spatial econometrics models.

Variables	Implemented Area		Non-Implemented Area		∣Wald Test∣
INTERCEPT	−6.6532	***	−7.4519	***	
POP	0.1116	***	0.1168	***	
OLD	−0.0002		−0.0030	***	**
FARM	−0.0008		0.0009	***	**
AGSALE	0.0212		0.0411	***	
AGLAND	0.0024	***	0.0017	***	
TYPE1	0.0007	*	0.0005	***	
TYPE2	0.0003		0.0005	**	
Rho	1.9256	***	2.025	***	
Lambda	0.7560	***	2.3409	***	
N	290		1098		
R^2	0.4758		0.6635		
$\overline{R}^2$	0.4628		0.6613		

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The values in Wald Test are converted to probability.

If other factors are held constant, the proportion of population (POP) was found to be positively associated with the standard of living in 1995 ($p < 0.01$) for both areas. The elasticity of living standard in an area with respect to population is 0.11–0.12, implying that a 1% increase in population is expected to increase the average living standard in an area by 0.11–0.12%. This suggests that rural areas that are more susceptible to urbanization encroachment may offer a better living environment. As expected, the presence of a large elderly population (OLD) in a given rural area is negatively correlated with the level of living standards in both areas. A 1% increase in the number of elderly results in a 0.3% decrease in living standard in the policy non-implemented areas at $p < 0.1$. However, the effect is much weaker (0.02%) for the policy implemented area with no statistical significance. We suspect that, during the past few decades, aging structure has changed dramatically due to out-migration of younger age groups in the policy implemented areas. This results in the prevailing abundance of elderly people in the policy implemented area. Proportion of farmers (FARM) markedly differs between the two areas. The independent variable is negatively associated with the living standard in the policy implemented area, although this relationship is not significantly different from zero.

The reverse is true for the policy non-implemented area, with the highest significance level at $p < 0.01$. This implies that individual farmers' contributions to enhancing living standard in an area is much greater in the policy non-implemented area than in the policy implemented area.

Agricultural sales (AGSALE), which represent agricultural productivity in rural area, are positively associated with living standard in the policy non-implemented area, but this effect is not significant in the policy implemented area. Rate of return of agricultural sales to the living standard is twice as large in the implemented area (4.1%) than in the non-implemented area (2.1%). This implies that agriculture is a major economic driver in most rural areas, although agricultural activity is not an enduring emblem for the poorer rural areas in Korea. As expected, the larger is the proportion of farmland (AGLAND) in rural areas, the better is the living standard of the area. This may suggest that agricultural land is functioning as an economic asset in both areas and the elasticity value suggests that a 1% increase in the farmland will enhance the living standard of an area by 0.24% for the policy implemented area and 0.17% for the non-implemented area.

The rate of return by crop to our dependent variable, standard of living in an area, showed the expected effects. The greater the cultivation of such crops as vegetables or upland crops (TYPE1) and fruit, special crops or flower (TYPE 2), the bigger the rate of return for the crops. A 1% increase with respect to the vegetables and upland crops results in a 0.05% increase of the living standard in the policy non-implemented area. The rate of return for the crop in the policy implemented area is slightly higher (0.07%) than in the non-implemented area. The estimates for both independent variables are statistically significant for the policy non-implemented area at $p < 0.05$ or higher. However, the effect is significantly different from zero for only the vegetables and upland crops in the policy implemented area at a marginal level, $p < 0.10$.

While some independent variables show similar patterns with respect to our dependent variable, other variables display significant differences between the two areas. To identify differences in the effects of each independent variable on the living standard between areas, we carried out the Wald test, assuming no covariance between the independent variables as shown below:

$$\text{Wald Test}: \ W = \frac{(\beta_i^{\text{Implemented}} - \beta_i^{\text{Not-implemented}})^2}{\left(\text{s.e.}\left(\beta_i^{\text{Implemented}}\right)\right)^2 + \left(\text{s.e.}\left(\beta_i^{\text{Not-implemented}}\right)\right)^2} \sim \chi^2(1) \tag{12}$$

We identified two independent variables (proportion of elderly people and proportion of farmers) that were significantly different between the two areas. The effect of an aging population on living standard in the policy implemented area was negative and statistically significant, whereas no significant difference was detected in the non-implemented area. As mentioned previously, farmers' contribution to enhancing living standards in an area was much higher in the policy non-implemented area than in the policy implemented area; that is, the relative availability of human capital was also a determining factor for the difference in living standards between the two areas. This finding is consistent with those reported by Agarwal et al. [55], who detected a strong relationship between economic performance and human capital in rural areas. We suspect that it was the impacts of these two independent variables that influenced the differential living standards between the two areas.

As mentioned before, the direct effect measures how a change in an independent variable in rural area *i* affects the dependent variable in the area, including feedback effects. The feedback effects occur as a result of impacts rippling through neighboring rural areas and then returning back to the original area. Indirect effects—also called spillover effects—compute the average impact of a change in an independent variable in area *i* on the dependent variable in all other different locations *j*. Direct effects are used to test whether a particular variable has a significant effect on the dependent variable within its own geographic area, while indirect effects are used to test whether spillovers into neighboring areas occur [65]. Table 5 presents the results of the direct and indirect effects of independent variables on living standards in rural areas in Korea.

Table 5. Direct, indirect and total effects from SAC model.

Variables	Implemented						Not-Implemented					
	Direct Effect		Indirect Effect		Total Effect		Direct Effect		Indirect Effect		Total Effect	
POP	0.1409	***	6.9629	***	7.1038	***	0.1235	***	7.3411	***	7.4646	***
OLD	−0.0003		−0.0155		−0.0158		−0.0031	***	−0.1836	***	−0.1867	***
FARM	−0.0010		−0.0511		−0.0522		0.0010	***	0.0579	***	0.0589	***
AGSALE	0.0257		1.2679		1.2935		0.0435	***	2.5856	***	2.6291	***
AGLAND	0.0030	***	0.1491	***	0.1521	***	0.0018	***	0.1064	***	0.1082	***
TYPE1	0.0009	*	0.0461	*	0.0470	*	0.0006	***	0.033	***	0.0335	***
TYPE2	0.0004		0.0207		0.0211		0.0005	**	0.0296	**	0.0300	**

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

We found that the direct effect estimates have the same signs and similar magnitudes as the point estimates of the independent variables in both areas, as shown in Table 4. Moreover, significance levels for individual parameters in both areas parallel those presented in Table 4, so explanations regarding the independent variables here would be redundant. The feedback effects of the independent variables on living standards in rural areas show a wide range of impacts and are not negligible. For example, the direct effect and the coefficient estimate of the population in the policy implemented area were 0.1409 and 0.1116, respectively, thus the feedback effect is approximately 21%. Other feedback effects range 20–50% in policy implemented areas and 0–17% in the non-implemented areas.

We found that the magnitude of the indirect effects is much larger than their associated direct effects. This may seem counterintuitive, as spillover effects would seem more similar to second-order effects that should be smaller in magnitude than would direct effects. Because the scalar summary measures of the indirect effects provided by [66] combine spatial spillovers in all other areas to produce a single numerical value for the indirect effect estimate, this is not unusual in diverse empirical applications (cf. [26]) particularly if spatial observations are large, as in the present study (1098 + 290 − 1 = 1387).

5.2. Decomposition Results

To determine the quantitative implications of the above estimates, the regression results must be simulated to calculate the mean differences of policy implemented and non-implemented areas of the CRVDP, while controlling for spatial characteristics of other independent variables. What is the net effect of mean differences of the policy on the program implemented areas compared with non-implemented areas? What areas where the program had not implemented before would be affected if this program had been enforced? To address these sequential questions, a treatment group should be composed of the areas where the program had been implemented, and a control group should be composed of the areas where the program had not implemented.

We utilize the regression results in Table 4 to conduct a decomposition method applying Equations (10) and (11), with results presented in Table 6. The results show that the difference between the two areas (0.6320) is composed of the negative endowment effect (−0.0264) and the positive residual effect (0.6584). This implies that the net policy impact calculated after ruling out the endowment effect (which can be explained by the difference of independent variables between the two areas) is 1.04 times as high as the observed impact. That is, the contribution of controlled independent variables in making a better living environment is negative (−4.19%). However, largely due to the uncontrolled policy effect in the residual effect, we can say that the standard of living of the policy impacted areas was enhanced following program implementation; in other words, while the changes in demographics, spatial and agricultural factors in the policy impacted areas are less favorable in producing a better living environment, diverse government policies (such as the CRVDP) intended to enhance living conditions in rural areas have offset the negative changes in the countryside.

Table 6. Direct, indirect and total effects from SAC model.

	Amount	Ratio (%)	Evaluation
Endowment effect	−0.0264	−4.19	Negative
Residual effect: Net effect	0.6584	104.19	Positive
Constant effect	0.7987	126.38	Positive
Coefficient effect	−0.1403	−22.19	Negative
Total effect	0.6320	100.00	Positive

The decomposition of residual effects also confirms that the CRVDP has been effective. A constant effect of 0.7987 (126.38%), an average effect contributing to living standards in an area, offset the negative coefficient effect of −0.1403 (−22.19%) to reach the positive residual effect, which implies that the impact of the policy can also be detected indirectly. These positive findings are much clearer when we look more deeply into the composition of individual coefficient effects decomposed from the net effect (refer to Table A7 in Appendix C). In explaining the total endowment effect (−0.0264), demographic variables contributed approximately 92% of total variation, approximately 12.5 times higher explanatory power than that of spatial/agricultural variables. Proportions of population and farmers in an area contributed approximately 89% of total variation of the endowment effect, implying that the major depreciation of the policy implemented area can be explained by these two variables. However, the explanatory power of the spatial/agricultural variables that the CRVDP mainly targets for improvement is approximately 10 times higher (−19.42%) than that of demographic variables (−1.88%). Therefore, the CRVDP can be said to have moderately helped to enhance living conditions in the policy implemented rural areas.

6. Conclusions

Evaluation is the process of valuing beyond philosophical musings [67]. The process determines which values must be included, measures and prioritizes these values and synthesizes the results. Accordingly, assigning and assessing values that are associated with the policy involves examining how the policy has affected the values and philosophies of the society. This study begins to fill the academic and practical vacuum by addressing one primary research question: Does a public policy that has been implemented in rural areas contribute to intended outcomes?

The objective of the present study was to conduct an ex-post quantitative evaluation of the CRVDP, a rural development program operated by the Ministry of Agriculture, Food and Rural Affairs, a central government agency in South Korea. This study conducted an ex-post evaluation of the outcomes after the termination of the program. We constructed a quantitative logic model, which is a stepping-stone to understanding the program and its evaluation mechanisms. The present study conducted an econometric analysis and simulations between policy-implemented areas and non-implemented areas using the spatial econometrics model and the decomposition method. This study found a moderate but significant positive impact of the policy in enhancing the standard of living in rural areas. We found that the CRVDP in Korea represents one of the most significant elements that reflect the recent trend of rural changes from an economy that is based on production to an economy that is based on consumption. We summarize our contributions and findings below.

First, the present study developed a unique means of evaluating the impact of rural policy on rural well-being in Korea, a subject that has largely been overlooked. The proposed process of policy impact evaluation involves three steps, with each step comprising quantitative methods that enable us to interpret the results directly. Second, our aggregated data showed that spatial dependency required correction. The results of the Moran's I and three spatial econometrics models showed that both the hypothesis of no spatially lagged dependent variable and the hypothesis of no spatially auto-correlated error term should be rejected at $p < 0.01$ in both areas, which justifies the selection of our econometrics models. Third, this study found that the proportion of the elderly and the proportion of farmers were the most significant differentiating factors between the two areas. We suspect that these two independent variables were primarily responsible for the differences in the standard of living between the two areas. Fourth, the application of the decomposition method revealed, largely due to the uncontrolled policy effect in the residual effect, the standard of living in the program impacted areas has been enhanced following the program implementation.

Based on the results of our analysis, we concluded that the effect of the CRVDP is positive. This result should be an encouraging one for the policymakers who designed the program, and it confirms the important role rural policy can play in improving living conditions in rural areas. Since disparity between urban and rural areas in Korea has been increasing, efforts to reduce poverty in rural areas must continue. While improved access to capital via government subsidies such as the CRVDP can help spark economic vitality in rural areas, rural communities can also use local cultural and historical amenities to shape development strategies. Recently, Korea has successfully promoted some traditionally poor regions as tourist and retirement destinations driven largely by diverse government policies. The Korean government has also initiated policies promoting the more tangible products that emerge from its rural commodities. The incumbent regime in Korea propagates so-called "creative economies" to restructure the national economy and champions the potential of such industries in contributing to rural economic development strategies. However, the lack of a neutral evaluation system may result in deviation from the intended objectives of government policy. Government must therefore be aware that impact evaluations of policies can provide an objective basis for understanding problems and guide future directions for existing policy. Thus, institutionalized establishment of an objective policy evaluation process based on quantitative methods is necessary, as exemplified by a diversity of international agencies [7,23].

Although our study can contribute to the policy evaluation literature, limitations with respect to data and methodologies must be addressed. First, the controlled independent variables to determine living standards in rural areas used in our study show a reasonable value of adjusted R-square in the cross-sectional setting, but more such determinants are needed to increase the explanatory power. Second, the quantitative evaluation method should be corroborated with a schema that can evaluate a pure monetary return of any policy impact. The current ex-post evaluation method with a stochastic property is much more persuasive than other ex-ante or non-stochastic ex-post methods, but this approach could be enhanced by the inclusion of a type of cost–benefit analysis. We believe that further investigations are required to identify monetary value of the policy effect and to distinguish this effect from the aggregate policy effect in the current methodology. Third, in addition to independent variables that are controlled by the quantitative model of the present study, other indicators regarding contextual effects on local and national scopes must be identified because these indicators may also influence the residual effect that this research may fail to capture. Moreover, to develop an evaluation system that covers the transition in rural policy paradigm, various theories and methodologies of the program evaluation must be applied to relevant policies.

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Appendix A. Factor Analysis

Variables used for factor analysis to derive an evaluation index (dependent variable) are presented in Table A1. As explained above, the goals of the CRVDP comprise the following four major categories: enhancement of income, betterment of residential environment, improvement of accessibility condition and modernization of housing facilities. The dependent variable derived from the factor analysis is designed to reflect those four major characteristics incorporating a total of 12 area characteristics, as shown in Table A1. Computational processes to construct the evaluation index via the factor analysis is well-known, so we will skip the detailed explanations here. We only provide main outputs of the factor analysis in Tables A2–A4.

Table A1. Variables for factor analysis.

Variables	Explanation
Income source	
Ratio_sales	Percent of farm households that sell agricultural products over 20,000 USD
Ratio_sideline	Percent of farmers with additional job(s)
Ratio_com	Percent of computer usage
Living environment	
Ratio_water	Percent of water supply
Ratio_waste	Percent of agricultural waste disposal by professional service (or recycling)
Public_trans	Frequency of public transportation runs
Accessibility	
Edu_ac	Percent of existence of formal school education facility
Bank_ac	Percent of existence of banking facility (cooperative bank)
Medi_ac	Percent of existence of medical facility (public health centre)
Housing condition	
Ratio_kitchen	Percent of modernized kitchen
Ratio_toilet	Percent of flush toilets
Ratio_bath	Percent of hot-water boiler

Note. All variables here are continuous. Source: Korea Agricultural Census in 2010, Statistics Korea.

Table A2. MSA values for factor analysis.

Variable	Ratio_ kitchen	Ratio_ toilet	Ratio_ bath	Ratio_ sales	Ratio_ sideline	Ratio_ com	Edu_ ac	Bank_ ac	Medi_ ac	Ratio_ water	Ratio_ waste	Public_ trans
MSA	0.7637	0.7311	0.6684	0.4527	0.7076	0.4540	0.7363	0.7102	0.7567	0.7525	0.7712	0.7849

Overall MSA (Kaiser's measure of sampling adequacy) = 0.7006.

Table A3. Eigen values for factor analysis.

Factor	Eigenvalue	Proportion	Cumulative (%)
1	2.9983	24.99	24.99
2	2.2918	19.1	44.08
3	1.4519	12.1	56.18
4	1.0708	8.92	65.11
5	0.9208	7.67	72.78
6	0.9000	7.50	80.28
7	0.6235	5.20	85.48
8	0.5083	4.24	89.71
9	0.3879	3.23	92.94
10	0.3271	2.73	95.67
11	0.2757	2.30	97.97
12	0.2440	2.03	100.00

Table A4. Standardized factor score and communality estimates.

Variable	Factor1	Factor2	Factor3	Factor4	Communality
Ratio_sales	−0.0401	−0.0336	0.6037	0.0676	0.8127
Ratio_sideline	0.2025	0.0882	−0.3173	0.0162	0.6007
Ratio_com	0.1150	0.0735	0.4311	−0.0823	0.5016
Ratio_water	0.0385	−0.0207	0.0598	0.5755	0.6201
Ratio_waste	0.1122	−0.0253	0.0574	−0.5148	0.4256
Public_trans	0.1152	−0.0102	0.0013	0.4078	0.4865
Edu_ac	0.0362	0.3607	−0.0250	0.0259	0.7983
Bank_ac	−0.0281	0.3635	0.0224	0.0322	0.7820
Medi_ac	−0.0137	0.3647	0.0068	−0.0579	0.7655
Ratio_kitchen	0.2795	−0.0387	0.1005	−0.0049	0.5446
Ratio_toilet	0.3279	−0.0001	−0.0580	−0.0129	0.7401
Ratio_bath	0.3397	0.0027	0.0543	−0.0815	0.7351

Note 1: Since the evaluation index of this study is the linear sum of factor scores weighted by scoring coefficients, the variables showing negative value are excluded. Note 2: The shadow of the table indicates the group which have similar value.

Appendix B. Regression Results of Spatial Econometrics Models

Table A5. Implemented areas, 2010.

	Spatial Econometrics Model						OLS	
	SAR		SEM		SAC			
INTERCEPT	−0.2325		5.0038	***	−6.6532	***	5.1077	***
Demographic variables								
POP	0.0932	***	0.0967	***	0.1116	***	0.0840	***
OLD	0.0007		−0.0003		−0.0002		0.0010	
FARM	−0.0017	*	−0.0014		−0.0008		−0.0022	**
Spatial variables								
AGSALE	0.0252		0.0263		0.0212		0.0265	
AGLAND	0.0035	***	0.0035	***	0.0024	***	0.0044	***
TYPE1	0.0006	*	0.0007	*	0.0007	*	0.0006	
TYPE2	0.0001		0.0001		0.0003		−0.0001	
Rho	0.8770	***			1.9256	***		
Lambda			0.9440	***	0.7560	***		
N	290		290		290		290	
R^2	0.3712		0.4543		0.4758		0.3980	
$\overline{R}^2$	0.3556		0.4408		0.4628		0.3831	

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A6. Non-Implemented areas, 2010.

	Spatial Econometrics Model						OLS	
	SAR		SEM		SAC			
INTERCEPT	−0.6793	***	4.9476	***	−7.4519	***	5.0536	***
Demographic variables								
POP	0.1045	***	0.1045	***	0.1168	***	0.0980	***
OLD	−0.0025	***	−0.0038	***	−0.0030	***	−0.0036	***
FARM	0.0007	***	0.0008	***	0.0009	***	0.0007	***
Spatial variables								
AGSALE	0.0253	***	0.0377	***	0.0411	***	0.0277	***
AGLAND	0.0032	***	0.0030	***	0.0017	***	0.0038	***
TYPE1	0.0005	***	0.0005	**	0.0005	***	0.0005	**
TYPE2	0.0005	**	0.0003		0.0005	**	0.0003	

Table A6. *Cont.*

	Spatial Econometrics Model						OLS
	SAR		SEM		SAC		
Rho	0.9360	***			2.0250	***	
Lambda			0.9890	***	2.3409	***	
N	1098		1098		1098		1098
R^2	0.5476		0.6267		0.6635		0.5943
$\overline{X}^2$	0.5447		0.6243		0.6613		0.5917

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Appendix C. Decomposition of Individual Independent Variables

Table A7. Decomposition of individual parameters.

	Endowment Effect	Ratio (%)	Residual Effect	Ratio (%)	Total Explanation	Ratio (%)
Intercept	0.0000	0.00	0.7987	121.30	0.7987	126.38
Demographic variables						
POP	−0.0198	74.97	−0.0431	−6.55	−0.0629	−9.96
OLD	−0.0007	2.78	0.0875	13.29	0.0868	13.73
FARM	−0.0037	14.03	−0.0568	−8.63	−0.0605	−9.57
Sub total	−0.0243	91.79	−0.0124	−1.88	−0.0366	−5.80
Spatial variables						
AGSALE	0.0004	−1.49	−0.1433	−21.76	−0.1429	−22.61
AGLAND	−0.0034	12.70	0.0119	1.81	0.0085	1.35
TYPE1	0.0004	−1.37	0.0058	0.88	0.0061	0.97
TYPE2	0.0004	−1.62	−0.0023	−0.35	−0.0018	−0.29
Sub total	−0.0022	8.21	−0.1279	−19.42	−0.1300	−20.58
Total	−0.0264	100.00	0.6584	100.00	0.6320	100.00

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Analyzing the Level of Accessibility of Public Urban Green Spaces to Different Socially Vulnerable Groups of People

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Abstract: This study estimates the factors affecting socially vulnerable groups' demand for and accessibility levels to green public spaces in Dhaka City, Bangladesh. Dhaka is a high-density city with one of the lowest levels of green space per capita in the world. Dhaka has just 8.5% of tree-covered lands, while an ideal city requires at least 20% of green space. Urban public green space provides a healthy environment to city dwellers as well as ecological soundness. This study aims to examine the effects of population density and size of a community area (Thana) on the social demand for and accessibility to green parks. To determine the socially vulnerable group demand index, this study used demographic data from the National Population and Housing Census 2011 conducted by the Bangladesh Bureau of Statistics. This study used geographical data extracted from Google Earth Pro to measure accessibility levels, and additionally analyzed geographical data with ArcGIS 10.0 and Google Earth Pro. We drew radius circles using Free Map Tools to measure time-distance weighted scores from community areas to urban green spaces. The results show that the large population size of socially vulnerable groups creates very high demand at the score of 0.61 for urban green public parks and small-sized, high-density community areas generate very good accessibility at 2.01% to green public spaces. These findings are highly useful to policymakers, urban planners, landscape engineers, and city governments to make a compact city sustainable, inclusive, and resilient. Moreover, the notion of a "smart city" might be a smart solution in order to manage Dhaka Megacity sustainably in this modern technological age.

Keywords: Accessibility; urban green space; social demand index; surface temperature; smart city; ecological wellbeing; population density; small-sized community; sustainable urban management; spatial equity; urban planning

1. Introduction

Urbanization is now one of the global development agendas. Based on the United Nations Sustainable Development Goal 11 (SDG 11), which aims to make urban communities and human settlements comprehensive, protected, strong, and sustainable, the United Nations extended the SDG Agenda by adopting the New Urban Agenda in 2016 [1]. Urban sustainability and inclusiveness depend on different criteria, such as planning, equitable spatial distribution, ecological services, urban management, green space quality, and socioeconomic facilities. The societal advantages provided by urban green spaces (UGS) to city inhabitants are indispensable to maintain and increment urban residents' personal satisfaction [2–4]. Public urban green spaces (PUGS) are essential for mitigating high surface temperatures in summer [2,5,6] and are also indispensable for air pollution removal and noise reduction [7,8]. The temperature contrast between urban and green regions is large in summer and small in winter. Furthermore, in summer, the contrast is bigger during the day than during the night, while in winter the reverse is true [9]. There have been the current economic value of 17 ecosystem services for 16 biomes, which are contributing to human welfare, both directly and indirectly [10].

Open UGS frame diverse sorts of green spaces, in particular in degrees of naturalness, kinds of vegetation, recreational foundations or social uses they can offer [11,12]. Public urban green space (PUGS), e.g., urban open parks, are typically the most important components of urban green frameworks [11,13]. They are basically overseen by government organizations and accommodated open utilize, and are focal components to advance living quality in urban areas attributable to their commitment to a decent urban condition, the experience of nature [11,14] and to expanding the interest for nature-based recreation facilities [11,15]. This study deals with city green public parks as green spaces but not city forested areas in cities and agriculture. We here state the characteristics of public parks. Previous research has expressed the various contributions of open UGS, which is a type of land cover that incorporates open parks and other (open or private) vegetated territories, to human wellbeing and prosperity [4,16–22]. These green spaces give biological community benefits that help human welfare in numerous ways [23–26].

Introduction to green spaces facilitates physical exercise and upgrades emotional wellness and the mental condition of elderly individuals [27–29]. The financial status of different groups has been examined to investigate the social value of green spaces; it was discovered that the high-income, white, and highly educated bunches living in the top networks had more access to green spaces [30,31], while socially vulnerable groups, such as working class, ethnic minority, and low-income groups [30] had less access to green space. The earlier literature has discussed the spatial equity layout of urban green public parks. More consideration is given to the value of parks' openness and free market activity [31] coordinating between various networks for vulnerable groups, e.g., the elderly in China. A few studies have asserted that the objective is to have a similar openness of minority groups and non-minority bunches in the network and even to offer a larger amount of availability [31] for low-income inhabitants in spatial dispersion in Western nations [32].

Green public spaces foster a sense of freedom and provide opportunities for leisure, political and social activities [33]. Additionally, green spaces reduce morbidity and improve physical health [4,34–36], increase social cohesion [4,37,38] and maintain biodiversity [39]. Human wellbeing could certainly be correlated to the measure, quality, and equity of green spaces. Likewise, wellbeing requires the sustainable and fair accessibility of these public spaces to different social classes. The accessibility approach has been broadly recorded within the planning literature and incorporates a long verifiable record [40–44]. Accessibility is characterized as the degree to which land-use and transport frameworks empower bunches of individuals to exercise or reach goals from transport modes [45].

Land use requires connecting green spaces (parks) among built-up systems in urban planning. The accessibility approach recognizes that the nonattendance or disappointment of any accessibility component is sufficient to square what individuals require [40,46]. For example, public services will be open for all, but if a person has restricted access for cultural or religious reasons, they will not be able to access those public services [46]. The same can also apply to the context of green public space accessibility measurement. This study measures the accessibility of urban green public parks to socially vulnerable groups in terms of visit frequency and quality. Furthermore, this work assesses the accessibility level of city parks in Dhaka, Bangladesh. Accessibility can be assessed in terms of the quality of the park, total community and park area size, population density, and park management.

A previous study investigated the social benefits of UGS, and incorporated recreational opportunities, stylish satisfactions, changes in mental wellbeing and physical health, enhancing social ties, and giving instructive openings [47]. Urban trees emphatically influence quality of life. However, the spatially unjust dispersion of urban trees in connection to race and ethnicity is another example of urban natural disparity that deserves more prominent thought in light of modern and energetic property relations inside capitalist social orders [48].

There are 54 green public parks and open spaces in Dhaka, 46 of which are owned by Dhaka City Corporation (DCC) [49,50]. On average, just 14.5% is open space (including playgrounds, parks, footpaths, water bodies, forestry, etc.), while 25% of open green space is a sustainable portion of the quality life of urban dwellers [50]. Usually considered the least are the numbers of play areas, parks, other open spaces and swimming pools per capita [50]. A great number of green parks are inhabited by destitute individuals, vendors, and a few have been changed over into brief markets, transport stops, ghettos, etc. [49]. According to a DCC study conducted in 2006, Dhaka has 8.5% tree coverage, while an ideal city needs at least 20% green space [45]. Additionally, local governments do not have sufficient logistics to manage public green spaces efficiently [48].

The criteria of accessibility of a good public open space include [51]: (1) Linkages; (2) walkability; (3) connectedness; and (4) convenience. Park quality is related with more elevated amounts of and by large physical exercises [52]. A previous study recognized that 45% of members spent around 2.5 h every week on park-based exercises. Moreover, more prominent park accessibility was related with a 2.97-fold increase in the chance of utilizing parks [53]. The large-scale open spaces used by the middle class for recreational purposes are often found to be associated with antisocial occupancy, thereby resulting in dehumanized areas [54,55]. The lack of open spaces and fair spatial distribution of Dhaka City parks are making them less accessible [54].

The study measured the demand and accessibility level of five selected socially vulnerable groups (women, illiterate, and ethnic-religious minority, unemployed people). Vulnerability is usually treated similarly to notions of need, risk, susceptibility to harm or neglect, or lacking durability or capability [56]. Relative vulnerability among people (by age, sex, and race/ethnicity), within interpersonal relationships (by family structure, marital status, and social networks), and by access to neighborhood resources (such as schools, jobs, income, and housing) [57]. We administered here the definition and reasons behind the selection of the target groups. Ethnographically different and non-Bengali people are defined as the ethnic minority in Bangladesh and their portion is very small compared to the majority (Muslims) [55]. They particularly live in Hilly Chittagong and a very few numbers of them live in Dhaka and other cities. In Bangladesh, literally government, constitution, and laws support the freedom of religion; however, attacks, discrimination against religious and ethnic minorities continued forever [55] Religious minorities (Hindu, Christian, and Buddhist) are, sometimes, at the bottom line and marginalized both in urban and rural society. Urban green space can promote them to inclusivity and resilient social cohesion. Dhaka ranked the seventh worst megacity in world for women [58] as air and water pollution, and water scarcity affect women's health and income status. The World Bank recommended to put Bangladesh on a greener growth trajectory to get rid of these challenges. Both employed and non-employed women who have been suffering from obesity and diabetes selected to study. Dhaka is Asia's most stressful city. Dhaka's regretful performance includes density, traffic congestion, perception of security, family purchase power, underemployment, and physical and mental health. Unemployed workers in the study refer to the workers who are working part-time, but intend to work full-time jobs [59]. Green space activities can mitigate the stresses.

Socially vulnerable groups (women, children, elderly and low-income people, the disabled, ethnic minorities, and mental patients) have less access to green public spaces in Dhaka due to the lack of public consciousness, adequate initiatives, and most of all, insensitivity of green space and wetland design to their needs [54,60]. Socially defenseless groups include youngsters, women, elderly individuals, ethnic minorities, the impaired, patients suffering from mental illness, the unemployed, laid-off specialists, dislodged populaces, asylum seekers, laborers and casual laborers, and hindered people as for work relations, for example, off-staff individuals and prior resigned on-staff individuals [31,52,61–63]. Helpless individuals in the public eye have more requirements, including better activity and all the more monetarily, and more advantageous-to-use facilities [28]. Most of the public parks in Dhaka (except a few large-scale parks) face enormous socioeconomic, environmental and management obstacles, let alone special arrangements for vulnerable groups.

This study predominantly aims to measure the factors and level of accessibility of public UGS (parks) to different vulnerable social groups. Earlier research proposed that, in light of an investigation of various examinations contrasting diverse sorts of green space indicators, aggregate beneficial indicators are more reliably connected to human wellbeing than community area closeness ones [64]. Based on previously identified problems, we developed the following research questions:

- How does the socially vulnerable group population size affect the demand for urban green public parks?
- What is the effect of community area size on the accessibility of green public parks?
- Does community area population density influence accessibility?

In this study, we investigated whether the size and density of the population of a certain community area affected the accessibility of public green spaces. A "community area" denotes a sub-district (Thana, local term) in the Dhaka City Corporation, while "Dhaka City" or "Dhaka" indicates the Dhaka City Corporation area in Bangladesh.

2. Methods and Materials

2.1. Methodological Design Flow

Figure 1 shows the methodological design flow of the study. Firstly, the chart displays the methodological approaches which include: (1) Time–distance weighted technique; (2) urban green space indicator (UGSI); and (3) range-institutionalized approach (social demand index (SDI) formula). These three techniques express accessibility level and SDI measurement methods. Secondly, Figure 1 displays the profile of study area and population including six diverse communities and five vulnerable people's group. Data is categorized by two types: Demographic and vector data shown on the chart at third steps. Data collected from 2011 population census conducted by Bangladesh Bureau of Statistics (BBS) and vector data from Google Earth pro. Finally, data analysis techniques and tools are shown on the flow chart and it has concluded in the findings steps.

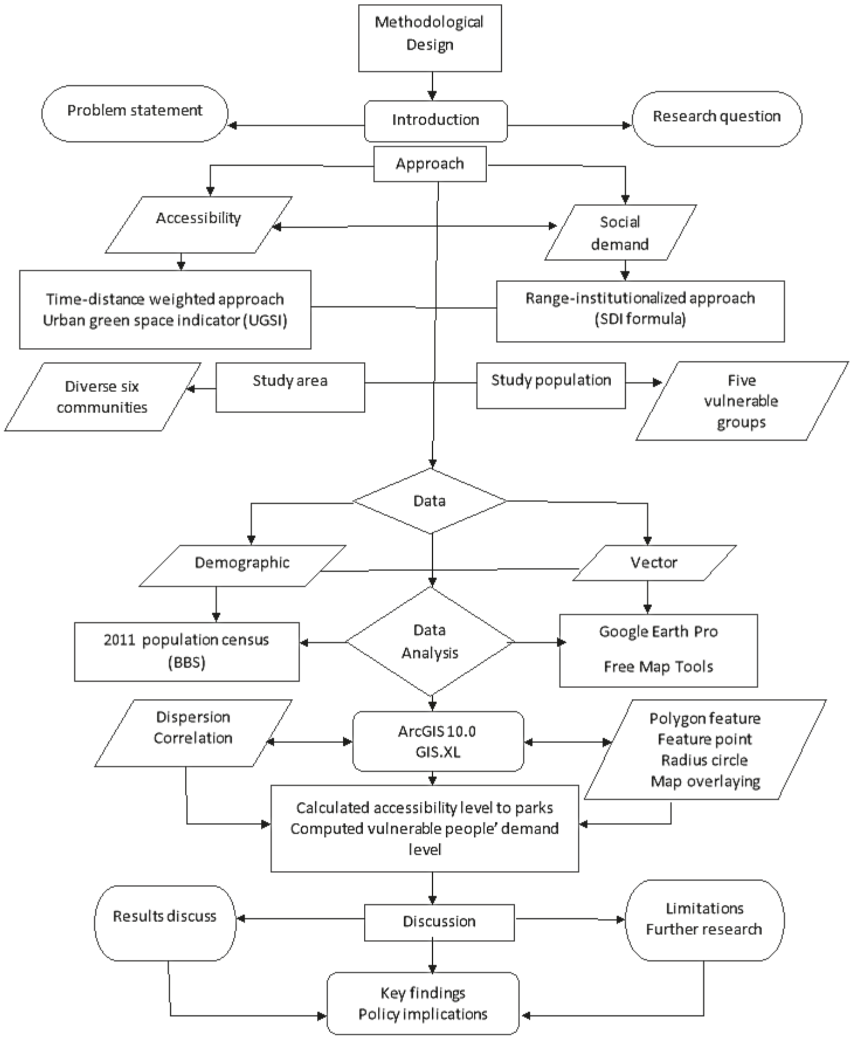

Figure 1. Methodological process flow map.

2.2. Methodological Approach

This study employed a multi-approach strategy to quantify the accessibility of green parks. The time-distance weighted technique portrays accessibility by estimating the time or distance that is required for dwellers to walk to open parks [28]. It is typically directed to dissect accessibility [65], the radiation impact and administration extent of urban open parks [23,66]. The study used the time-weighted distance method to assess the accessibility of the nearest parks by walking from specific circled residential areas in the central urban zones of Dhaka. The method is based on raster data converted into vector data by the ArcGIS 10.0 Software Package. The accessibility of urban green open parks, which is a critical subject related to urban natural space, is characterized as the relative or extreme level of trouble that people encounter when utilizing a specific transportation device to defeat space resistance from urban open parks from a given place [24].

Accessibility is considered to be most favorable when the travel time required to reach a park is less than three minutes on foot (walking speed between 1.1 and 1.3 m/s) [28]. When the time spent traveling to a park was more than 30 min, the park was regarded as having poor accessibility (Figure 1) [31].

This study applied a socially vulnerable group demand index (hereinafter SDI) to calculate the accessibility level of various green parks in Dhaka to vulnerable social classes. Vulnerable groups were defined as social groups that possess minimal assets and thus experience high relative dangers of hardship and untimely mortality [67]. Vulnerability also refers to a person's social status and living standard other than physical conditions. This study deals with particular social groups such as women, the illiterate, and unemployed religious and ethnic minorities. We measured the accessibility of public parks to these vulnerable groups and which community areas provided accessibility and to what extent. The idea of a socially vulnerable groups' demand index [25] was considered and mirrors the distinctions in the spatial appropriation of defenseless groups and impartially shows the potential prerequisites of helpless groups for sharing urban ecological space. The index measures the potential demand of socially helpless groups that enjoy parks at the community level [30], and indicates how much green space is available in this community unit.

2.3. Accessibility Level Measurement 1

According to the survey, accessibility was characterized as being the most ideal when the time required to reach a green park was less than three minutes by walking (walking speed was approximated at between 1.1 and 1.3 m/s), while a travel time of between three and eight minutes was viewed as being comparatively ideal ("Raster Calculator") [31]. Normative data indicates that non-patient community-dwelling men aged 60 to 69 years walk at an average of 1.34 m/s; women walk 1.24 m/s. By the time individuals reach 80 to 99 years, average gait speed has slowed to 0.97 m/s for men and to 0.94 m/s for women [68]. The author also showed that men aged 30–49 years walk at 143 m/s and women walk at 134–139 m/s. The vulnerable people of this study could not be limited within age frame. In addition, walking speed depends on age, height, road, load, terrain, etc., and we apply an average walking speed in the study, as a different walk speed could conveniently not be calculated. It is suggested that it can be further researched to get specific outcomes. This study analyzed the accessibility level of Dhaka based on road connectivity and open green space patches by applying two unique measurements: (1) In terms of distance, by expanding the radius of the surrounding region around green spaces from 0 to 800 m, including four categories (0–100, 100–200, 200–500, and 500–800 m); and (2) in terms of walking time, by accepting a normal walking speed between 1.1 and 1.3 m/s. Dhaka is a compact city, and accordingly the distance of 0–100 m with a two minute walking time was regarded to represent very good accessibility.

2.4. Accessibility Level Measurement 2

Different indicators have been developed for measuring the level of accessibility of UGS patches. The UGSI was developed to assess green space accessibility in the context of improving health ailment, fortify approach intercession and help evaluate general wellbeing impacts [18,69–71]. In this study, we used an accessibility indicator (UGSI) of urban green space proposed by the WHO [21,71–73]. UGSI is an approach to measure the accessibility of green spaces based on the total population of a city and the accessible population numbers. The indicator esteem is computed by utilizing the number of inhabitants with open urban green zones (N_{ACC}), the total number of residents across the city (N_{TOTAL}), and the score of inhabitants living around the chosen distance to urban green regions (UGSI). It is calculated as follows [73]:

$$UGSI = N_{ACC}/N_{TOTAL} \times 100\%$$

The straightest distance to the boundary limit of UGS at least 1 ha in area was set as 300 m. The investigation results showed that the indicator value reduced [74] with the expansion of green spaces and the reduction of distance to green spaces.

2.5. Socially Vulnerable Groups Demand Index (SDI) Assessment

Only based on the spatial distribution characters of vulnerable groups, the accessibility study can really reveal the spatial equity of green space resources. Therefore, the concept of a socially vulnerable groups' demand index [75] is adopted, and it reflects the differences in the spatial distribution of the vulnerable groups and also objectively manifests the potential requirements of the vulnerable groups for sharing urban ecological space [31]. Through the spatial equity of public green space, it is attainable to social inclusivity and equity. Thus, vulnerable groups can avail the public ecological property and meet up with their own requirements. This index measures the different demand levels for green space of five vulnerable groups (females, the illiterate, religious minorities, the unemployed and ethnic people) at the community Thana level. For computational simplicity, each of the indicators recorded above was standardized with the range-institutionalized technique [32]. This task included a range-change approach. The formula used is as follows:

$$C_i = (F_i - F_{min}) / (F_{max} - F_{min})$$

where C_i represents a community indicator or name, F_i is the average value of all groups' demographic values of a certain community area and F_{max} and F_{min} denote the maximum and minimum values among the groups' value of a certain community, respectively. According to the calculations, the six Thanas were partitioned into three grades according to the SDI outcomes: Very high demand (SDI > 0.6), high demand (SDI 0.5–0.6), and low demand (SDI 0.4–0.5).

2.6. Study Sites Overview

The city of Dhaka was used as the study area in the present study. A total of six out of 40 Thanas (subdistricts) were chosen for investigation. Dhaka is a densely populated city inhabited by different classes of people. The Accessibility of public green parks to city dwellers is not healthy; people in socially vulnerable groups are in critical condition as well. Compared to population density, the availability of green parks and their distribution is not the same for the whole population. We investigate which community areas have the highest or lowest accessibility to socially vulnerable people.

Dhaka's urban development has not kept up with the city's fast growth; its urbanization process has been untidy and uneven. The need for satisfactory arrangement has led to congestion, destitute livability and vulnerability to surges and earthquakes. Dhaka's numerous inhabitants include 3.5 million slum tenants [76]. Between 1995 and 2005, the area of street surface in Dhaka grew by around five percent, while the city's population grew by 50% and its activity by 134%. Congestion in Dhaka wastes 3.2 million working hours per day [76]. Moreover, spatial distribution is also seriously unfair; for example, open green space patches are associated with unplanned and uneven construction. Dhaka City has two parts: Dhaka City Corporation (North) (DNCC) and Dhaka City Corporation (South) (DSCC). The DNCC does not accommodate green parks in two out of five zones (zone 2 and 4). It has been developed as a "New Dhaka" and is largely inhabited by middle- and upper-middle class people. Likewise, zone four of the DSCC contains no green patches or playgrounds, even though its population density is around 97,560/km^2 [77].

Dhaka, previously known as Dacca, is the capital and biggest city of Bangladesh, as well as the country's main economic, political and social focal point. It is the fourth most densely populated city in the world [78], with a population of 18.89 million in the Dhaka City Corporation Area. Dhaka is one of the most important urban zones in South Asia and is the largest city in Eastern South Asia. As part of the Bengal Plain, the city is situated on the Buriganga, Turag, Dhaleshwari, and Shitalakshya Rivers.

The city is situated in an eponymous locale and division [79]. Figure 2 displays the location of Dhaka with sub-district (Thana) boundary distributions.

Figure 2. The location of Dhaka with sub-district (Thana) distributions.

Dhaka City is located at 23°42′ N 90°22′ E on the eastern banks of the Buriganga River. It lies in the lower ranges of the Ganges Delta and covers an aggregate territory of 306.38 km^2 [80]. Tropical vegetation and wet soils make up the land, which is level and close to sea level. Dhaka City is limited by the districts of Manikganj, Tangail, Munshiganj, Rajbari, Narayanganj, and Gazipur. Dhaka City Corporation is a self-administering zone that runs the affairs of the city. Dhaka City was established on 1 August 1864 and achieved "metropolitan" status in 1978. The territory inside city partnerships is partitioned into a few wards, which each have a chosen official. Altogether, the city has 40 Thanas, 130 Wards, and 725 Mohallas.

Under the Köppen climate classification, Dhaka has a tropical savanna air. The city has a specific monsoonal season, with a yearly average temperature of 26 °C (79 °F); temperatures range from 19 °C in January–February to 29 °C in May–June. Roughly 87% of the yearly average precipitation of 2123 mm (83.6 in) occurs between May and October [81]. There are various parks inside Dhaka City, including Ramna, Shishu Park, Suhrawardy Udyan, Gulshan Park, Chandrima Udyan, Dhaka Zoo, and the National Botanical Garden. There are lakes inside the city, including Crescent Lake, Banani Lake, Dhanmondi Lake, Hatir Jheel-Begunbari Lake, and Uttara Lake.

Figure 3 appears that two patterns are clearly recognizable from the figure: (1) Built-up zone and uncovered soil expanded slowly over the periods; and (2) water body and vegetation declined steadily. More particularly built-up zone expanded by 88.78% within the past 20 years, from 1989 to 2009 [82]. The maps' results propose that around 49% and 57% of the Dhaka City region will be changed over into "built-up area" land cover sort in 2019 and 2029, separately (Figure 4) [82].

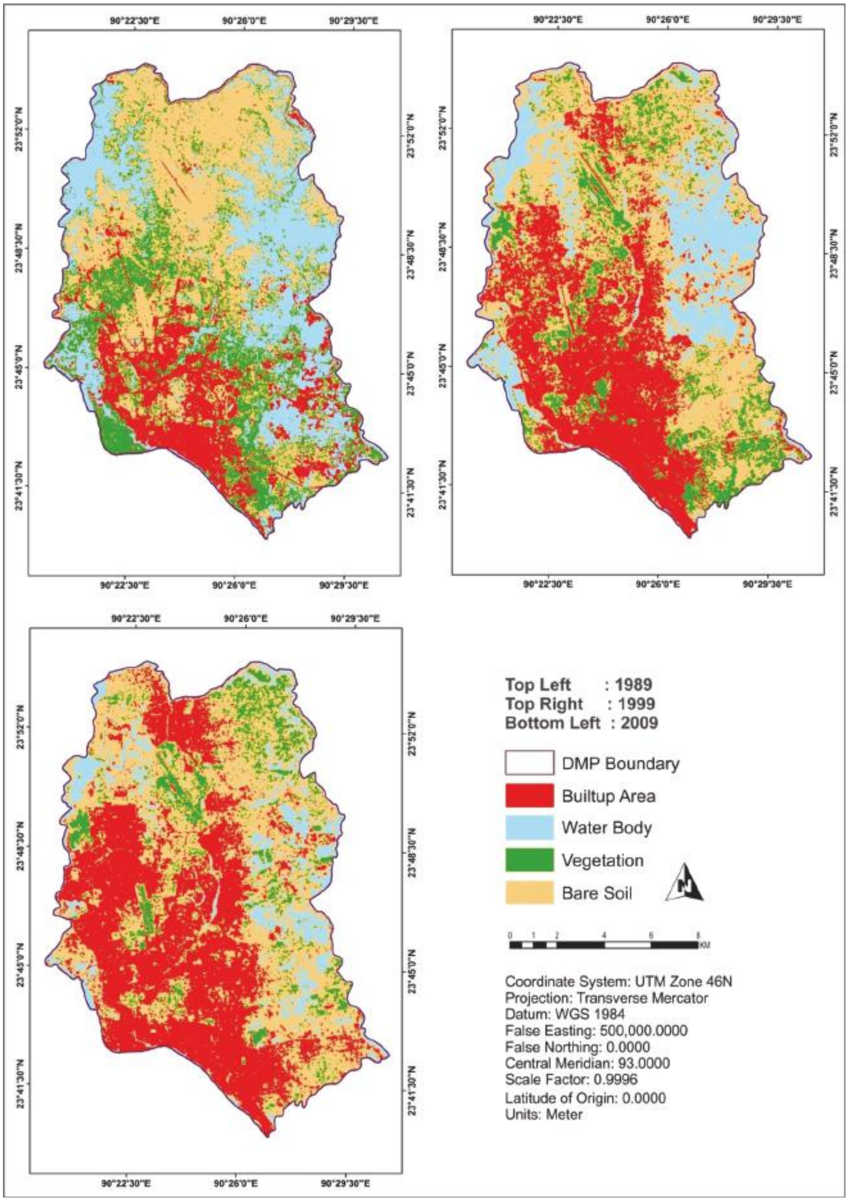

Figure 3. Land use and land cover maps of Dhaka City [82].

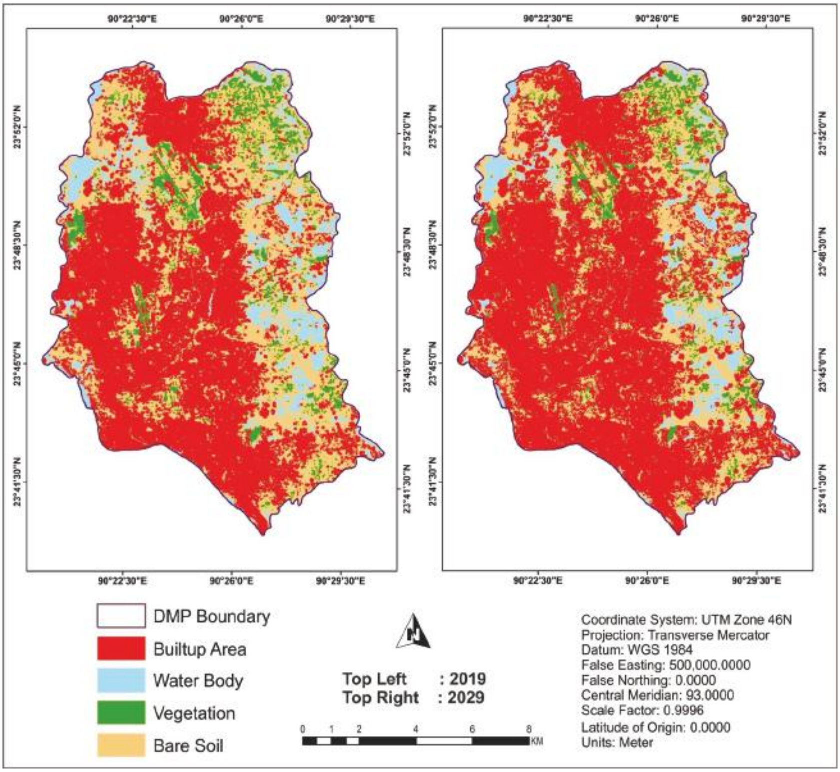

Figure 4. MLP Markov model simulated land cover maps of Dhaka City area (2019 and 2029) [82].

Dhaka City, which is continuous with areas comprising the more extensive metropolitan region, was home to more than 15 million people as of 2013. The population is increasing by an estimated 4.2% every year, one of the highest growth rates among all Asian cities. This growth rate influences migration movements from rural zones to Dhaka, which accounted for 60% of the city's expansion between 1960 and the 1980s. The Far Eastern Economic Review estimates that Dhaka will have a population of 25 million by 2025 [83]. Dhaka is highly socially stratified: A total of 63.60% of people belong to the lower class and 36.40% to the upper and middle classes [84]. Additionally, 23% of the population of Dhaka City people are classed as vulnerable (women, illiterate people, religious minorities, ethnic minorities, and unemployed people) (Figure 5); as of 2011, 25.40% of Dhaka's population were illiterate, 11% were religious minorities and 1.1% were ethnic minorities [84]. Therefore, the majority of Dhaka's population are either of low class or vulnerable.

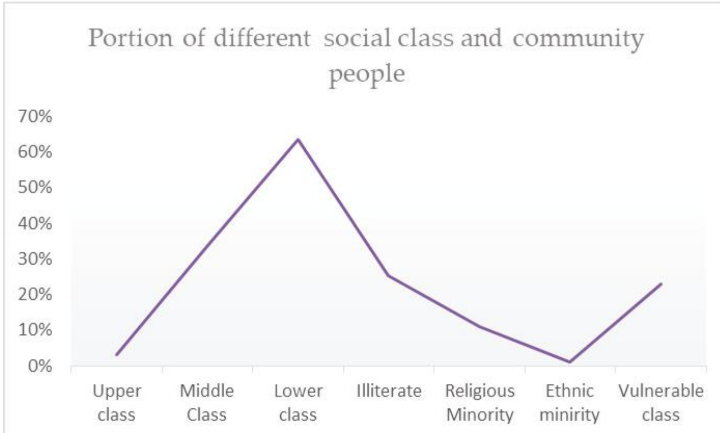

Figure 5. Social class and community profile in Dhaka.

The education rate in Dhaka is rising rapidly, and was around 69.3% in 2001. The literacy rate had increased to 74.6% by 2011, which is higher than the national average. The demographics of Dhaka City include people from each district of Bangladesh. Between 15,000 and 20,000 of the Santal, Mandi, Rohingya, Chakma, Garo, and Khasya peoples live in the city. Table 1 shows that Sher-e-Bangla Nagar and Badda have the largest number of socially vulnerable people (26.56% and 26.4%, respectively). The lowest average number of socially vulnerable people is in Kotwali (17.7%). On average, 23% of the population of Dhaka are socially vulnerable and thus demand the highest accessibility of public green spaces for their socio-physical and psychological wellbeing.

Table 1. Demographic proportions in six communities.

Community	Proportion of the Female Population	Proportion of the Illiterate Population	Proportion of the Religious Minority Population	Proportion of the Ethnic Minority Population	Proportion of the Unemployed Population
Kotwali Thana	35.10%	27%	2.50%	0.30%	23.60%
Ramna Thana	46.10%	27.70%	16.90%	0.10%	29.60%
Sher-e-Bangla Nagar Thana	44.80%	21.80%	29.90%	0.10%	36.20%
Shah Ali Thana	46.50%	29%	21.10%	0.10%	27.40%
Gulshan Thana	44.50%	25.20%	4.70%	0.20%	26.40%
Badda Thana	43.70%	27.70%	5.30%	0.20%	26.40%

In the City Corporation region, there are only 1286 km of roads, which is generally about 6% within the city zone (Figure 6). Just 9% of roadways and 6% of asphalted land is accessible, of which 62 km is utilitarian essential, 108 km is auxiliary and 221 km connector streets used for city transport. The United Nations Economic Commission for Europe (UNECE) recommends around 25% of road network for a sustainable city (Figure 6). The accessibility of green patches requires safe, smooth, and low-cost connectivity, which are regrettably lacking in Dhaka City.

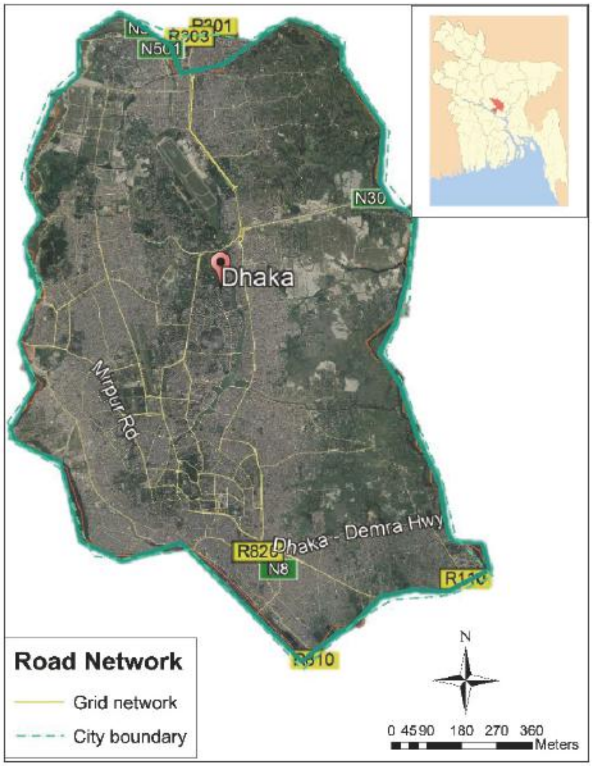

Figure 6. Time–distance weighted grid map of Dhaka.

Figure 6 shows that the connectivity networks in the northern and eastern parts of Dhaka City lack proper connectivity, since the Southern part is comparatively fair, but are not properly connected due to population density. The Northeastern part of Dhaka City has been developed in recent decades, and predominantly middle and upper-middle class people are settled in these zones. Several residential zones (Uttara, Baridhara, Gulshan, Banani, Bashundhara, and DOHS residential areas) have been developed in a planned way, however road connectivity here is visibly uneven, unfair, unavailable, and unplanned. As a result, demand for green space attachment increased more where accessibility facilities decreased in an equivalent manner.

2.7. Six Selected Community Areas

The study investigated six community areas (subdistricts, or Thanas) (Kotwali, Ramna, Sher-e-Bangla, Shah Ali, Gulshan, and Badda) out of forty. The forty Thana are diverse in terms of human and non-human features. Figure 7 shows that the built-up area of Badda has the highest community area (36.84 km^2) and Kotwali has the lowest (0.6735 km^2). Shah Ali has the highest amount of green space (1.6 km^2) and Badda has none. It is worthy noted that Kotwali is the most densely populated community area (97,438/km^2) and Badda is the least densely populated (14,566/km^2).

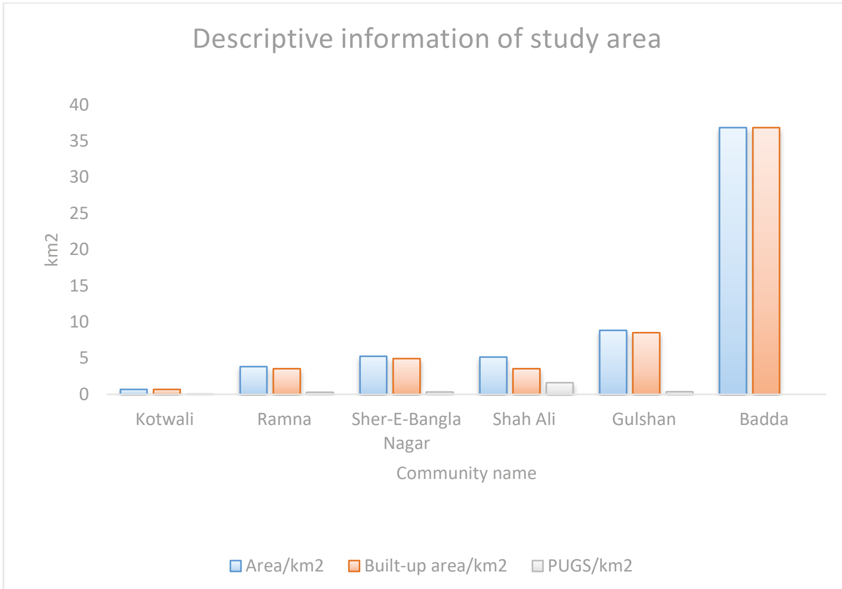

Figure 7. Descriptive statistics of study areas (UGS: urban green space).

It is noted that Kotwali holds only 0.0065 km^2 of green parks, while Badda Thana has no green patches at all. Shah Ali has 1.6 km^2 of green parks, meeting the demands of 22,425 people/km^2. Dhaka City has an average of just 0.0002 m^2 of green park per capita. Only 0.0005 m^2 of green park per capita remain in Kotwali, where around 17.70% of the population are classed as vulnerable (women, illiterate, religious and ethnic minorities, and unemployed) (Figure 8 and Table 2).

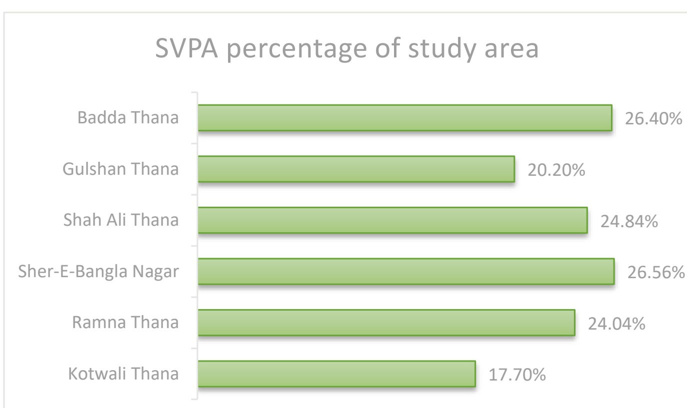

Figure 8. Vulnerable population percentage of the study areas. (SVPA denotes the socially vulnerable people average).

Table 2. Area of Green Park per capita of the study areas.

Community	PUGS (m^2/per Capita)
Kotwali	0.0005 m^2
Ramna	0.017 m^2
Sher-e-Bangla Nagar	0.025 m^2
Shah Ali	0.15 m^2
Gulshan	0.015 m^2
Badda	0 m^2

Sher-e-Bangla Nagar has 26.56% of vulnerable people and 0.025 m^2 of green patches per capita. Badda has no green public parks and about 26.40% vulnerable people. According to the World Health Organization, an ideal city requires 9 m^2 of green patches per capita to maintain quality of life and ecological balance. In spite of high demand, poor grid connectivity, congestion, and lack of security gear reduces the accessibility of green patches.

2.8. Sampling

The study selected six community areas (Kotwali, Ramna, Sher-e-Bangla, Shah Ali, Gulshan, and Badda) out of forty following cluster sampling technique. We applied simple random sampling strategy in selection process of the six community areas in Dhaka. In cluster sampling, cluster, i.e., a group of population elements, constitutes the sampling unit, instead of a single element of the population. The main reason for cluster sampling is "cost efficiency" (economy and feasibility) [85]. These communities are diverse that includes the diversification of geographical location, distribution of green parks, grid connectivity, social stratification, community size, and population density. The study endeavored to gather data and results from the diverse environment so that it could lock out key findings. Likewise, the paper chose the five vulnerable groups based on the simple random sampling strategy. Additionally, suitable data availability was a strong consideration on the selection process of socially vulnerable groups.

2.9. Data Collection and Process

This study used imagery and statistical data. Imagery data included topographic, featured and spatial distribution maps. Statistical information incorporated the National Population and Housing Census (NPHC) 2011 data on Dhaka City and the data on socio-spatial, demographic and public green spaces of the study areas. We collected population and housing census data from the Bangladesh Bureau of Statistics (BBS), Dhaka, Bangladesh. Data on socially vulnerable groups were also collected from the NPHC. A geo-referenced master map of Dhaka City, which includes the administrative units, was also acquired from the BBS and Google Earth Pro. We extracted raster maps of the study areas and park distribution from Google Earth Pro powered by Google Satellite (www.maps.google.com). A time-distance grid network map was processed and extracted from Google Earth Pro. We collected historical Thana (subdistrict) maps from Banglapedia, an open data source platform for Bangladesh, which is the National Encyclopedia of Bangladesh (www.en.banglapedia.org).

This paper calculated time-distance scores (based on area calculation) from the residential area to public green spaces (parks) by drawing a radius circle around a specific point on the map; this process was achieved using the Free Map Tools (https://www.freemaptools.com/radius-around-point.htm). We showed the spatial distribution of the study areas by making polygons and points on Google Earth Pro. We then performed geo-processing in ArcGIS 10.0. Public green parks were displayed by drawing points.

3. Results

This section predominantly deals with the accessibility index estimation of different classes of people and socially vulnerable groups. We examine the components that affect the accessibility to green parks. Figure 9 presents the spatial distribution of study areas (Thanas) and public green parks. It shows the six areas selected for the study and five green park patches. Figure 10 shows the spatial location of community areas, including the time-weighted scores of accessibility level. Table 3 displays the accessibility level of public green spaces to communities in Dhaka City. It shows that Kotwali has the highest accessibility, with a score of 2.01%. Ramna has good accessibility, with a score of 6.52%. The accessibility of Shah Ali Thana is fair, while Sher-e-Bangla Nagar, Gulshan, and Badda are the least accessible Thanas, with scores of 9.52%, 7.68%, and 5.57%, respectively (Figure 10).

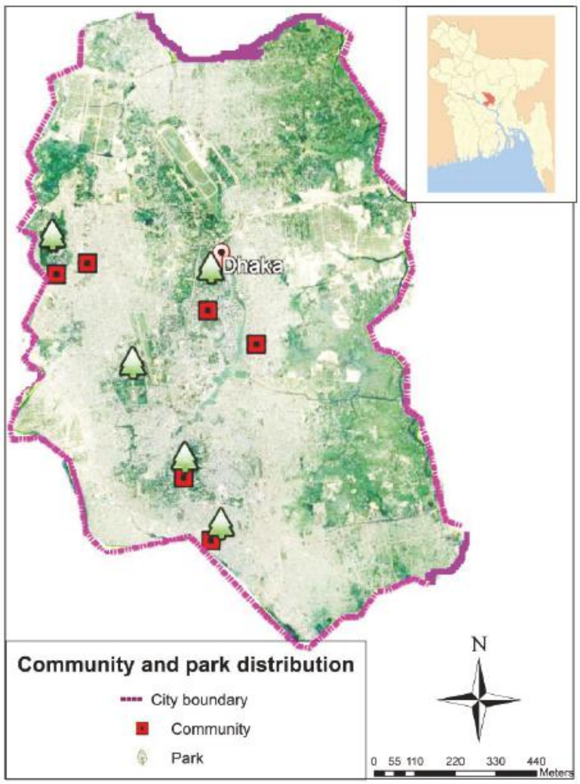

Figure 9. Spatial distribution of study areas and green parks.

Dwellers in Kotwali Thana can use nearby green parks within the least time. They have a 'very high good accessibility' to green patches within a two-min walking distance (Table 3). This is a highly compact and small-sized community area in the older part of Dhaka established for century past. After that, there are green parks in Ramna within a five-min walking distance resulting in a 'good accessibility' of the surrounding people to green parks. It is also a compact community area, and the population density is higher. Gulshan and Badda are the 'poor' accessible communities, and the residents of these Thana have to get access to nearby green patches in the largest 20-min-way of walk. These are the parts of newly developed areas. These communities have been expanded unplanned and unfair as Badda has no green patches and road connectivity, developed a completely discriminatory way. It is worthy to note that these are the areas of less population density in comparison with other study areas. Figure 6 shows the location of Badda and it is not connected with the city major grid. Figure 6 shows that the North-Eastern part of the city is principally disconnected from the main city grid. Figure 10 and Table 3 shows the accessibility level score of vulnerable group people; and even the travel distance and time are calculated from surrounding green patches to communities in linear way measuring technique. Yuan et al. [31] showed a survey results that accessibility of vulnerable people was the most acceptable when travel time required to reach a green park was less than three minutes on foot (walking speed approximated at between 1.1 and 1.3 m/s). This study used the travel time to calculate the accessibility level score of vulnerable groups.

On the other hand, Shah Ali is the community of a 'common' accessibility (Table 3). The users have to spend the largest 20 min to get access to parks on foot. The Thana in the North-Western part of Dhaka, which is a recently developed community with the area of 5.15 km^2 (Figure 8) that does not accommodate the high density of population. It clutches two sizable green patches (1.5 km^2) and connected to a practical city grid. It was however, the area at an edge corner of North Dhaka City Corporation, far away from the central point of Dhaka. Figure 11 shows the location of the study areas and Figure 10 shows the site and size of six communities. These communities have been selected as they have a pivotal diversification in the consideration of community place, their size, green patches distribution, and spatial, demographic, and connectivity syntax. The communities are characterized by the heterogeneity of human and non-human components that influence the accessibility level to green spaces.

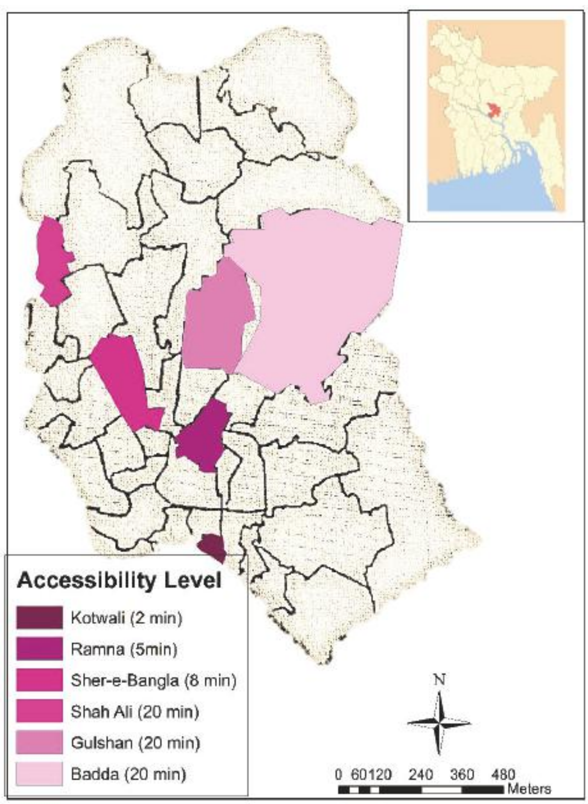

Figure 10. Accessibility level measurement of community (study) area.

Table 3. Statistics of communities' accessibility level.

Time (Min)		<2 min	2–5 min	5–10 min	10–20 min
Accessibility Level		**Very Good**	**Good**	**Common**	**Poor**
Kotwali Thana	Proportion (%)	2.01	17	15	0
Ramna Thana	Proportion (%)	0.78	6.52	12.24	13.8
Sher-e-Bangla Nagar	Proportion (%)	0.58	5.97	8.95	9.52
Shah Ali Thana	Proportion (%)	0.61	4.5	9.13	7.13
Gulshan Thana	Proportion (%)	0.34	3	5.2	7.68
Badda Thana	Proportion (%)	0.08	0.68	1.28	5.57

Table 4 shows that Kotwali has the highest and Badda the lowest accessibility to green space (20% and 9.52%, respectively). Ramna, Sher-e-Bangla Nagar, Shah Ali, and Gulshan Thana have accessibility score 12.5%, 11.76%, 10.53%, and 11.96%. Kotwali has the highest population density (98,898/km^2) and its community area size is the smallest one of the study areas (Figure 8). On the other hand, Badda has the lowest density (14,566/km^2) and the largest size community area. Other communities show almost similar features about the impact of population density and community area size on urban green space accessibility level. Ramna and Gulshan are the second highest accessible community, and their population density is 50,824 and 28,593/km^2. Shah Ali has the second lowest accessibility to green patches scoring 10.53% and its population density is also in the second lowest (22,425/km^2). It is worthy to note that the total and accessible populations of a community do not have an effect on accessibility level (Table 4). Figure 3 shows that the highest accessibility depends on the community size (small-sized community); however, Table 4 displays that population density influences the highest accessibility level.

Table 4. Estimation of green space accessibility based on population.

Community	Total Population	Population Density	Accessible Population	UGSI (%)
Kotwali Thana	145,431	98,898	29,086.20	20
Ramna Thana	195,167	50,824	24,395.88	12.5
Sher-E-Bangla Nagar	137,573	26,202	16,185.05	11.76
Shah Ali Thana	115,489	22,425	12,156.74	10.53
Gulshan Thana	253,050	28,593	25,305	11.96
Badda Thana	536,621	14,566	51,106.76	9.52

Note: UGSI denotes urban green space indicator.

Table 5 and Figure 11 show that Sher-e-Bangla Nagar Thana has the 'pretty high' (score = 0.61) and Gulshan and Badda have 'low' demand level (0.45 and 0.47, respectively). The 'high' demand areas include Kotwali, Ramna, and Shah Ali Thana, for which the scores are, respectively, 0.51, 0.52, and 0.53. Figure 6 shows the community area spatial distribution presenting the social demand scale. Figure 8 offers that Sher-e-Bangla Nagar accommodates the highest percentage of the socially vulnerable population (26.56%) and holds the second highest public green parks per head 0.025 m^2. Thus, results show that the highest percentage of the socially vulnerable population has an impact on demand for green space.

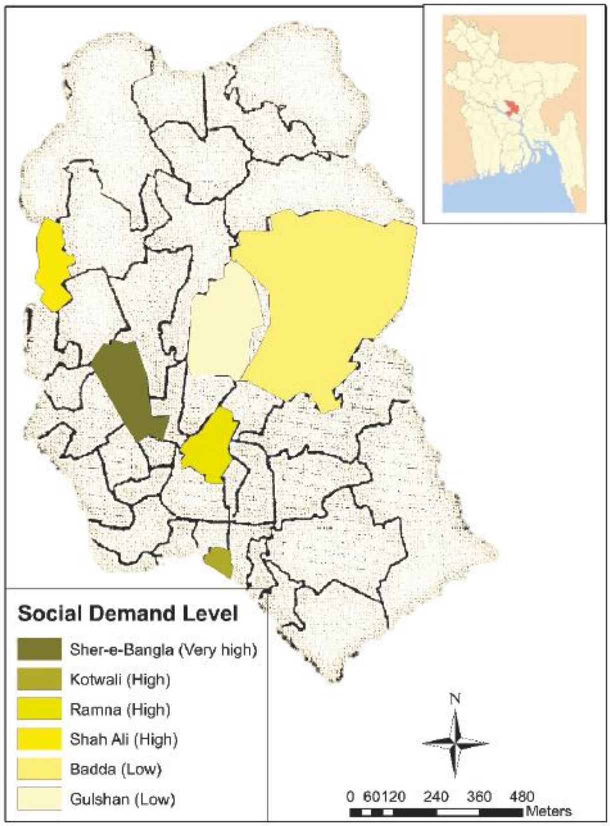

Figure 11. Projection of the demand index of socially vulnerable groups in the study areas.

Table 5. Calculation of socially vulnerable groups' social demand index (SDI) for different communities.

SDI Classification	SDI > 0.6	0.5 < SDI < 0.6	0.4 < SDI < 0.5
Demand Level	**Very High**	**High**	**Low**
Kotwali Thana		0.51	
Ramna Thana		0.52	
Sher-e-Bangla Nagar	0.61		
Shah Ali Thana		0.53	
Gulshan Thana			0.45
Badda Thana			0.47

Spatial Equity Measure

The spatial overlay is a scientific approach to measure the equitability of park distribution according to SDI. We overlaid the accessibility level and demand index results shown in Table 5 above. The results show that the overall spatial equity is low for Sher-e-Bangla Nagar Thana, which has the highest demand for green spaces (parks) and the lowest accessibility. Furthermore, Shah Ali Thana has high accessibility demands, but only has a fair accessibility score. Kotwali and Ramna have high accessibility demands and very good and good accessibility. Gulshan and Badda have low demand and low accessibility, but not an equitable spatial distribution of healthy accessibility to parks.

Table 6 shows that Sher-e-Bangla Nagar has the highest demand and Gulshan and Badda the lowest demand. Kotwali has the highest and Gulshan and Badda the lowest accessibility to urban green public parks. Table 6 shows that Sher-e-Bangla Nagar has the highest demand and Kotwali has the highest accessibility to public green parks in Dhaka.

Table 6. Overlay result analysis of accessibility level (AL) and SDI.

SDI Classification \ Accessibility Level	Very Good Accessibility	Good Accessibility	Common Accessibility	Poor Accessibility
Low demand (0.4 < SDI < 0.5)				Gulshan Badda
High demand (0.5 <SDI < 0.6)	Kotwali	Ramna	Shah Ali	
Very high demand (SDI > 0.6)				Sher-e-Bangla Nagar

4. Discussion

This section discusses the results based on the existing literature and scientific arguments so that it can be feasible whether they are significant and rational. We also picked out the key findings through a comparison between present results and previous studies. The results show that Sher-e-Bangla Nagar Thana has a very high demand and Gulshan and Badda have a low demand for green space. Kotwali has very good accessibility and Gulshan and Badda have poor accessibility. Additionally, the outcomes show that the park distribution of Dhaka City is unequal, and unjustified, as the gap between demand and accessibility (supply) is wide. Kotwali and Ramna are the most densely populated (population densities of 101,693 km^2 and 48,292 km^2, respectively) and smallest (0.68 and 3.84 km^2, respectively). The demand and accessibility score of these two Thana are higher than others. Gulshan and Badda have the least demand and accessibility score. The size of these communities is larger and their population density is lower than others. It was found that small sized and densely populated communities have a pivotal effect on the social demand for and accessibility of urban public green parks. Likewise, large-sized and low-density community areas have low social demand and accessibility. The demand index of Sher-e-Bangla Nagar Thana has the highest score, and for this, Thana accommodates the highest proportion of the socially vulnerable population in the study areas (26.56%). The size of the vulnerable population affects the increase of the demand index: If a community area has a high number of socially vulnerable groups, it has a high demand score for urban green public parks.

The results, therefore, showed that Kotwali has a 'very good' accessibility, and 'low' is for Badda. If we discuss the factors behind the effects, we can view that demographic and geographic factors influence the accessibility level. The community, with densely populated and small-sized, is highly accessible to green parks. Kim et al. [86] conducted a study in Seoul City on the accessibility to health care centers (hospitals). He investigated that small-sized densely populated catchments have the high accessibility to hospitals. Additionally, he could see that large size of hospitals and high-income groups have high accessibility. Dhaka is almost a compact city like Seoul; that is why we opted its findings to this study to prove the accessibility accurateness. We found that a densely populated small-sized community (catchments) has very good accessibility to others.

On the other hand, the study can treasure the significance of the accessibility level if the existing literature are reviewed profoundly. It is conceivable to gauge the spatial value of urban open parks with the accessibility and demand index of people in a socially defenseless group, which can viably describe the reasonableness and social value of urban environmental space [32]. Green space accessibility can be expanded either by enhancing the walking courses or by building more small-to-medium sized green space patches that can cover the area [87]. Urban public park accessibility is highly important, since without adequate accessibility, the provision of good quality open spaces would be of very limited value. There have been investigations into the current situation of accessibility of urban public parks for planned and unplanned city neighborhoods [88]. Road parks or ground squares in Hong Kong are frequently brought together and disconnected from places of business, which require dynamic visits with particular purposes and expectations [89]. Singapore, however, has built up a model "City in a Garden", which has a coordinated nature with structures in daily life [79]. Most open green spaces in Singapore are intended to coordinate building structures in daily travel schedules [90]. Open green spaces in a network effectively affect community connection [25], with a unified open green space design having a more prominent impact than scattered open green spaces. Existing studies showed that accessibility pivots on green space size, walk way of green patches, and quality of open parks. Additionally, accessibility (nature attachment) in Singapore hinged on the nature coordinated structures as it is a highly compact city (difficult to greening expansion horizontally there). However, this study estimated the effects of community size on the accessibility level of green space.

By applying the Gini coefficient, research has shown that there are disparities in green space arrangement in major German cities. Additionally, solid incongruities identified in green space arrangement at a city level ranged from 2.5 m^2 per capita (city of Schwerin) to 36.3 m^2 (city of Bergisch Gladbach) within a 500 m buffer around the place of home [91]. Discernments of distance to travel were the major obstructions to the frequent use of peri-urban green spaces. Additionally, it is worth noting that green passages empower agreeable and simple access to semi-natural spaces in and around the city [92]. The accessibility to hierarchy (characterized based on work and size) of UGS is basic for the visiting and ideal utilization of UGS since it advances social interaction and physical movement among city populations [93]. Another study expressed diverse scenarios in terms of the rank of green space accessibility, unequivocally impacted by the chosen distance metric (Euclidean vs. Network) [94]. The works revealed that unequal green space distribution, travel distance to and from residence, and park size and quality have an impact on accessibility to green space, but this work displayed that the density of population and the size of green space influence the accessibility level. On the other hand, vulnerable people's demand for green park attachment turns on the population size of vulnerable groups in a particular community.

The existing literature predominantly focuses on the spatial equity of public green spaces, the impact of the size of green patches on accessibility, the quantity or quality of the role of public parks in accessibility, the greening approach or model, and the impact of urban planning on urban greening. Few studies have highlighted the health and ecological effects of public green spaces [10]. The present study investigated the factors affecting the social demand and accessibility level of urban green public parks. Two studies showed that disparity in green space arrangement, green passage, and hierarchy of UGS influences the accessibility level. The effects of community area size and population density on accessibility to public UGS has not yet been investigated.

This study made several new findings, including that: (1) The size of the socially vulnerable population in a certain community has an effect on increased demand to gain access to UGS; (2) population density affects the accessibility of parks; and (3) the size of a certain community area influences the accessibility. If a community area has a high number of socially vulnerable groups, it has a high score of demand for urban green public parks. A community with a high population density begets high accessibility to green parks; likewise, a small-sized community area provides high accessibility.

We collected demographic and geographical data from the BBS and faced a few difficulties due to the official service process. The data, to some extent, is inadequate and the data sorting process was time consuming. These are the limitations of the study. Moreover, patient (diabetes), children, and elderly people are seriously vulnerable in Dhaka and they needed to be included in this study. But they could not be incorporated in the study due to insufficient demographic data. Additionally, due to very compactness, traffic congestion, unzone residential and administrative boundary, unavailability of green patches, the perfectness of accessibility, and demand level calculation might not be adequate enough to a few extent.

Dhaka is a densely populated city that is comparable to the Singapore model and its approaches to the urban greening process. Urban greening is a crucial component of health and ecological wellbeing. As land reclamation in the horizontal level is almost impossible, vertical greening is a prime solution for compact cities. Singapore presently performs vertical gardening or greening (green wall, sky garden, green roof, pervasive greening, verdant wall, green building, and roof playground). In view of the Representative Green Features in Singapore Compact Land Use Policy, the green surface region in

Singapore will reach 328.7 km^2, which will account for around 46.3% of Singapore's property territory in 2030 [95]. The study recommends further research on the following question:

> *How to develop a 'green space creation model' for women and children in the densely populated urban communities?*

Particularly adult women and middle school children of middle and upper social classes are getting vulnerable with obesity, overweight, and diabetes. The prevalence of overweight and obesity was found 20.5% and 24.1 %, respectively, and also the prevalence of overweight and obesity among boys were 16.4% and 26.9%, respectively, and for girls were 26.7% and 20.0%, respectively, in Dhaka middle school children [96]. Even, the overall prevalence of diabetes is 11 %, and the prevalence is slightly higher in women (11.2 %) than men (10.6 %) in Bangladesh [97]. In this regard, open green space can mitigate these challenges providing physical exercise and recreational facilities. Increasing pressure of urban population, environmental pollution is causing a serious threat for the dwellers especially the vulnerable groups' people. Nearly one million people in Bangladesh, mostly poor, are at risk of air and noise pollution, which can lead to IQ loss and neurological damage, especially for children, and can increase the risk of miscarriage and stillbirth among pregnant women [57]. In this regard, green space might be the mitigation source of health hazards of women and children. However, traffic congestion and insecurity in Dhaka are the vital disturbance in the cutting down of the accessibility of women and children to green patches. Open green space is getting decreased along with the rise of built up areas. Planners and researchers can attempt to develop a 'green space creation model' for women and children to address the challenges. On the other hand, compact city governance has to adopt, gradually, the initiative for establishing the 'smart city', as its utility, safety, accessibility, and efficiency are sustainable. When a city will turn into a smart city, it will run through a sustainable digital system that everything (including green space for vulnerable people) will come under a unique system [98]

5. Conclusions

This study can draw three key findings: (1) The large size of socially vulnerable groups generates 'very high demand' for public UGS; (2) densely populated areas have 'very good accessibility' to green parks; and (3) small-sized community areas provide 'very good accessibility' as well. It is worth noting that people in small-sized community areas can find green space patches within walking distance (within 2–5 min or 200–500 m). However, the population of a large area cannot reach green parks because, in Dhaka, green space patches are inadequate. The Southern part of Dhaka is regarded as the old city, and consists of small-sized and high-density community areas. These areas were constructed during British colonial periods and the number of green public space patches constructed in that period was remarkably high [99]. However, the newly developed Northern part of Dhaka lacks green patches as a result of land scarcity due to the pressure of migration. As a result, Kotwali and Ramna Thanas, which are located in the older part of Dhaka, have high accessibility. The population density in these areas is also high compared to the newer part of Dhaka City.

Dhaka is expanding in all directions, and especially in the Northern and Eastern parts. The municipal government can adopt a legal and planning initiative so that newly expanded urban dwellers or organizations must ensure 9 m^2 per capita (WHO recommended) of green space on their construction works. Governmental and non-governmental organizations should come forward to build social awareness of the benefits of UGS. Existing green spaces can be highly effective by having initiative for park equipment, fundraising, security, natural settings, utility service, special arrangements for vulnerable groups, and cultural events. Dhaka is city with high levels of diabetes, hypertension, obesity and pollution, and as such there is no alternative to increasing accessibility to UGS.

These findings are highly useful to urban planners, landscape engineers, urban governance and policymakers. Policymakers can formulate urban management policies by bearing in mind these findings. They can divide large-sized Thanas into smaller ones, and in large-sized Thanas, they can set up small green patches in consideration of population density. Moreover, vertical greening is an efficient solution in compact cities. Urban planners can also plan new urban areas according to these findings. This means that green space construction increases instead of horizontal expansion in land. Dhaka is a highly compact city where land cannot be acquired horizontally for green zones. Apart from, "smart city" concept is highly recommended to adopt as a sustainable management tool of Dhaka Megacity as well as other compact cities. It is argued that smart cities research has the potential of contributing to research on megacities (smart megacities and clusters), cities (smart cities) and villages (smart villages) [100]. It is argued that smart cities research needs to be based on real tangible experiences of individuals inhabiting rural and urban space and that it also needs to mirror and feed into policy-design and policymaking processes [100]. In order to manage Dhaka Megacity sustainably, the "smart city" notion might be the smart solution in this modern technological age.

In Singapore, modern advancements must include plant life, within the frame of green rooftops, cascading vertical gardens, and verdant dividers. The thrust to "go green" extends to development as well; green building has been obligatory since 2008 [91]. In Marina Bay, all advancements comply with a 100% greenery substitution approach. The Pinnacle@Duxton, the tallest public housing improvement in the world, has seven 50-story buildings connected by gardens on the 26th and 50th floors [95]. The Singapore urban vertical greening model might be a fruitful approach in densely populated cities. Vertical greening is therefore a rational approach to increase the green system. The roofs of large-sized buildings (public or private) can be used as playgrounds with a greenery setting. Balconies, windows, indoor furniture tops, and building walls can also be used to host greenery to mitigate indoor pollution. Footpaths, home and office premises and wetlands might be turned into micro gardens in Dhaka as well as in other compact cities across the world. By this way, all walks of people can have access to the benefits of a greenery system directly and indirectly.

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Consumers' Preference and Factors Influencing Offal Consumption in Amathole District Eastern Cape, South Africa

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Abstract: This study was conducted to determine the consumers' perceptions and factors influencing offal meat consumption in Amathole District in the Eastern Cape Province of South Africa. A total of 202 consumers from Amathole District were randomly sampled from three municipalities. The study revealed that consumers were more influenced by the freshness, price, and availability of the product and these factors determine the point of purchase. The most preferred purchase-point for offal meat in this study was butchery. However, sheep offal was more preferred to cattle offal. The point of purchase, however, remains a prominent factor among other factors that could influence decision making for any consumer. When it comes to offal meat, the results showed that the majority of consumers purchased more liver, intestine, and tripe, which is because they are often sold in a combo at the butchery. Furthermore, it was revealed that consumers have nutritional knowledge of the offal meat products before making their purchase but health reasons emerged as a factor that the consumers considered the least at the point of purchase.

Keywords: offal; consumers; perception; consumption; meat quality; purchase-point

1. Introduction

About three decades ago, normal markets for offal meat progressively declined due to the outbreak of Bovine Spongiform Encephalopathy (BSE) otherwise called mad cow disease. The exclusion of offal meat for human consumption in the food chain was done to protect the public from the spread of BSE disease [1,2]. Although the re-occurrence of the reported outbreak or spread of the BSE disease declined in a remarkable manner after the exclusion of offal from the human diet and animal feed [1]. Consequently, purchase of offal meat decreased in regions that were affected because of the undesirable brand image of the by-product and was strongly constrained into pet food products [3].

Presently, offal meat is now seen as an excellent source of protein for several people across the continents and are now considered as delicacies used as basic traditional dishes. This is due to its potential to combat protein malnutrition and food insecurity in many countries [4]. In this regard, offal meat has been re-incorporated as constituents of traditional diets in many countries. At times, offal meat may be utilized on regular basis in a low-cost approach, as in pastries (for example, steak pie, pepper steak pie, and steak and kidney pie), to get high-quality protein and nutrition. In South Africa, carcass meat may be preferred but abattoir managers would have preferred that an animal produce twice or more offal than what they get presently. This is due to the increase in demand for offal meat consumption and the inability to keep up with such demand. Presently, meat and offal meat are a vital piece in the human diet as a result of the nutritional benefits obtained from these products [5]. The nutritional benefits enjoyed by society cannot be over emphasized. However, meat and offal meat has proven to be an excellent source of protein, fats, vitamins, and minerals that resourcefully enhance outstanding performance in human body systems [6].

Grunert et al. [7] in their study reported that consumers' perception of various products are influenced by attitudes and belief. Beliefs play a key role in the acceptance or rejection of a product because it could change the perception and image of that product [8]. Therefore, perception is defined as the method where consumers select, organize, and interpret information for immediate decision making [9]. Consumers usually form their feelings about the expected quality for meat while at the point of purchase [10]. "The decision to buy and eat meat is a direct outcome of how meat is perceived by the consumer" [11]. This is directly related to quality cue, which could be better explained as informational stimuli accessible by the consumer prior to purchase [12,13]. Quality cues are prerequisite required for consumers to evaluate displayed products and make a final decision at the point of purchase [14]. On the other hand, "perceived cues" are expected or experienced attributes of the offal meat that forms consumers approach towards the product. Previous experience plays a pivotal role in consumers' judgments about expected quality as some cues may be perceived as being more relevant than others [15,16]. However, past research revealed that consumers may differ in their dependence on both intrinsic and extrinsic cues as well as in their capability to correctly measure product cues accurately [17–19]. For this reason, it is important to understand the respective influence of quality cues in consumers' perception of offal quality appraisal to enhance attributes most likely to influence consumers' opinions. It is well known that offal tends to have an undesirable brand image before now and this may affect the emotions and consumers behavior [8]. This negative approach toward offal meat production and consumption could be weakly exhibited in the behavior and perception of the consumers. Typically, the attitudes and belief of the consumer on offal may depend on the acceptance of the product and their features [7]. Presently, offal products are now relevant in our meals and diets regardless of the earlier global negative outlooks towards them [8]. This is because consumers have passed the stage of vague ideas in which some confidence is placed on offal as an odd animal product.

Normally, consumers' perception on carcass meat quality is directly related to the visual appearance (color, fat content, marbling, and drip loss) and their preferred point of purchase [20]. The visual appearance of meat related products has a close interaction with the meat color, therefore indicates a systemic relationship. In addition, meat color is associated with the diverse forms of the sarcoplasmic protein myoglobin [21] and it is also considered as the key fresh meat features that consumers look for before purchase [22]. In beef, for instance, dark colored meat could face acceptability problem when customers are actually looking for a bright red meat at the point of purchase [10,23]. The freshness of meat is therefore related to the bright color of carcass meat for predicting meat quality. Consumers normally believe that freshness of meat in a sanitized purchase outlet provides assurance for safer meat [24]. However, some of the consumers in South Africa are too casual about meat safety, hence the purchase of meat and offal from street vendors which may be susceptible to health concerns [25].

Acceptability of meat and offal meat may be influenced by tradition, norms, and custom of a particular society. For this reason, assessment of quality cues could take place within the thoughts of consumer and altered by individual preference, thus judgments on meat quality vary from persons through societies and cultures [16]. As a result of this, preferences have been observed to vary within the same region and outside different regions [26]. Therefore, Steenkamp [15] concluded that whenever a quality assessment is carried out by any consumer, it is done and established on their past accumulated knowledge and information about the product.

Several studies on consumers' perception of fresh meat quality, the perception of consumers on the quality of mutton, factors associated with perceived beef quality, consumer perception and the role in the meat industry have been published [6,27–30] but those studies did not consider offal meat.

However, to the best of our knowledge, limited studies have focused on consumers' perception of offal meat consumption. In South Africa, however, there are insufficient data on consumer preference for offal meat consumption and the effects in the offal supply chain. It is therefore important to understand the factors influencing consumer actions when purchasing offal meat and their preferred outlet for such a purchase. This study, therefore, sought to identify factors that were more important to the consumer in offal consumption and purchase in Amathole District of South Africa.

2. Materials and Methods

2.1. Study Site

The Amathole District Municipality is the third largest of the seven Districts in the Eastern Cape Province in terms of population after O.R Tambo and Nelson Mandela bay Metropolitan areas in South Africa. It has a population of about 898,000 people, of which 53.03% and 46.97% are females and males, respectively. Majority of the population (99.66%) are black. About 31% (281,000) of the population is over 40 years. The District is situated in the central part of the Eastern Cape Province [31]. It spans along the Sunshine Coast from the Fish River Mouth and alongside the Eastern Seaboard along the Wild Coast. It is bordered to the north by the Amathole Mountain Range. Amathole District Municipality is comprised of six local municipalities: Mbhashe, Mnquma, Great Kei, Amahlathi, Ngqushwa, and Raymond Mhlaba. The study was conducted in three different municipalities in the Amathole District of Eastern Cape Province of South Africa using random sampling. The selected municipalities were Mbhashe Municipality (Butterworth and Kentani), Raymond Mhlaba Municipality (Alice and Fort Beaufort) and Ngqushwa Municipality (Peddie and Hamburg).

2.2. Selection of Respondents

A total of 202 consumers from Amathole Districts in Eastern Cape Province from three randomly selected municipalities (Mbhashe, Raymond Mhlaba, and Ngqushwa municipalities) were sampled from a total of six towns in the municipalities. Consumers were randomly selected by selecting members of the community who could have basic knowledge and give better information about offal consumption. The participants were interviewed in their shops, schools, butcheries, parks, garages and those that were close to the shopping areas. The key quality indicators such as the color of offal, packaging, fatness, freshness, visual display, and consumption pattern (flavor, tenderness, and juiciness) which point toward the acceptability and preferred offal meat were included in the interview.

2.3. Data Collection

For the purpose of this study, a structured questionnaire was prepared, pre-tested and used to interview the consumers. Part of the questionnaire was translated into the vernacular (Xhosa) language for simplicity of administration to those who do not understand key terms in the questionnaire and where the use of English language was poor. The respondents were asked to complete a self-administered questionnaire while interpretation was done for some of the respondents. Patterns from similar recent studies on individual contributing factor on offal meat preference based on their demographic characteristics [32,33] were used. Demographic information such as educational status, gender, monthly income, age, and family size was included (Table 1). The consumers also answered questions pertaining to offal meat demanded in the last three months, preferred offal meat and preferred purchase-point (butcher, supermarket, and others), in line with Verbeke et al. [34]. With respect to approach, consumers were asked to indicate which factors influence their demand for offal meat, precisely for purpose of nutritional value, health reasons, cheapness (price) and availability [7]. The questionnaire further included eleven attributes on a five-point Likert scale to determine consumers' knowledge on the offal meat quality attributes by visual assessment (color of offal, packaging, fatness, freshness, and visual display) and consumption pattern (flavor, tenderness, and juiciness) but were all measured on a descriptive scale. Each volunteered respondent who participated in the interview was requested to sign a written consent letter.

Table 1. Demographic characteristic of consumers interviewed in Amathole District.

	Variable	Percentage	Frequency
Gender			
	Female	53.5	108
	Male	46.5	94
Household size			
	0–5	75.8	153
	6–10	23.2	47
	>10	1	2
Age			
	15–24	11.4	23
	25–34	29.7	60
	35–44	27.2	55
	45–54	13.4	27
	55–64	11.9	24
	65–74	5.9	12
	75–84	0.5	1
Monthly Income			
	<R500	14.4	29
	R501–R2000	56.4	114
	R2001–R4000	12.9	26
	R4001–R6000	6.9	14
	R6001–R8000	2	4
	R8001–R10,000	2	4
	>R10,000	5.4	11
Educational Status			
	Grade 1–7	4.5	9
	Grade 8–12	22.3	45
	Matric	46	93
	Tertiary	27.2	55

2.4. Statistical Analyses

Data generated were entered in Microsoft Excel and were summarized as frequencies of respondent profiles on consumers' perception. Descriptive statistics was used to determine associations between age, income, educational status, and other factors influencing offal consumption using SPSS version 20 (SPSS 20, IBM, Armonk, NY, USA) for the analysis. Chi-square statistics were used to test the association between variables at a 95% confidence interval. $p < 0.05$ was considered as statistically significant.

3. Results and Discussion

3.1. Consumer Demography and Attributes

In Table 1, the total number of 202 respondents who were interviewed, the majority of the respondents were females (53.3%) while males represented 46.5% of the research sample. Furthermore, it was observed that most of the respondents had formal education. However, the findings showed that 4.5% of the respondents had the lowest form of education and had stopped at elementary grade. Meanwhile, 46% had gone through matriculation and 27.2% possessed at least an undergraduate degree (Table 1). The majority of the respondents were either working within the governmental departments, private sector or owned their personal business earning from R500 to more than R10,000 on monthly basis. In Table 1, the most prevailing earned income among the respondents was R501–R2000 (56.4%) while the least represented incomes were R8001–R10000 (2%) and R6001–R8000 (2%), respectively.

Correlation analysis was performed to establish the relationships between offal meat attributes and demography. The result showed that there was a significant relationship at *p*-value 0.026, *p*-value 0.012, *p*-value 0.020 and *p*-value 0.031 but a positive correlation between gender and color, packaging, tenderness and juiciness of the offal meat products (Table 2). This means that the color, packaging, tenderness, and juiciness of the offal meat products tend to vary from male to female at the point of purchase.

The estimated relationship between the education of the respondents and their perception about the smell of the offal was significant at *p*-value 0.025 but was weakly correlated. On the other hand, the level of education was significant at *p*-value 0.018 with a positive correlation with the visual display at the point of purchase. This shows that, as the level of education increases, consumers attach more credence to the visual display of the offal and this influences decision at purchase-points. Demography has been used to a great extent for interpreting consumers' purchasing behavior. However, Romano and Stefani [35] revealed that there is a narrow line between demographic variables and purchase decision. This is in agreement with the results obtained from this study where variables such as age, monthly income, family size, and gender were observed to be weak factors influencing consumers' purchase decision.

3.2. Attributes and Consumers' Choice of Purchase-Point

The findings from this study revealed that most of the respondents preferred sheep offal (83%) as compared to cattle offal (33%), although the percentage of those who preferred sheep and cattle offal (86%) was the highest (Table 3). This result was in agreement with Walsh [36] who described that sheep offal is in more demand than cattle offal. Furthermore, the findings are similar to the recent study conducted in Ghana by Ayroe et al. [37] who reported a higher preference for both cattle and goat offal.

With respect to purchasing decisions, the interview focused on the preferred place of purchase, preferred offal, and offal meat products consumed in the last three months. When consumers were asked what type of offal meat products they like to eat and from which type of animal, it was observed that consumers were selective in the type of offal they consume, for example, liver (94.1%), tripe (78.2%) and intestine (68.8%) were the most demanded products and consumed in the last three months (Figure 1). This showed that the percentage of consumers who eat certain types of offal products differ from one another. The preference shown in this study concur with Nonterah et al. [38] who reported that the most preferred offals are liver and stomach at the point of purchase. This same trend for the demand of liver, tripe, and intestine was seen among the respondents that prefer sheep offal (37.6%, 32% and 31.2%, respectively) and cattle offal (15.3%, 12.5% and 8.9%, respectively).

In general, it could be deduced that consumers explored all the retail outlets (butchery, supermarkets, and other retail outlets) for the purchase of offal meat. However, the majority of respondents preferred to buy offal meat from butchery (Figure 2). A greater percentage of respondents who purchased liver (64.4%), heart (42.6%), tongue (40.1%), kidney (37.6%) tripe (59.4%), spleen (34.7%), intestine (59.4%), and lungs (37.6) did so in butcheries as compared to other outlets. This concurs with the recent study by Ayroe et al. [37] who reported that consumers purchased their favorite offal products mostly from the butcher shops.

Furthermore, the respondents were asked why they chose the butchery in preference to other selling or retail outlets. The respondents replied that the offal meat sold at butchery was fresher and cheaper. In addition, the respondents alluded to the fact that they preferred the butchery because the other types of offal meat were not readily accessible in other outlets as compared to the butchery. Moreover, it emerged that purchase of offal meat at the butchery also gave the consumers the opportunity to buy a combination of different offals as a single item otherwise called "combo" as compared to the supermarkets where the chances of purchasing in bulk are limited. Nevertheless, there were a few respondents who chose to buy fresh offal products occasionally from supermarkets and street traders.

Table 2. The correlation coefficients between demographic and perception on eleven offal meat quality.

Demography	Color	Leanness	Presence of Fat	Smell	Freshness	Flavor	Packaging	Price	Tenderness	Juiciness	Visual Display
Age	0.227	0.292	−0.660	0.310	−0.231	−0.899	−0.029 *	0.702	−0.867	−0.952	0.889
Gender	0.026 *	0.668	0.474	−0.392	−0.820	0.750	0.012 *	0.248	0.020 *	0.031 *	−0.149
Education	0.876	−0.175	0.102	−0.03 *	−0.982	−0.460	0.174	0.414	0.573	0.061	0.018 *
Income	0.088	−0.145	0.523	−0.187	−0.904	−0.816	0.774	0.228	−0.107	0.145	0.084
H/Size	−0.397	0.865	0.029 *	0.234	−0.173	−0.933	−0.242	−0.87	−0.459	0.860	0.291

* Correlation coefficients is significant at the p-value < 0.05.

Table 3. Distribution of specific preferred offal type as indicated by consumers.

Offal Type	Percentage	Frequency
Sheep	41.1	83
Cattle	16.3	33
Sheep and Cattle	42.6	86

The interviews were similarly focused on visual and quality assessment of offal meat (color, packaging, visual display, fat inclusion, freshness, and price). Assessment of visual appearance was derived from previous work by De Andrade [39] and measured on descriptive scales using a five-point Likert scale (disagree to strongly agree). The variables which best described the quality of offal meat with respect to their importance in the consumers' decision to purchase offal are shown in Figure 3. The results showed that respondents who purchased fresh offal products from retail outlets cited freshness as the major factor which assisted them to distinguish the quality of the meat offered in any retail outlets. Consumers' perception on the freshness of offal is, therefore, very important at any selling point. These results commensurate with Verbeke et al. [33] who reported that freshness is the most effective factor that influences consumers' decision to purchase fresh meat. Jabbar [40] also concluded in his study that freshness and price among other quality attributes play a vital role for consumers to make their decision at the point of purchase.

The price of offal was also observed and presented by consumers as one of the major attributes of quality for offal meat when compared to other types of meat, which are more expensive. Most of the respondents felt the price was a strong factor which contributed to whether to eat or purchase offals. Some respondents acknowledged that offal products sold at the butcher shop were relatively cheaper and the quantity was high as compared to the supermarkets. The findings also indicated that the more the consumers ate any offal meat products the higher the demand for the products in the last three months. A likely reason could be as a result of the price of offal, which was found to be considerably cheaper at the butchery than supermarkets. This is in agreement with the law of demand which states that the quantity of goods leads to a rise in demand as the price falls, and vice versa. Offal meat products still account for an insignificant part of meat markets and their demand is still far behind the production potential of resources available [41].

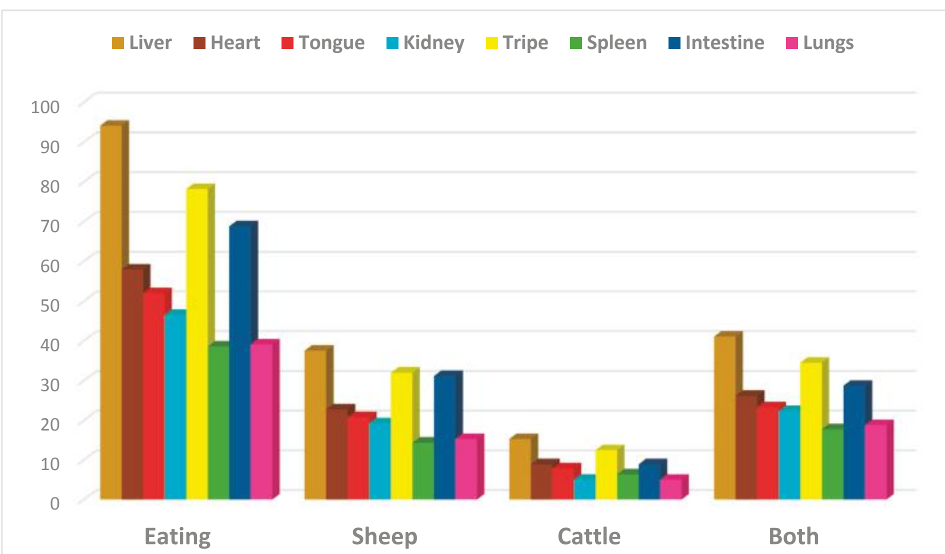

Figure 1. Distribution percentage of offal meat demanded and preferred offal type.

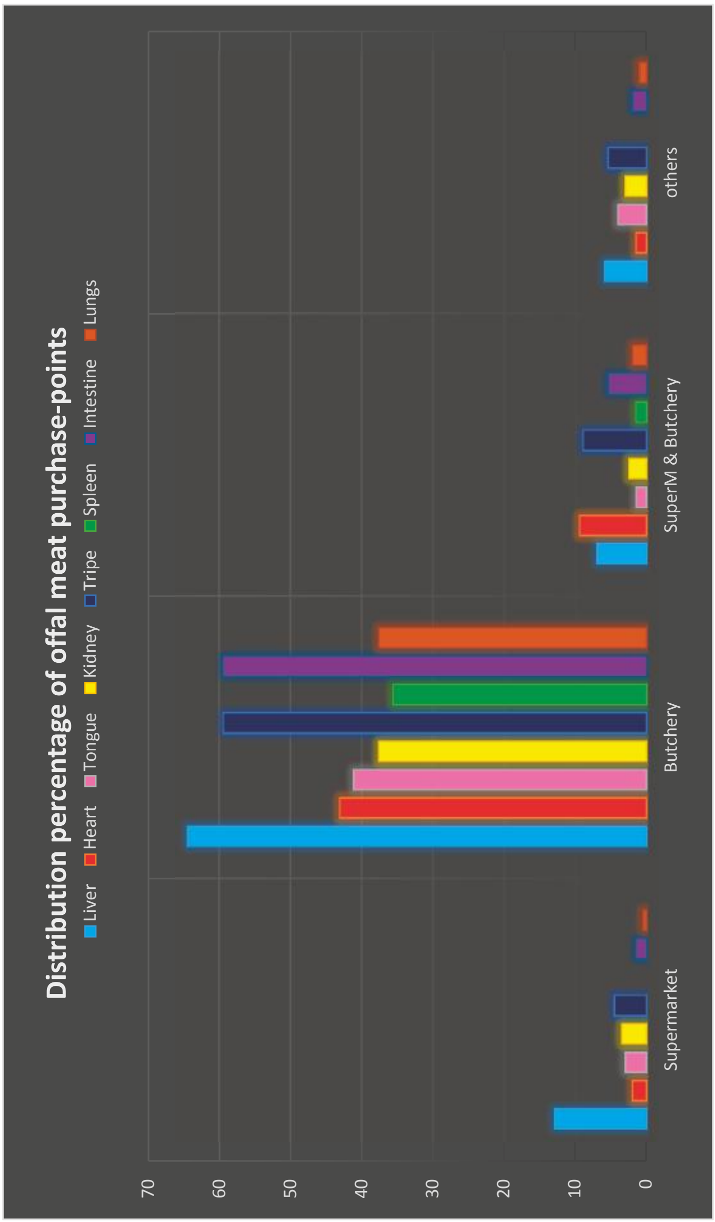

Figure 2. Distribution percentage of offal meat purchase-points.

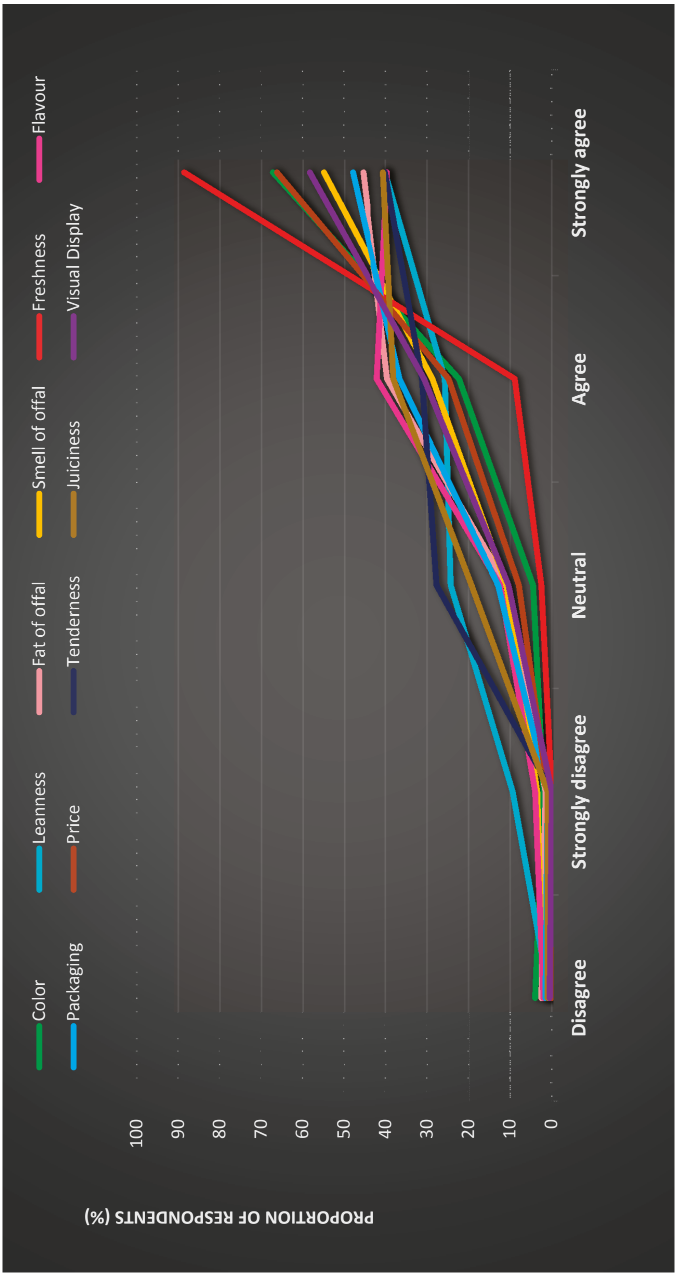

Figure 3. Ranking of offal meat attributes influencing consumers' purchase.

It was further observed that the highest point of preference when offal meat is to be purchased is the price of offals, i.e., whether they are cheap or not. This implies that the price, availability and nutritional value of the product in a regular succession are critical (Figure 4). These three factors form the major factors influencing offal demand. The price of liver (43.6%), heart (30.7%), tripe (43.1%), spleen (18.8%), intestine (40.6%); and availability of liver (41.1%), heart (28.7%), tongue (20.8%), kidney (22.3%). tripe (39.1%), spleen (15.3%), intestine (39.1%), and lungs (22.85) emerged as being very important for the demand of offals. The consumers also revealed that they have nutritional knowledge of the offal meat products before making their purchase. Meanwhile, health reasons emerged as the least factor that the consumers considered at the point of purchase (Figure 4). This, however, contradicts the observation of Jabbar [40] that price is the least important quality factor relative to the income of the consumer. In as much as Jabbar's [40] observation may be true for purchases of beef, it does not apply to offal meat.

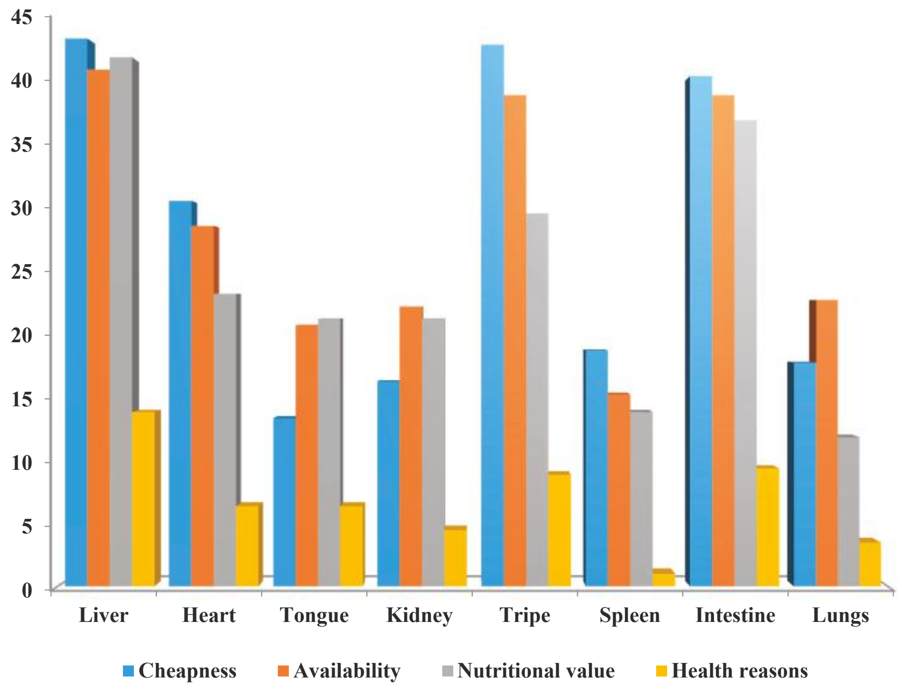

Figure 4. Factors influencing the demand for offal meat.

4. Conclusions

From the respondents who participated in this survey, it was revealed that consumers had a higher preference for offal meat products from the butchery because it was cheaper, readily available and fresher. Most of the consumers strongly agreed that the meat quality attributes influenced their decision during the purchase of offal meat. However, variables such as the color, price, freshness, visual display and packaging of the offal were ranked as the most influential in making choice to purchase in comparison to other factors such tenderness and fat content. The point of purchase, however, remains a prominent factor among other factors that could influence decision making for any consumer. When it comes to offal meat, the results showed that the majority of consumers purchased more liver, intestine, and tripe because they are often sold in a combo at the butchery. However, some consumers may expect distinct or special quality attributes based on their individual experience. It is also known that consumers' mental attitude and insight about acceptable quality attributes could be attached to their socioeconomic status and personal preference.

In addition, the findings of the study inferred that nearly all types of offal meat are consumed in Amathole district, especially liver, kidney, tripe, intestines, heart, and tongue, while kidney and spleen were mentioned by some respondents to be mostly consumed by men. The foremost factors influencing offal consumption comprised of availability of offal meat, price, freshness, nutritional value, and health reasons. These offal meat products are nutritionally appropriate for different age groups, especially children and women. The perception of consumers on offal meat consumption is similar to the indicators and factors that are considered when the consumer is about to purchase red meat, which suggests the results are important for developing effective growth strategies to promote the offal meat market in the municipality. In addition, this means that municipalities need to re-orientate and enlighten people about the nutritional benefits, as well as food safety and health implications of offal consumption.

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Sustainable Tourism: A Hidden Theory of the Cinematic Image? A Theoretical and Visual Analysis of the Way of St. James

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Abstract: The attractiveness of a tourist destination is derived from multiple material and immaterial elements. Cinema is both a tourist communication channel and provides a target market for a destination. Many regions offer a great variety of potential locations desirable for their scenic beauty and artistic and monumental heritage. The main aim of this paper is to analyze the concept of sustainable tourism as a pillar of the contemporary cinematic discourse on pilgrimage routes, combining theoretical and empirical methodologies. It begins by analyzing how, given their power, images are narrative instruments that assume a true performative value of geographical reality. The research then focuses on the cinematographic space and visual cinematographic discourse. The case study is sustainable tourism along the Way of St. James (Spain). The material is a corpus of two documentary films. Their moviescapes highlight the presence of a sustainable filmic theorem within a potential cinematic genre—pilgrimage movies. Thus, this study contributes to the investigation of how sustainable pilgrimage tourism practices are used in cinematic production as a possible movie theorem. It presents a conclusive critical evaluation of the role and message of these moviescapes.

Keywords: pilgrimage and religion tourism; sustainable pilgrimage tourism; moviescapes; the Way of St. James

1. Introduction

The impact of visual media on the public is undeniable. Film and television productions place the spotlight on stories, artists, places, lifestyles, customs, and practices, both real and active. In doing so, they are able to seduce millions of spectators. This seduction can then engender the acquisition and the consumption of goods associated with a much-loved production: think about the phenomenon of the products associated with blockbusting series, such as the toys and clothing of *Star Wars* and *The Lord of the Rings*. Film and television productions are also tools for promoting natural and cultural environments. The viewer is able to reject these elements or, on the contrary, dream about them and eventually endorse them [1].

The intention of the present paper is to examine beyond some of these introductory and consolidated issues in order to propose new research approaches that create a dialogue between tourism sustainability and the film industry. This work is situated within the realm of tourism studies that have placed their academic and scientific interest on the Way of St. James. The Way of St. James is a medieval pilgrimage route and was declared the First European Cultural Route in 1987. Subsequently, the French Way was declared a World Heritage Site by UNESCO (United Nations Educational, Scientific and Cultural Organization) in 1993. These recognitions have assigned the pilgrimage the role of a star tourist product in the Autonomous Community of Galicia, an achievement that was reached due to the construction and restoration of hospitality facilities for pilgrims [2,3]. Today, the French Way is a reference for pilgrimage tourism; its inclusiveness of pilgrims with different profiles has transformed it into a popular destination that can have negative impacts for the territory. However, the pilgrim, unlike the tourist, acts more respectfully and sustainably toward the environment, and this is what will be visualized through the primary sources analyzed.

From a historical perspective, pilgrimage tourism has shared traits with sustainable tourism. Both are respectful of the natural, urban, and monumental environment, and interpret the tourism tendencies of the 21st century as well as the behavioral guidelines of the mobile person. According to Saarinen [4], the idea of sustainable tourism includes the concepts of responsible tourism formulated by Goodwin [5], as both refer "to tourism development principles and practices aiming to make places better for people to live and visit". Both forms of tourism "intend to minimize the negative and maximize the positive social, economic, and environmental impacts of tourism in destination communities and environments, by promoting ethical consumption and production among all stakeholders" [4] (p. 2).

The present study is inspired by the new approach demanding reflection on the relationship between pilgrimage and religious tourism in sustainable terms. This relationship can be expressed in various ways; this study turns its attention of one of the most commonly used visual media (the cinema) as a tool of communication and sensitivity toward these behavioral precepts. The filmic language has always been able to narrate the permanence of time and history. These attributes emerge in a pilgrimage route that wants to provide a sustainable model, even after more than 12 centuries of existence [6]. Heritage and recreated landscapes are sustainable, too. The return to slow movement, calm conversations with other pilgrims, and itineraries understood as a walk evoke the refusal to grow and condemn the useless consumption of energy. In other words, this model minimizes the ecological footprint. Finally, anything the pilgrim consumes (whether true or false) is considered local, natural and healthy. The gastronomy of the Way of St. James is seen as the result of an ancestral culture, derived from peasants, and associated somehow with the myth of traditional agrarian sustainability.

Until now, cinematic research and pilgrimage tourism has been neglected. For instance, few studies have explored the relationship between the Way of St. James and cinema. Previous studies, such as those by Lopez et al. [7], Rodríguez Campo and Fraiz Brea [8], Escudero Gómez [9] and Smith [10] have addressed this relationship by considering cinema as a touristic resource that is able to project a local image onto an international scale. They considered cinematographic production a space of (re)production of historical and local identity. This general research line contributes to media and marketing studies as it highlights the increasing promotional function of cinema. Because of this, the present article departs from a reflection on functions of the moving image, to demonstrate our working hypothesis: the presence of a filmic theorem relating to sustainability along the Way of St. James. This is translated and projected through the many documentaries available online. We consider that the paradigm of sustainability inspires and directs cinematographic productions and determines the behavior of tourists, who in some cases are the spectators themselves. Another factor that differs with respect to previous studies is the sources. Amongst the different cinematic genres, we choose to qualitatively analyze two documentaries, as they represent the closest proximity to reality. If road movies are thematically dominated by movement [11], pilgrimage movies can become a filmic genre promoting sustainable tourism. By means of cinematographic creative tools, movie pilgrimage movement is characterized by sustainable features (slow mobility, local economic activities, and contact with local community) that the selected moviescapes highlight. Thus, this study contributes to the understanding about how sustainable pilgrimage tourism features are used in the cinematic production as a possible movie theorem.

This article is divided into four sections. The first provides a literature review divided into two sections. In it, we analyze the characteristics and advantages of considering film as a cultural product and medium for territorial studies [12,13]. For this reason, the main concern of film analysis is to prove the authenticity of the representation of the place in which the film is set. Despite the fact that the content of the film industry is now the subject of interdisciplinary studies, this analysis focuses on the tourism industry, which in recent years has turned its attention on the influence of the moving image when undertaking a journey [14–16]. In the second part, we justify the reasons why film provides useful data for geographical interpretation and becomes an important document for information for the discipline [17]. In this section, we explain the qualitative methodology used. In the results and discussion sections, we support an interpretive and comparative interpretation of the filmic theorem according to moviescapes and a literature review on the Way of St. James. In the conclusion, we review the contributions of cinematographic production to the promotion of sustainable tourism and highlight the need for studying documentaries and filmic images.

2. Literature Review

2.1. Moviescapes

Seeing and travelling are evocative and inseparable elements for any film lover, demonstrated by the transformation that often occurs from the *voyeur* into the *voyageur*. The English language renders the movement between the gaze and the place, sight and site, a fluid whole that allows us to perceive the importance of the spectator who becomes the *voyageur* and a tourist of the places that have been emotionally moving and made an impression. According to Escher, a cinematic landscape or landscape in movies may be interpreted as the representation of material, real-world, and subjectively organized scenery on the earth's surface, which is loaded with cultural additions, or a fictitious environment in the day-to-day dimension. Similar to the themes and subjects used in painting, literature, photography, and even movies, this works because there is no landscape that has been seen for the first time [18] (p. 309) (cf. [19]).

The audience perceives a landscape it has seen before, and thus it is a purposefully created product, so they process this as a substitute in its own subjective sense of perception. It is not a question of whether the landscape presented actually reflects how the audience sees the physical world, but rather of whether the recipient trusts the representation and the manner in which certain landscape elements are selectively perceived. These imaginary landscapes contribute to the success of the movie through various positions and mechanisms of action. The varied representation and narrative function of landscape in movies is thus visualized in the area of tension between setting and emotion [20,21].

The landscape can be verbally, visually, and graphically described, but it can also be narrated. In that case, they are relational spaces in which the places, subjects, and events do not exist in a void but are intersected in social time and space, collaborating in the construction of an image. The landscape is one of the elements that lead the filmmaker to select a place in which to set their narratives. To experience the landscape and, in particular, an urban landscape, is thus equivalent to its cinematographic representation. In *Paris, Capital of the Nineteenth Century*, Walter Benjamin [22] invents the contemporary urban landscape as a place explored by the *flâneur*, a place that is traversable but elusive, a mirror of the social phenomena of the time. Also, from its inception with panoramic films, cinema has been a genre of media composed of scenographic sights that transform the journey from one place to another, then into a diffuse practice. The dawn of cinema invented the panoramic view, which included site-seeing journeys and the spatial-visual desire to circulate and move, which characterized the new modern times. Filmic representation was no longer static, as it is not only the protagonists that move in the landscape; rather, it is the representation technique itself that inspires movement (see, for example, a film such as *Panorama from Times Building, New York* of 1905). As for site-seeing, film creates its own architectural landscape that engages the gaze in its relationship to movement. When film produces travel stories, it creates a space for seeing and scrutinizing. Behaving as a traveler, the itinerant spectator reads the panoramas in movement as exercises of imagination. Between geography and visual narration, it is possible to grasp two-dimensional relationships based on the conviction that spatial analysis can obtain assistance from indirect sources, capable of offering a new dimension of reality to geographic knowledge, based on lived and interpretable space [23–26]. It is an analysis of those individual geographies that shape human territoriality. According to Butler [27], people often choose their tourist destination depending on what they have seen via popular audiovisual means, like television and cinema. The influence of these images can be voluntary, involuntary, accidental, conscious, or unconscious. He also suggests that because people now read less frequently, anything appearing in films and television penetrates society more easily.

Specific weight is given to the role of autonomous factors like "the news" and "popular culture". In contrast to elitist or fringe culture, which influences a small percentage of the population, popular culture strengthens and reflects models of communication and consumption for the wider general public. Films are an important fragment of popular culture. They can transmit essential information about a destination in a short time and to many people. Regarding the role of popular culture in shaping a "destination image" within the framework of tourism, Urry (2002) claims that one of the basic motivations for tourists to visit a location is the expectation that these people may have different experiences to those they would have in their home location [23].

Today, however, it is territories that "exploit" cinema, using it as an instrument for promoting tourism (Figure 1). It is not easy to answer the question of why films and fictions induce tourism, by transforming a location into a tourist destination. For a long time, it was thought that it was because in some films or fiction you can see images that entice the viewer to go and visit the locations admired during the viewing. In reality, the phenomenon is more complex and also has to do with the themes of the film, the sequences and the relationships between the characters: in short, it is the magic of the film as a whole that makes the set palatable. But this happens when the film in all its elements works because it is a "soft sale" of the territory, able to appeal not only to rational elements, but also and above all to emotional ones [24,25,28,29].

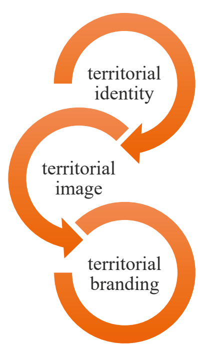

Figure 1. The role of cinema in the construction of the tourist space. Own elaboration.

2.2. Film-Induced Tourism

Pioneering studies on the subject of film-induced tourism have been completed by Cohen [26] and Butler [27], and later by Riley et al. [14]. Investigations in the field have proceeded slowly, with Beeton, a scholar at the University of La Trobe (Melbourne, Australia), providing significant contribution with her work *Film-Induced Tourism* [25]. Notably, both Butler [27] and Beeton [28] revealed traces of the origins of the phenomenon in travel diaries and postcards from the time of the Grand Tour, and the descriptions, images, and photographs of places made popular by novelists during the Romantic period. Travel and cinema, like travel and literature, are activities that allow people to escape from their daily routine, allowing them to delve into new realities and contexts and thus broaden their knowledge and horizons.

Tooke and Baker [15] raised the concern that the film location will not often have the carrying capacity to cope with large increases in visitors. This could result in a number of potential undesirable consequences, such as increased vehicle traffic, pedestrian congestion, and loss of privacy and local facilities for locals. The destruction of the natural environment is also a concern. For example, filming of *The Beach* and the subsequent film tourism resulted in extensive environmental damage to Phi Phi Lae Island in Southern Thailand. Another problem that occurs is when the location appears different to how it is portrayed in the film, resulting in a decrease in visitor satisfaction [30]. Whereas Karpovich [31] is one of several researchers to state that film tourism, teletourism, and movie tourism are the same concept, Torchin [32] distinguished between movie- and television-induced tourism, asserting that television has a longer, more levelled impact on featured localities because it has lasting appeal, drawing visitors for many years [33]. Previous studies have shown that television programs actively increase visitor numbers to certain destinations [16,34–40] or cause increased interest in these places [41]. Quite possibly, viewing localities through visual media is even a destination experience itself, offering the opportunity to gather additional information [14,40].

In terms of the importance of this sector of tourism, research by O'Connor et al. [37] suggested that a fifth of inbound U.K. tourists visit to explore film locations. This figure is expected to grow over the coming years due to the increasing amounts of time people are dedicating to watching television, greater interest in film, and continuous technological developments [42–46]. Tooke and Baker [15] studied four television dramas and documented their subsequent effects upon numbers of visitors to featured locations. In each case, visitor numbers increased dramatically. There are many different forms of film-induced tourism and Table 1 provides a comprehensive overview, along with their common characteristics and various examples in relation to published academic literature:

Table 1. Forms and characteristics of film-induced tourism [25,34,35,43–46].

Type/Form	Characteristics	Examples
Film location as an attraction in its own right	Location is the primary travel motivator and an attraction in its own right	*Captain Corelli's Mandolin* (Kefalonia); *The Full Monty* (Sheffield); *Troy* (Çanakkale)
Film tourism as part of a holiday	Tourists and visitors visiting film locations; e.g., booking studio tours as secondary activities within a larger holiday	On-location *Gavin & Stacey* tours (Barry Island); *Il Postino* (Salina Island)
Film tourism occurring due to special interest	Such special interests include booking holidays to destinations as a direct result of their TV profiles, visiting celebrity homes, film locations with celebrity status, and locations representative of another historic period	*The Andy Griffith Show* (1950s); *Heartbeat* (1960s); *The Passion of the Christ* (2004)
Film tourism icons for tourists to gaze upon as a focal point for their visit	Natural scenery, historical background, storyline theme, actors, movie premieres, film festivals, symbolic content, and human relationships all serve as movie tourism icons	Cannes Film Festival; *Lord of the Rings: Return of the King* premiere
Film tourism to places where filming is only believed to have taken place	Tourists and visitors travel to places represented even if the film shows a different actual setting	*Chicago*, Chicago (filmed in Toronto); *Braveheart*, Scotland (filmed in Ireland); *Romeo + Juliet*, Italy (filmed in California and Mexico)
Film tourism as a part of the romantic gaze	Tourists like to gaze upon TV and film locations in solitude and privacy, establishing an inner relationship	*Blue Juice* (1995), North Cornwall; *Notting Hill* (1999), London
Film tourism for pilgrimage	Nostalgic film tourism can take the form of visiting locations that represent another time. Film tourism pilgrimage involves visiting film sites to pay homage to the film	*Steel Magnolias*, Doune Castle, (*Monty Python*); *The Lord of the Rings* sites; *Pride and Prejudice*, Lyme Park in Cheshire, U.K.

Film-induced tourism is defined by the Scottish Tourism Board as, "the business of attracting visitors through the portrayal of a place or a place's storylines in film, video, and television" [47]. Beeton, like Buchman et al. [48] (p. 233), defined it as, "visits to sites where movies and TV programs are filmed as well as to tour production studios, including movie-related theme parks [. . .] what is of interest is the tourist activity associated with the film industry" [25] (p. 9). Hudson and Ritchie [49] suggested that film tourism is the tourism that is generated as a result of the appearance of a destination or attraction in film, video, or television. In their analysis of this phenomenon, they identified four general fields of analysis: the estimation of the distinct influence of the film on travel decisions, the formation of specific categories of film tourists, the measurement of the effects of films on the number of incoming tourists and on the lives of residents, and the analysis of destination marketing activities connected to film tourism.

Another term used particularly in the British media is set-jetters [50]—tourists who choose to travel to a specific place with the purpose of visiting the surroundings, the areas, and the locations used for one or more films. It is therefore a segment of tourism demand particularly characterized and determined by the influence of an image on the small and big screens, a market that benefits from travelling to places where film stars have performed or stayed, and is influenced by what Anglo-Saxons define as celebrity culture [51].

3. Materials and Methods

Particularly due to the power of the images it is capable of producing and emotions it evokes, film can assume a true performative value in relation to its geographic reality [29,43]. This is because, once internalized by the local community, it is reproduced in individual and collective behaviors, providing identity references that guide and characterize the process of territorialization. Setting, location and decor represent some of the essential components in the production of a film, a story, a TV series or a documentary. A film or series feed off the genius of the directors and the charm of the actors, but also from the real or reproduced locations in which the films are shot; in fact, for many television and film productions, the sets themselves become protagonists [46]. Shooting across different regions, creating and projecting content with territorial identity value can be strategies of patrimonial tutelage [52]. The cinematographic space possesses a spatial system that can be compared to a representational space [53] because it employs the physical space and its objects, it is experienced and represented through images and symbols and is a space that the industry appropriates for its own purposes. The language of film encompasses all narrative modalities: verbal, non-verbal, audio and visual [54]. The expression "cinematic discourse" encompasses all modalities of cinematographic representation, meaning and communication [55] and is based on two planes: diegetic (history of the film, narratives and actors) and extra-diegetic (the film as an artistic product of professionals) [54,56].

We opted to characterise cinematographic space through visual cinematographic discourse of the diegetic plane. In 2001, Rose [57] published the volume *Visual Methodologies*, which manifested the growing contemporary importance of the visual dimension for the cultural construction of Western social life. In this tribute to visive methodologies, she highlighted the importance of images in transmitting knowledge, power, and culture. Stafford [58] defended the construction of knowledge of the world based on images rather than written text. Thus, the act of seeing has been transformed into an act of knowing [59], especially in Western cultures. As far as cinema studies are concerned, in "Everyday experience in Israeli cinema: The port and the city's margin", Peri-Bader [60] proposes a qualitative interpretation of cinematic production in order to confirm his working hypothesis. His cinematographic analysis is based on the reconstruction of urban spaces departing from the projected images. Drawing on this precedent, we propose a qualitative study of cinematic production relating to the Way of St. James, with two documentaries as our sources. For our qualitative research, we also draw upon statistical data relating to pilgrimage from the Pilgrim's Reception Office and the Way of St. James Observatory. In this latter case, only the series up to 2010 is available, as the entity ceased to exist for economic and political reasons. Furthermore, we support our working hypothesis and our interpretation of the moviescapes using Way of St. James literature.

Firstly, to explain the methodology adopted, we consider that each image follows its project, responding to a figurative work in which the production is both a theoretical proposition and a formal demonstration [61,62]. Didi-Huberman [63] introduced the idea of theory in images in relation to the iconographical program., Images are also conceptual and perceptive: they are vehicles for storing, manipulating, and communicating the information that allows one to be in contact with the physical and visual environment [64]. There is a variety of elements that compose a work and that can be treated differently, allowing different analyses [65,66]. Analysis of a film has an ontological nature in that it belongs to the order of knowledge and it moves on a double level: an empirical space determined by movements and a plane of ideas crossed by the theme [67]. Each cinematographic production has its primordial idea and a determined orientation that is reflected in its images [66]. The universe of the film is understood through the relationship between the changes in places and states of the film. The result is a visual experience with representational and sensory aspects that connect the documentary's pilgrims and their viewers.

Each visual analysis has its own methodology based on the objectives and message of the project [68], which depends on the critical understanding of the person advancing this visual reading. For this reason, to analyze the cinematographic visual language of the selected material, we mark some qualitative methodological guidelines. Our working hypothesis is the presence of the new filmic theorem of sustainability [33] in the Way of St. James documentaries. To examine this, the criteria of Deleuze are used: the need to reflect on the thinking of the film is shown, the formalities of representation are highlighted, and the theoretical figures of the documentaries are interpreted as significant elements [69]. For this reason, we assume the role of film analysts, deciding which documentaries and which images to select [65]. We set a scale of interpretative focuses that correspond to the message theorized in the documentaries. These images have a range of driving forces of filmic syntax; in using them, a certain coherence is produced in the decodified message. They are qualitative indexes used to read and interpret sustainability [68,70].

We think that these present particularities allow us to speak of an iconic recognition through which identification requires conceptual knowledge [64]. The figures selected are" theoretical figures" [63], that is, figures able to produce and interpret the thematic axis (Figure 2). We recognize the moviescapes that contain iconic signifiers [71], which, when representing specific sociocultural objects, become key factors of sustainable urban tourism. Likewise, it must be possible to recognize an equivalent of reality. As stated, the relationship with tourism sustainability is the selection criteria of these visual messages, which are presented below through a selection of cinematographic images. The framework used in sampling the images in the two documentaries included their level of representation of sustainable aspects that are detailed in the following paragraph. Images were selected according to the presence of *theoretical iconic images*. Through this process, the qualitative analysis of an audiovisual production is based on a semiotics of the images, through which a grammar and semiotics of the movement that organizes the meaning is achieved [70]. Through theoretical images, social dynamics and territorial phenomena are observed and interpreted and linked to urban tourism sustainability. Through this interpretive exercise, we highlight the potentialities of the visive language when investigating knowledge and theories hiding behind the camera. Their immediate value is an ally for the promotion and learning of customs and habits.

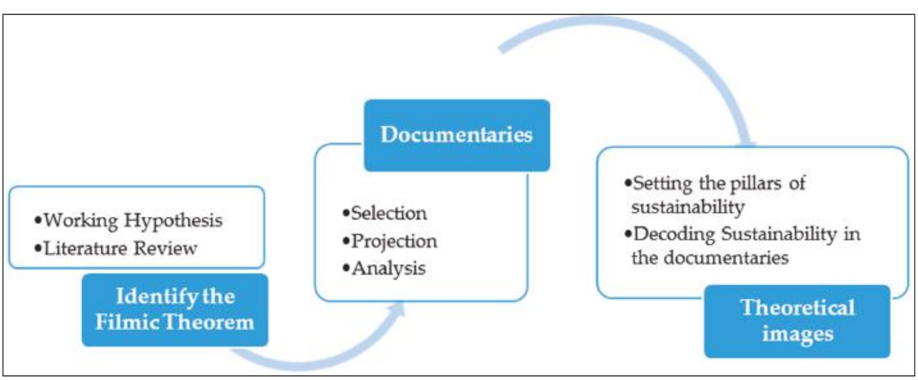

Figure 2. Methodological steps. Own elaboration drawn from [61–66,69,72].

The set of existing relationships between geography and film is based on the premise that spatial analysis can draw on indirect sources, offering geographic understanding a new vision of reality based on the experienced and interpretable space [73]. Documentaries are considered the origins of cinema and the first sequence in the history of French cinema is a documentary [74,75]. Each documentary is a unique work that presents a relationship with reality. Unlike a film, nothing needs to be invented or staged, as the information it transmits is based on reality. Those who participate in its production are closely linked to reality. They are not playing a role, and they are free in front of the camera [74]. The documentary character and accessibility of the sources are two aspects to consider if we are to measure the determination capacity of a film. A documentary implies a greater level of reality and the desire of the producer, which often coincides with the protagonist, to reproduce details and emotions to reach a level of empathy with its spectators. Accessibility is a great advantage as it contributes toward achieving the objective of democratizing the sources and information.

In Table 2, we present the documentaries referring to the Way of St. James that are available online.

Table 2. Online documentaries on the Way of St. James.

Title	Duration	Year
El Camino di Santiago no un camino de rosas	00:09:59	2006
Camino de Santiago Documentary Film—The Way	01:15:38	2010
El Camino de Santiago	00:44:00	2011
Walking the World—Cammino de Santiago 1° week	00:51:51	2013
Walking the World—Cammino de Santiago 2° week	00:51:54	2013
Walking the World—Cammino de Santiago 3° week	00:51:04	2013
Walking the World—Cammino de Santiago 4° week	00:51:10	2013
Walking the World—Cammino de Santiago 5° week	00:52:21	2013
Walking the World—Cammino de Santiago 6° week	00:51:26	2013
Uma Jornada pelo Caminho de Santiago	02:08:48	2014
Sei vie per Santiago	01:24:20	2015
Camino de Santiago 2015—La Via de la Plata	00:33:58	2015
Diario di viaggio	00:56:03	2015
In Cammino | Strada per Santiago 2016	00:54:22	2016
Santiago—Anime in Cammino	03:13:26	2016
Il Cammino di Santiago—La via francese	00:50:13	2018

Table 3 summarizes the two films analyzed, which are:

Camino de Santiago Pilgrimage—The Way Film is a documentary film produced by Mark Shea, who completes the French Way between April and May 2004 over 34 days. The documentary is the result of his pilgrimage, which he documents and shares with others. He is the presenter and acts as a guide and producer of the film. His documentary is a guide as it accompanies the journey with explanations and interviews.

Uma Jornada pelo Caminho de Santiago is a documentary film about the French Way that takes place over 35 days. The languages employed are music and visuals. It is a sequence of images representing the Way of St. James and the pilgrims. The music is the only sound in the film, and this places all the spectator's attention onto what is being seen. It is an excellent and carefully shot video about the Way, in which good, high-definition images stand out. The scenes are interesting, with movement in the light, and a full tour of the Way and places of interest in the cities along the pilgrimage. The Way is the real protagonist, with its natural landscape and heritage treasures. This technique allows the spectator to better reflect on what they are watching. Perhaps this combination of images and music reinforces the sense and desire for the journey.

Table 3. Research sources [76,77].

Title	Camino de Santiago Pilgrimage The Way Film	Uma Jornada pelo Caminho de Santiago
Genre	Documentary	Documentary
Year	2010	2014
Country	Australia	Portugal
Duration	01:15:38	2:08:48
Starting Point	Saint-Jean Pied de Port	Saint-Jean Pied de Port
Protagonists	Mark Shea	Andre Luiz
Source	http://www.overlander.tv/the-way-camino-de-santiago-film/	https://www.youtube.com/watch?v=DLsPX2K9vv0movie=tt2406422

After the collection of data about the online documentaries (Table 2), we selected two of them, as indicated in Table 3. The criteria for their selection are:

(1) Their producers come from two different countries: Portugal and Australia, a close and a distant country. This geographical distance might determine a different territorial perception and representation.
(2) The starting point of the two documentaries is Saint-Jean-Pied-de-Port. Thus, the representing territories would coincide throughout the projection. Documentaries were downloaded from the Internet and saved on a personal computer.

They were watched by using a media player reproducer, which allows stopping the projection and copying the current moviescape. We viewed the documentaries three times. The first time was meant to understand its main content and to confirm the coherence of the choice. During the second viewing, we proceeded to select those moviescapes that responded to our analytical framework aimed at showing the sustainable aspects of the pilgrimage tourism (mobility, accommodation, sociability, local heritage and gastronomy). In terms of the heritage and local offer, we propose some of their potential moviescapes that responded to well-known attractions along the Way of St. James, such as the Cathedrals of Burgos and Astorga, in order to point out the marketing power of cinematic images. In the case studies, the cinematographic narratives in movement generate a sense of meaning, as one of the pillars of analysis is precisely that the slow movement of pilgrimage gives way to significant practices that can be used to understand the features of tourism sustainability. Some of the theoretical figures are introduced in the following paragraph, through which dialectics between reality and production make the production's discourse explicit.

4. Results and Discussion

As was asserted in the introduction, our working hypothesis is to recognize and make explicit the filmic theorem of sustainability (slow mobility, pilgrims' healthy practices, and permanence of the Way), which inspires documentary productions about the Way of St. James pilgrimage. As a pioneer in terms of theoretical and thematic research into audiovisual sources about the Way, we link the results with other Way of St. James studies which, being related to more than only cinema, are situated within the context of territorial studies on pilgrimage. We highlight very general results, and others that are more specific. In general, both documentaries demonstrate an intention to highlight the value of the Way, especially the French Way, which, as is shown in Figure 3, is the most popular route amongst pilgrims and is the route that receive the most attention.

The valuation of the Way occurs on two levels: spatial and experiential. At the spatial level, the Way of St. James is the protagonist; it is the real space of the Way that coincides with the setting of the documentaries. This reinforces the sense of space and the capacity of the spectator to experience it as a visual experience. Let us look at the second aspect in which the visual experience of the Way is expressed through images in movement. It is a slow movement that facilitates the relationship and the recognition of theoretical figures, of filmic figures that we employ to decodify production. With regard to the specific results, we present them below through the visual support of moviescapes that highlight the function of pilgrimage in the promotion of sustainable tourism and, when possible, with statistical data from the Santiago de Compostela Pilgrim Office [78]. To this end, we assume that the distinctions between pilgrimage and tourism are not clearly defined, since a tourist can also be interested in visiting a church [79,80] and this is because religious and pilgrimage tourism are considered a sub-group of cultural tourism [81,82]. Although initially pilgrimage presupposed an existential modality, nowadays, it shares some recreational and leisure aspects with tourism.

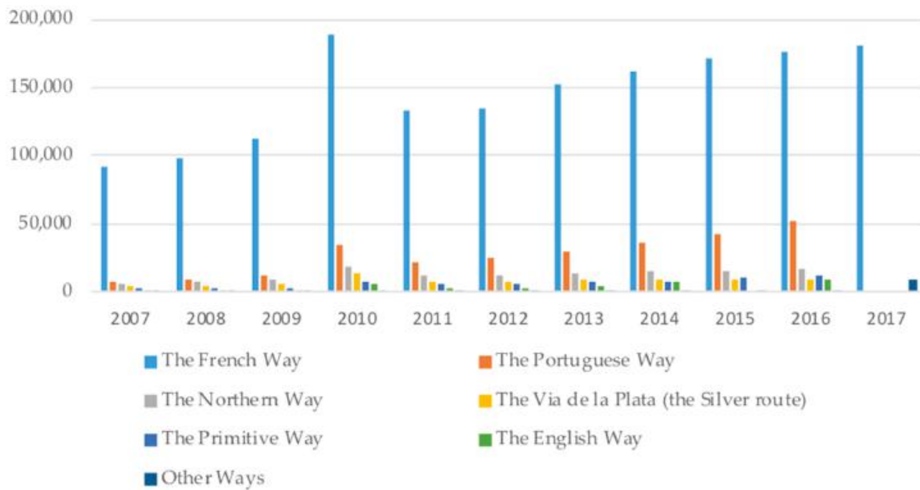

Figure 3. Comparative representation of the chosen St. James itineraries [78].

Firstly, we demonstrate the Way as an opportunity to recover and enjoy means of transport that are respectful of the environment through the expression slow mobility [82]. The means of transport used to travel it are walking, bicycle and horseback (Table 4). Since the Middle Ages, the Spanish verb *peregrinar* (to make a pilgrimage) meant "to walk", and this is the most authentic way to undertake the Way [83,84]. A famous and often repeated phrase by Goethe, "Europe was made on the pilgrim route to Santiago", is a reminder of the reiteration of this practice, which continues today and is consolidated through the increase in the Way's success [6,83,84]. Even now, walking is an identity of the Way that is highly regarded, as itis associated with the objective of rest that holidays prioritize [85–88].

Table 4. Means of undertaking the Way [78].

Year	Walking	Cycling	Horseback Riding	Sailing	Wheelchair	Total Pilgrims
2007	94,329	19,766	364	0	7	114,026
2008	104,178	21,248	293	0	30	125,141
2009	121,959	25,127	342	0	39	145,877
2010	237,873	33,277	1230	0	37	272,135
2011	153,078	29,948	341	0	11	183,366
2012	164,749	27,406	281	0	22	192,488
2013	188,187	26,649	977	0	66	215,880
2014	210,939	25,325	1520	0	98	237,983
2015	236,707	25,343	326	0	71	262,516
2016	254,025	23,347	342	15	125	277,913
2017	278,490	21,933	417	153	43	301,036

Figure 4. Pilgrims walking [77].

Figure 5. Pilgrim walking and enjoying the cultural heritage [77].

Figure 6. Pilgrims riding in urban centers along the Way [77].

The slow mobility of pilgrimage means assuming a sustainable behavior that is respectful of the environment. Slow mobility is a trait that enables travelers to renew the original relationship between human beings and the environment, to rekindle social relationships, to perform a healthy activity and to enjoy the experience [84,89]. The films that represent the Way as such, and pilgrimage in general, contribute to promoting the ideal of slow tourism, in harmony with the environment, and the rural and urban landscapes. Figures 4–6 visualize sustainable tourism based on slow mobility, on foot or on bicycle.

As shown by the data in Table 4, statistics from the Pilgrimage Office confirm that the two most common means of traveling the Way are walking (Figures 4 and 5) and by bicycle (Figure 6). Furthermore, in recent years, the number of pilgrims undertaking the Way by bicycle has increased. This is a post-contemporary reinterpretation of the route that simultaneously consolidates the sustainable practices of the Way. The number of programs and companies that offer assistance to those pilgrims who have to send their bicycles back home once they have reached their goal has grown.

Another sustainable legacy from the past is related to accommodation. Although the profile of the pilgrims is changing because of the increase in pilgrims and the importance of the route, meaning that the number of pilgrims that stay in hotels is growing, the majority continue to choose hostels. They are only allowed to stay for one night at these hostels, except for reasons beyond their control such as illness. According to data provided by the Way of St. James Observatory [89] (latest report of 2010), almost 50% of pilgrims sleep exclusively in hostels and 75% use them occasionally. In this case, pilgrims tend not to stay in the same place or the same establishment for longer than one night unless in exceptional circumstances. This causes a high turnover and flow of pilgrims. In addition, pilgrims are not demanding in terms of accommodation and often chose existing religious and/or public structures (Figures 7 and 8).

Figure 7. Pilgrims' hostel [77].

Figure 8. Pilgrims meeting outside hostel [77].

As shown in Figures 7 and 8, the documentaries highlight the most traditional accommodation option, raising awareness amongst viewers, thus promoting the network of hostels.

These cinematographic productions can be considered as strategic in fostering and promoting sustainable tourism in minor centers through pilgrimage. In general, film is a key element in constructing the destination's image [45], since its functions can provide a source of income, help to improve the local economy and generate forms of employment for the community. Film is beneficial for the receiving community, but above all, it impacts the tourism sector, becoming a sources of high added value for the land, since it provides greater visibility and publicity of places, increasing the attractiveness of a place, municipality, or region. Notably, pilgrimage no longer has a solely religious purpose, but is nowadays rather secular. This semantic evolution turns the movement of pilgrimage into a type of slow tourism, into a desirable model for the touristic development of the territory, and therefore, of minor cities.

Through the visual cinematographic discourse, we are able to access information pertaining to the heritage offering of the places along the Way (Figures 9–12). In this case, the heritage found along the route is an attraction factor and is well valued by the pilgrims [88–90]. Visiting the heritage offerings of the cities along the pilgrimage route has become a contemporary practice for the Way, as it enriches the experience of and empathy with the territory being explored [91]. The Way is a heritage space, also defined as an open-air museum by B. Castro Fernández [92]. As a consequence, a documentary on the Way must reflect its monumental richness that also expresses its historical roots. This message is conceptualized in the cinematographic images that capture the heritage symbolic elements of the stages traversed. Through these moving images, spectators discover the Way's heritage. According to the interviews completed by the Way of St. James Observatory [89], heritage was one of the reasons for people undertaking the pilgrimage (Figure 13). Despite its temporal distance, in the audiovisual productions, we recognize how heritage continues to be a *theoretical image* of the Way. Considering that the producer is likely to be interested in the success of their documentary or film, the spectator accesses these urban and heritage locations through captivating images, whose allure is reinforced by the camerawork. In *Camino de Santiago. Documentary Film*, Mark Shea stops to represent each detail of the Cathedrals of Burgos and León. The same technique is employed in the case of *Uma Jornada pelo Caminho de Santiago*, in which the Cathedral of Astorga is presented as below.

Figure 9. Pilgrims and Urban Heritage [80].

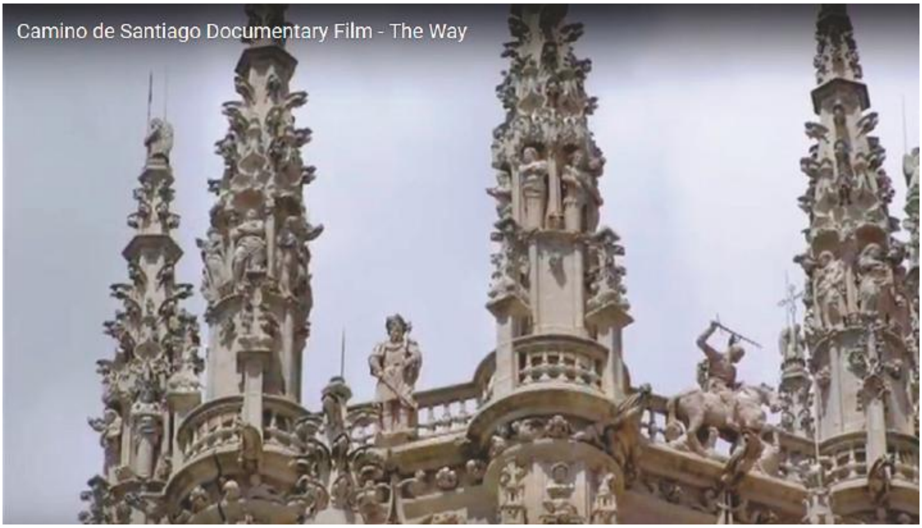

Figure 10. Roof detail of the Cathedral of Burgos [77].

Figure 11. Sahagun. Centro del Camino [77].

Through the following figures, we highlight a key factor in pilgrimage, which is derived from slow mobility: sociability. After a long day walking or pedaling, the rest of the day is spent resting or socializing inside the hostel, which is an essential place for exchanging experiences [87]. From the perspective of sustainability, respect for the environment is also translated into respect for and from the people along the Way. Figures 14 and 15 below depict urban contexts located along the Way and express how the Way's paradigm of sustainability is also applied to the cities traversed.

Figure 12. Cathedral of Astorga [77].

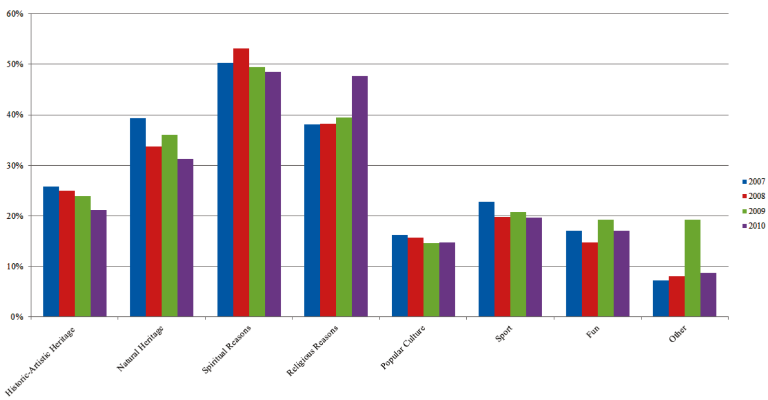

Figure 13. Main reasons to undertake the Way (2007–2010) [89].

Figure 14. Social moments along the Way [76].

Figure 15. Social moments along the Way [76].

Pilgrimage is an experience that elicits interest because it is another process of understanding humans and their relationship with the land. Furthermore, slow mobility teaches us to understand the land and its resources [91]. The productions analyzed, like many of those linked to the Way, function as a display that allows wine and gastronomy of the region to be promoted (Figure 16). As displayed in the documentaries, pilgrims prefer to consume local products and therefore those based on gastronomic traditions that allow them to harmonize with the surrounding land. The post-contemporary tourist's curiosity and desire to acquire new knowledge also inspires the pilgrim, who fully experiences the Way. One of these experiences is linked to local resources that are used by audiovisual productions. Given that a film needs a location [25,29], an active collaboration between cinema and local resources is necessary [4,5]. The cases analyzed are proof of geographical appraisal through cinema, as they visualize the Way's rich offerings: cultural, social, ethnographic and culinary heritage.

Figure 16. Local resources and cinema production [77].

The results that have been presented coincide with previous studies and with the statistics available relating to the Way of St. James. With these as our basis, we advance a visual theorization of tourist sustainability that emerges from the case studies, which allows for a film-induced sustainable tourism to be talked about, characterized as follows:

- Slow mobility: inspired by contemporary trends that impose new holiday rhythms and styles [91], the cinema directors and producers exploit the slow mobility of the Way of St. James to films promoting this practice and to teach others how to get closer to the location.
- Film-specific aspects: the cinema productions (especially those available online) are partners in creating successful on-location marketing [37]. The actors' experiences are a sort of visual guide through which the viewer learns about the location, looks ahead to their experience, or can relate to it. Furthermore, cinema tourism can be considered an efficient tool for urban regeneration and economic revitalization.
- Economic benefits: the cinematographic representation not only represents a creative or artistic expression, but also defines a set of complex economic activities based on logic and economic determinants that influence its development and evolution. The local community realizes benefits in the short term, as film improves the destination's image and increases tourist presence, as well as income [25,30]. In the mid-to-long term, films boost the area's popularity, and they can reconvert or reinforce the location's image, to improve the infrastructure, optimize the receptive structures, and enhance local artistic and cultural heritage [45]. For the territory and the areas in which it operates, the company that manages the economic activity generated by a cinematographic production represents a direct, indirect, and induced economy, able to generate immediate gains in terms of spending during the processing of the film as well as mediated or induced gains in terms of popularity, positive increase in the image of the destination, occupation, and arrival of flows of tourists and visitors. In the case study, a cinema tourist decides where to stay or stop depending on what they have seen.
- Tourist policies: they should be focused on managing this type of cinema tourism as a competitive geographical strategy [1,36]. Some policies could address the need for a load capacity study (possibilities, pros, and cons, etc.), and the promotion of cooperation between public and private actors, so that the enhancement process involves all stakeholders [46]. Also, for the smaller town centers, producing movie maps to complement the itinerary maps) would allow the Way of St. James to be experienced differently, focusing their attention on less congested town centers. We must not forget to consider the tourist sustainability of the destination in relation to protecting and respecting the territory and environment, as well as the place's history, identity, and community. Public and private entities do not yet seem to fully perceive the extent of the problem, since policies are not always outlined to control the effects on the territory resulting from the intensive development of tourism. A real change in course in these new destinations will occur only when these places are considered as real, integrated systems where the interests of public and private actors can converge.
- Sustainability aspects: attention must be paid to the location-community relationship [4,46]. The community could feel threatened by the arrival of huge influxes of tourists, and then might not be able to seize all the potential advantages that they would bring to the local economy. In order to avoid these undesirable effects, those responsible for local policies must try to anticipate and assess the consequences that the increase in tourism could involve for the location.

5. Conclusions

Tourism is a modern metamorphosis of travel and pilgrimage [86,87]. This secularization has changed its symbolic meaning, transforming places into tourist locations [80,88,90]. The growing dimension of contemporary tourism, its characteristics and the transversal dimension of its industry are the main driving forces that have led the search for new tourism approaches. The present work sought to examine the development of a new sustainable tourism approach related to film-making promotion of a well-established global pilgrimage, such as the Way. The film-induced tourism effect plays a pivotal role for a territory. To capture its value and consolidate its effects, tourism offerings must match the expectations created by the filmic narration and appreciate and love the territory's resources and identity, and raise awareness.

As "film genres are produced by the discourses which describe them" [11] (p. 2), filmic productions representing pilgrimages are engendering a promotional discourse that might slowly turn into a proper genre. Given the original essence of pilgrimage, documentary cinematographic productions coincide in the diffusion of a filmic theorem based on sustainability. As a consequence, this produces practices and regulations for production and configuring the space that are reproduced on an international level. Documentaries about the Way are, therefore, consolidating a framework for signifying space. These documentaries represent the space and they want to create sensations. The moving images amplify these sensory properties as they allow experiences that strengthen the sense of the place to be relived. The representational power of the images is also due to their ability to reproduce the same experience in viewers. It is through this experiential recognition that images have most success. Due to cinema visibility, the Way's town centers, especially those that are smaller in size, could take advantage of the film-induced tourism for their sustainable development (Table 5). Turning these small cities and towns into cinema locations would have an immediate, direct economic impact and an increase in occupancy of hotels. It would increase the professionalism of human resources and tourist consumption, which would require the location to have products, goods, services, professionalism, specialized companies, and facilities. Along the Way of St. James, and throughout the route seen in the films (the French Route), there are already services and facilities linked to tourism (accommodation, restaurants, etc.).

Table 5. Socio-economic impacts of tourist flows in the places of the Way.

Cohesion of Local Community	Economic Benefits	Social Incentives	Social Impacts
Income generation for civil projects	Increase in seasonal employment opportunities	Increased leisure opportunities	Traffic increase
Enhancement of local image and identity	Development of the tourism system	Promotion of organizations in the area	Load capacity exceeded
Building the sense of belonging to the community	Increase for the induced tourism	Growth opportunities for cultural exchange	Increased pollution

The impacts of film tourism on the community have been the subject of some discussion, primarily by Beeton [25]. Although most impacts are rather similar to tourism in general (increase in revenue, modification of community structure, intra-communal conflicts over tourism development, employment opportunities, improvement of quality of life, conflicts between local community and tourists, cultural exchange, commodification and loss of authenticity and revitalization of local culture), impacts specific to film tourism have yet to be researched in detail, as a review of existing literature suggests little difference between the two. However, how film tourism specifically impacts the local community is arguably the issue of authenticity and representation.

One of the advantages that of the active collaboration between tourism and cinema is the enhancement of the territory through the cinematographic medium, which has the power to enhance the cultural, social and ethnographic heritage more effectively than an image and brand campaign, as a film is, by its very nature, promotion, and communication. A film or series needs a territory for a purely material reason, to provide a context to the narration and for an aesthetic reason to ensure that the territory is coherent with and possibly exalts the screenplay. The cinematographic representation does not represent only a creative or artistic expression, but also defines a set of complex economic activities based on logic and economic determinants, which influence its development and evolution. The company that manages the economic activity generated by a cinematographic product is the production that creates a direct, indirect, and induced economy for the territory and the areas in which it operates, able to generate immediate gains in terms of spending during the processing of the film, and mediated or induced gains in terms of popularity, positive image growth of the destination, occupation, and arrival of tourist and visitor flows (Table 5).

A film production requires the use of specialized and heterogeneous goods and services for processing. The production process interacts with the territory on two different levels: one organizational and management, the other purely aesthetic and artistic. The territory is a fundamental resource for production, since it is simultaneously environment, landscape, historical, and artistic heritage, local culture, climate, society and folklore. The aesthetic motivations, such as the uniqueness of the territory as the sum of resources suitable for the subject, the plot, the atmosphere, and the screenplay of the film; and the economic-organizational motivations of project management, such as time, costs, and resources; constitute the decisive mix for choosing one set rather than another. The aesthetic motivations prevail every time the territory necessary to the creation of the artistic product is recognizable in a single location without alternatives. When the film presents various possibilities of setting, the production tries to find the least expensive location in terms of costs, time, and resources. For the territory that is chosen, there are significant opportunities for the economy of the area: direct and immediate economic impact, increase in employment, business specialization, professionalization of human resources, and tourist consumption. The production requires the presence of products, goods, services, professionalism, specialized companies, and structures. The most requested are those that characterize the tourism sector, such as hospitality, transport, and catering. The presence in the same territory of all these resources together, in addition to determining the preference for one location over another, allows the production to work without moving from the locality, saving time and money and with direct, indirect, and induced economic impacts on the host territory. Among these, the occupational repercussions, both during the processing period and permanently, are perhaps the most important, as they allow the specialization of a large number of people and the possibility for local entrepreneurial realities to grow and acquire useful knowledge. What the producers expect from the territory is adequate problem-solving capacity, so those places that guarantee these services are preferred.

Despite the relevance for stakeholders, no research has examined on the theoretical and visual exploration of these sources, which are accessible and are frequently consulted online by potential pilgrims. Likewise, this work advances a new line of research that invites reflection on possible theorizing in the audiovisual industries. The two documentaries highlight how tourist sustainability joins with the simplicity of pilgrimage, in that the pilgrim and/or tourist does not need much to thrive [84,86,91]. Bringing the pilgrim figures closer to tourist practices confirms the growing overlap of behaviors and the need to investigate the pilgrimage experience from new perspectives. Regarding advertising and communication tools, cinema has revolutionized perceptions when reproducing geographical spaces and its movements [93]. At present, we limit ourselves to defending theoretical possibilities of the documentaries, which are tools for disseminating a filmic theorem that is amplified when they can be consulted via the internet. It is true that this research has its limitations, as direct contact with producers and participating pilgrims would allow our results to be confirmed, but we think that in this preliminary stage, the scientific backing of the previous investigations is important in order to confirm our hypothesis. The communication potential of cinema highlights geographical resources and, in the case studies, contributes to understanding the films as tools for reflection on the potential for town center destinations. For this reason, as far as future research directions are concerned, destination management organizations must consider the economic advantages of film-induced tourism along with its negative economic, social, and environmental impacts. Networking between stakeholders representing different interests can help with planning and controlling film-induced tourism within a more ethical and sustainable context. Therefore, film-induced tourism must be an instrument capable of activating interventions and generating long-term benefits for the offerings of destinations, with the aim of not only of increasing arrivals in the short-term, but also encouraging trips to be repeated, or tourists to extend their visits (Table 5). The territory's task is to specialize in supplying quality resources, services, and interventions in favor of productions, and have the ability to respond to the opportunity that this demand is able to provide. In this sense, if television can attract viewers and make them aware of a place, it can be considered an instrument of indirect promotion, so it is important that the location assigned to tourist destinations is effectively equipped and ready to welcome visitors. Thus, there is a need to reflect more deeply on the local and behavioral impacts of moving images. The new format of territorial promotion that has used cinema and television in recent years can represent, for Santiago de Compostela, an opportunity for the rejuvenation of the target of visitors, tourists, and users and for its tourist image that has been expanded to the domestic and international markets. The potential of the cinematographic medium is manifold. It is a vehicle of attraction for tourists who would not have otherwise visited the place, encourages the return of prior visitors, and generates longer stays and greater expenditures. Moreover, it is a tool that is able to expand the target market of a destination and to implement place marketing actions. Interpreting tourism in this new light allows operators in the sector to use the film product further to trigger a process of socio-economic growth, especially in those local areas that need to create opportunities for younger generations.

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Article

Future Development of Taiwan's Smart Cities from an Information Security Perspective

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Abstract: Smart cities are primarily based on information and communications technology development and applications across various academic subjects and domains. Integrating new-generation information and communications technologies, including the Internet of Things data collection, cloud computation, big data applications, and mobile network, smart cities organize the people and things of a city according to application needs to perform real-time computation and processing. Information transmission must be rapid and reliable to protect personal privacy and to secure data. All types of information security problems can lead to disastrous consequences; in particular, they pose great challenges to traditional information security systems. To explore possible solutions to the challenges that Taiwan's smart city information security faces, this study used the enterprise architecture method and discussed the emphasis and investment capacity of the government and enterprises on information security. Moreover, this study reviewed correct methods of using a smart information security collaborative system to protect not only privacy, however also networks with a large attack surface; the purpose was to establish a reliable data sharing practice and alleviate the cascading effect of failures of smart networks. Finally, this paper provides future research directions for building smart cities and encouraging further explorations in this domain. It is hoped that smart cities can conduct overall planning for information security during the process of construction. Future researchers will be able to propose more effective solutions for smart city information security while developing information and communication technologies.

Keywords: smart city; information security; cloud computation security; big data information security; Internet of things information security

1. Introduction

In the report "Transforming Our World: The 2030 Agenda for Sustainable Development", the United Nations announced its Sustainable Development Goals (SDGs), which cover economic development, quality of life, human resource education, infrastructure, distributive justice, green energy development, and a sustainable environment. The United Nations set the target of 2030 to achieve the SDGs [1].

The white book of the Global Future Cities Industry Alliance delineates the connotation of smart cities to using information and communications technology (ICT) to achieve sustainable city development and to improve people's quality of life, as well as using data to create insights [2]. Built on an ICT infrastructure, smart cities take advantage of the Internet of Things (IoTs) for information collection, as well as big data mining and analysis, and cloud computation, which are the three major cores and applications of IC [3,4].

Taiwan's government has promulgated various policies on information security to provide directions for building the information security systems of Taiwan's smart cities. The smart city concept, based on integrating and using the new generation of ICT, offers a new mode of development for future cities [5]. However, it is crucial to recognize that smart cities pose severe challenges to conventional information security systems; any type of information security problem can lead to disastrous consequences and greatly affect people's livelihood [6].

1.1. Overall Structure of Smart Cities

The building of smart cities must be based on an elevated macro-level perspective, as well as on multidimensional integration, which includes technology, public infrastructure, data, services, security protection, and human resources. The integration of these various application domains must be considered when setting up smart city systems with a unified platform, city operations center, and a perception–network–platform-incorporated smart network that can grow and expand and is sustainable [7]. To ensure the effective construction and operation of a smart city, well-defined top-down smart city development goals should be defined; simultaneously, it is critical to build smart infrastructure, achieve highly effective information system operations, and establish an effective network and information security protection system and supporting infrastructure. This structure is shown in Figure 1 [8]. The ultimate goal is to achieve sustainable city development for convenient public services, refined city management, a suitable living environment, smart infrastructure, and long-term information security [9].

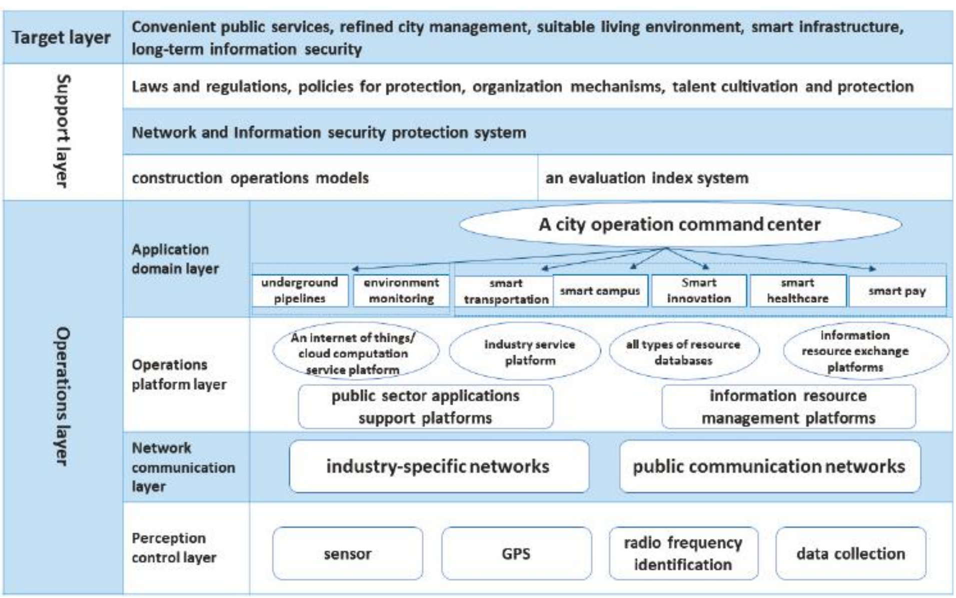

Figure 1. Top layer framework of a smart city.

1.1.1. Target Layer

To improve people's overall sense of well-being and Taiwan as a whole, the Taiwanese government has worked at its full capacity to comprehensively promote national construction. In addition, according to the SDGs and the spirit of inclusive development, the government has set the following five major goals for building Taiwan's smart cities: stimulating cultures, promoting green high-technology industries, building a smart country, achieving social justice, and creating a happy living environment [10].

1.1.2. Support Layer

Information security protection and supportive laws and regulations are essential for constructing a smart city. The government should plan and set up a smart city security protection system based on unified standards and should coordinate smart information security measures and resources. It is crucial to build a comprehensively planned smart city security framework with a definite structure, as well as protect and support the framework in all dimensions through laws and regulations, standards and specifications, organization management, technology, infrastructure, and manpower cultivation. Another crucial task is to establish evaluation indicators, assessments, and construction and operations models to provide a complete foundation and support for smart city development. The principles of the Information Assurance Technical Framework (IATF) should be adopted as guidelines for building a smart city security protection system that covers the three areas of people, technology, and operations [11].

1.1.3. Operations Layer

The operations layer is the core of smart city operations. Unified standards and specifications should be established for building smart infrastructure, a highly effective information system, and constructing supporting platforms for cloud computation and big data, thereby optimizing and integrating resources in areas such as city operations, city management, and smart industries. In addition, city management and operations procedures should be set to provide smart economic development and effective and convenient smart services for the public. The operations layer is focused on comprehensive ICT applications and can be divided into four sublayers: perceptual control, mobile network, supporting platform, and application domain [4].

The perpetual control layer primarily comprises the end-point perceptual infrastructure. Data related to the operations and states of a city's big data are digitalized and informatized to provide numerous end-point perceptual capabilities as well as interactive capability between the public and enterprises. As for information sharing, information is transparently transmitted through the network communication layer to the city's supporting platform. The mobile network layer is a crucial part of smart city infrastructure that comprises high-speed, ubiquitous, and highly reliable wired optic fiber networks and wireless broadband networks. Its key function is to set the foundation for realizing smart city applications and high-speed information transmission. The supporting platform layer mainly comprises an information resource management platform and a public sector applications platform. With extensively deployed perceptual end-points and peripheral perceptual capability, smart cities will be able to generate a massive volume of data and information that requires not only information databases, however also secure and effective data management. Moreover, public-oriented IoT, cloud computation, and industry-based public service platforms will be available for users from various industries, and smart city core public capabilities will be developed [12]. The fourth and final layer is the application domain layer, which provides smart cities with convenient public services, refined city management, a suitable living environment, smart infrastructure, and other application and information systems based on long-term information security. It is critical to simultaneously aggregate and interconnect data from the information systems of various institutions and government agencies to construct a smart city operations command center.

Information security working space demarcation and protection strategies of the operations layer are described in detail in Section 2.1.

1.2. Smart City Construction in Taiwan

In 2017, Taiwan launched a project called Development, Innovation, Governance, Inclusion, plus, or DiGi+, to achieve the following three fundamental digital nation supportive measures: establishing a friendly legal environment, cultivating multidisciplinary digital talent, and promoting advanced digital technology. The ultimate goal is to create a safe and reliable digital and innovative infrastructure environment and a digital government in a network society [13]. The critical infrastructure includes the energy, water resources, high-technology parks, communications and broadcasting, transportation, banks and financial institutions, emergency rescue, and hospitals of central as well as local governments [3]. Simultaneously, large funds, partly from nongovernmental sources, are to be invested into building ultra-broadband networks for the information society infrastructure.

1.3. Smart City Information Security Framework

The information security specifications from the National Institute of Standards and Technology (NIST) have been applied by countries worldwide. According to the NIST, organizations should adopt a top-down information security management structure, enabling continuous feedback to reduce information security risks [14]. The US Federal Enterprise Architecture Framework (FEAF) [15] covers the five dimensions of businesses, data, applications, performance, and technology, and provides public structures that facilitate the coordination of public business procedures, technology introductions, information flows, and system investments among federal agencies. Furthermore, the framework lists the principles and goals of information security and provides directions for interoperability, open systems, public access, end-user satisfaction, and security problems among various domains. The information security management guidelines of ISO27001 [16] and of the Information Technology Infrastructure Library (ITIL) are focused on constructing, implementing, operating, monitoring, reviewing, maintaining, and improving information security based on the essence of plan–do–check–act or plan–do–check–adjust (PDCA) to achieve information security using an organized approach. The IT management structuralized method of the IT service domain has been widely accepted. Information technology service management (ITSM) has been developed for integrating people, processes, and tools [17]. Whether from the perspective of the best practices of ITIL or ISO, the goal is for smart cities to offer the highest information service quality built on accumulated and shared experiences.

ISO/IEC 27001 provides the most standard and complete risk analysis and processing procedures to assist organizations in establishing a complete information security management system in order to effectively solve current asset security problems and reduce the risks that information security management may encounter in the future. ITIL® is a framework for standardizing IT service management. It utilizes processes to optimize existing resources that enhance the level of IT services and combines with business purposes to prove the value of IT organizations for enterprises.

Smart city information security is pluralistic, and under the NIST's information security specifications, a comprehensive smart city information security structure can be built to complete the long-term information security of a smart city, covering the three areas of information security technology, operations, and the management system. These are based on the essence of the IATF and the FEAF framework, simultaneously incorporating ISO27001 PDCA as advanced management standards and the best practice guide of ITIL/ITSM.

2. Information Security

In the 2017 Global Risks Report of the World Economic Forum, data fraud or theft ranked fifth worldwide and large-scale cyber-attacks ranked sixth. This indicates that information security has deeply affected people's lives [18]. The Global State of Information Security Survey 2018 by PricewaterhouseCoopers showed that more than 40% of enterprises globally lack a comprehensive information security strategy [19]. When risks increase substantially because of complex systems, the real danger is no longer more damages, however it becomes runaway collapses or an abrupt transition to a new yet suboptimal condition [18]. Smart cities are closely related to various sectors and the livelihood of people. As a result, a complete information security concept is essential. To increase the breadth, depth, and speed of information security, the Taiwanese government has planned to incorporate big data analysis and artificial intelligence (AI) technology to structure a smart information collaborative system for government agencies, critical infrastructure, and the regional governance of local governments. Such a system will be capable of forecasting the trends of information security attacks, thereby improving the speed of responses to information security incidents [20].

2.1. Scope of Smart City Information Security

Smart cities are composed of different information technology objects. Through systemic software/hardware and service integration, smart cities enable people to perceive, decide, and act according to the various application and scenario requirements. During the construction of smart cities, conventional information security technology will remain crucial and irreplaceable. The conventional classification, demarcation, and key protection strategies are still useful in the construction of a smart city's information security technology system. Simultaneously, the IATF will continue to provide the highest guiding principles. According to the smart city information procedure, five information security working spaces are demarcated (see Figure 2) [4,21]. The information security is responsible for authorization, verification, and encryption tools. Kerberos is a network authentication protocol used for secure identity authentication of personal communication on insecure networks. Lightweight Directory Access Protocol (LDAP) is an open, neutral, and industry-standard application protocol that uses IP protocol to control access and maintain the directory information of distributed messages. Guardium automates all compliance workflows in a heterogeneous environment to ensure the privacy and integrity of reliable information in the data center [4].

Intelligent Operations Center (I.O.C.) is a service monitoring platform for smart cities that can monitor the operations of a smart city information system at any time and can be processed by operators in real time. The Smart City Data Center is equipped with smart city-related information entity equipment and a traditional enterprise information center, which is similar to the traditional enterprise information center. Information security is the core that must be targeted under the operation of smart cities. In Figure 2, we only outlined several products that are commonly used in the industry, such as Kerbero, LDAP, ThreatSonar, Guardium, etc. These have been included in Table 1.

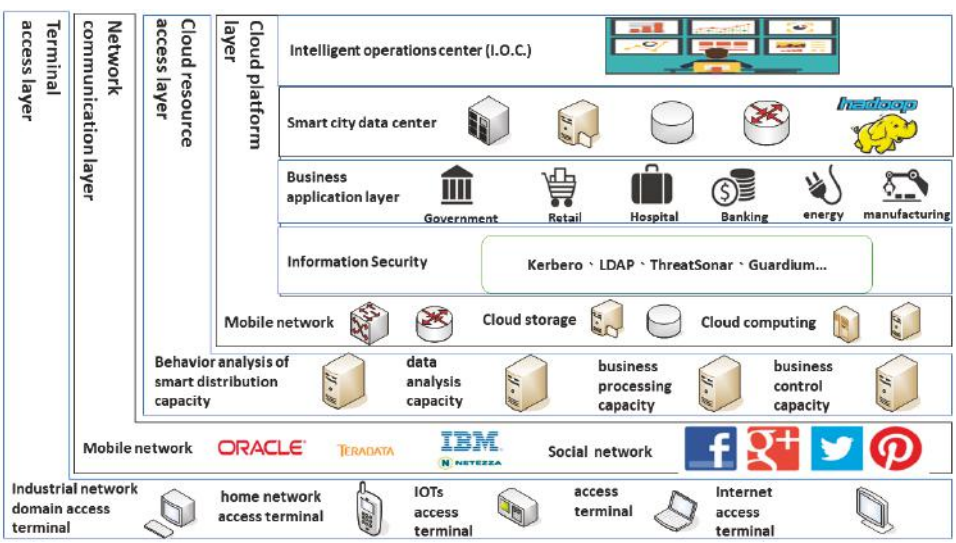

Figure 2. Smart city security demarcation layer map.

Information can be accessed from various types of terminal access layer (including end-user terminals of IoT devices and the smart city information system). Next, information reaches the data and service supporting layer of the smart city technology system, which comprises the data and service supporting layer and the cloud platform layer, through the border of the mobile network communication layer and the cloud resource access layer, to drive the operation of the overall information flow. The whole process involves the IoT, mobile networks, cloud computation, big data, and other ICT domain-related security issues. See Table 1 for more details.

Table 1 shows the business application system paired with the business application layer. This application system operates in the cloud platform virtual environment. It implements rigorous access control, invasion detection, action and behavior audits, digital identity authentication and identification, scanning for security vulnerabilities, and other safety measures. Similarly, cloud platforms, cloud resources, and the network communication layer must be strictly controlled. The terminal access layer requires much more stringent virus filtering, alarm and isolation, terminal access authorization, terminal security management, field control, application layer filtering defense, IoT security defense, and other control measures.

Table 1. Smart city security working space demarcation and security protection strategies.

Information Security Working Domain	Applications Involved	Basic Information Security Protection Strategies
Business applications	All types of smart applications, user data, network data, business data, and big data	Access control, invasion control, and action and behavioral audits are rigorously implemented, and digital certificates are used for identity certification, identification, and scanning for vulnerabilities.
Cloud platform	Cloud storage, cloud computation, cloud networks, cloud resources, and big data	Protection is implemented according to the 13 critical domains listed in the Cloud Security Alliance cloud computation security guidelines.
Cloud resource access layer	Cloud resource controllers, load balancer, bandwidth aggregation, and distributed storage	Access control, invasion control, and action and behavioral audits are rigorously controlled, and digital certificates are used for identity certification and identification. Furthermore, application layer protection and data recovery are implemented.
Mobile network communication layer	Communication links, wide area network access devices, and wireless base station devices	Rigorous access control, invasion detection, and encrypted transmission are implemented to ensure network communication security.
Terminal access layer	Desktop terminals, mobile terminals, IoT (Internet of Things) sensor terminals, and smart electric appliances	Virus filtering, alarm and isolation, terminal access, terminal security management, field control, application layer filtering defense, and IoT security defense.

2.2. Cloud Computation Security

Commonly based on the dynamic, easily expandable functions, and virtual resource services provided by the Internet, cloud computation enables users to share platform resources. Data centralized in the shared data center and storage devices pose a threat to data securities. On 28 July 2017, the Cloud Security Alliance (CSA) issued the Security Guidance for Critical Areas of Focus in Cloud Computing Version 4.0 (CSA. V4.0) [22] and listed 13 critical areas of cloud platform layer security that require protection management. Under the existing information security standards, various related international organizations have individually started to adopt cloud computation information security measures. In this study, the key information is summarized for the following three categories: information security guidelines, application standards, and technical standards (see Table 2).

Table 2. Summary of cloud computation information security management standards.

Type	Name	Description
Information security guidelines	Cloud computation security guidance	CSA. V 4.0
	Guidelines for Improving Security and Privacy in Public Cloud, NIST (National Institute of Standards and Technology, Special Publication).	NIST SP 800-144
	27017 and 27018 for cloud computation data and privacy protection standards, the International Organization for Standardization (ISO).	ISO 270xx
	Business continuity management system (BCMS).	ISO 22301
Application standards	The Health Insurance Portability and Accountability Act of 1996 (HIPAA) provides data privacy provisions for medical facilities and subcontractors.	HIPAA
	Data security check provisions for financial institutions, Federal Financial Institutions Examination Council (FFIEC).	Finance FFIEC
	Information privacy provisions for credit card and debit card information, the PCI (Payment Card Industry) Security Council.	PCI
	SAS 70 (the Statement on Auditing Standards No.70) for performing risk control audits of financial institutions and of institutions providing information services.	SAS 70
Technical standards	Key and certificate management: KMIP (Key Management Interoperability Protocol) and PKCS (Public Key Cryptography Standards).	KMIP stands for the Key Management Interoperability Protocol, whereas PKCS stands for Public Key Cryptography Standards.
	Information storage security: The Institute of Electrical and Electronics Engineers (IEEE) P1619.	Data storage encryption method and key management structure, the Security in Storage Working Group of IEEE.
	Identity authentication: SAML (Security Assertion Markup Language) and X.509 certificate.	SAML stands for Security Assertion Markup Language; Public key management and infrastructure (X.509 authentication) of the International Telecommunication Union Standardization Sector.

When evaluating security based on cloud computation, a key feature is that enterprises lose their physical control; the security infrastructure, platforms, and application programs are directly controlled by cloud suppliers. The primary security concern is legal compliance and the secondary concern is safety control. Although consumers may require all these security control measures, they should contemplate whether cloud suppliers' infrastructure is capable of providing comprehensive security protection [23].

2.3. Big Data Security

The contextual integrity principle of Helen Nissenbaum (2004) provides a conceptual or strategic framework to resolve privacy issues related to big data [24]. Data analysis technology concerns using data inputs, processing and computation analysis, and other programs with support from ICT technologies such as cloud computation and the Internet to generate computation results [25]. The Big Data Working Group of the CSA published the Expanded Top 10 Big Data Security and Privacy Challenges and the Big Data Analytics for Security Intelligence [26,27], the contents of which can be classified into the following four categories: infrastructure safety, data privacy, data management, and integrity and reactive security. More details are summarized in Table 3.

Table 3. Big data safety, privacy categories, and 10 major challenges.

Category	Ten Major Challenges for Big Data Security and Privacy
Infrastructure safety	Decentralized computing architecture security; Security best practices in nonrelational data stores.
Data privacy	Data mining and analysis of privacy protection; Data security with boosted cryptography; Refined access control.
Data management	Data storage and transaction record security; Refined audits; Data source.
Integrity and reactive security	Terminal input authentication and filtering; Real-time security monitoring.

The first category, infrastructure safety, can be divided into decentralized computing architecture security and security best practices in nonrelational data stores. Decentralized computing architecture security uses network interconnection for data transmission, communication, and coordination; some notable considerations here are critical security problems such as data leaks, privacy breaches, and incorrect computation results. For example, the MapReduce architecture divides data into multiple blocks; each block is first processed by the Mapper before the Reducer generates the result by clustering values of the same key. This procedure protects the security of Mapper programs and the data. In terms of security best practices in nonrelational data stores, because of a wide variety of big data sources and the complicated format types, security policies related to data classification and storage are essential for security and protection.

The second category, data privacy, faces the following three challenges: privacy-preserving data mining and analytics, cryptographically enforced data-centric security, and granular access control. In the process of automatically searching information with special relevance hidden in a massive amount of information, mining and analysis becomes extremely difficult because the information is often deidentified. For the security of sensitive or important data, attribute-based encryption is often adopted to ensure that access to the data is limited to authorized personnel [28]. Access control must be refined further to completely block nonauthorized parties from accessing the data.

The third category, data management, also faces three challenges: secure data storage and transaction logs, granular audits, and data provenance. The amount of big data is not only enormous, however it is also expanding rapidly; as a result, data saving strategies must meet security needs. In addition, the audits must be refined further to detect any potential information security risks or invasions. Data source reliability is another key concern here because inappropriate data will lead to incorrect analysis results.

For the fourth category, integrity and reactive security, two related issues must be tackled: end-point input validation and filtering and real-time security monitoring. For the various types of terminal device, it is important to study related algorithms and filter out malicious sources to ensure the validity of data sources. When applying the massive amount of information from big data, using the smart collaborative defense system [29,30] for real-time security monitoring enables administrators to handle a crisis immediately, accelerating the response to information security incidents effectively.

2.4. Mobile Network Security

According to the definition provided in the Regulations for Administration of Mobile Communications Business by the National Communications Commission, R.O.C., mobile communications refers to the use of radio terminal equipment for voice or nonvoice communications through a mobile communication network [31]. The term "mobile communication system" refers to a communication system composed of mobile stations, base stations, switching equipment, network management, and accounting management. A mobile communication network consists of a mobile communication system and telecommunication line equipment. Cellular technology has become increasingly influential in mobile communication networks because for the majority of people, cellular technology is the main portal to the Internet. Lastly, a mobile communication network should be equipped with an effective switch certification protocol in terms of security and effectiveness [32,33].

As personal wearables and embedded devices rapidly become ubiquitous, the number of networks—large and small and of varying levels of complexity—are certain to multiply substantially [34]. Cisco suggested that with the use of IP network-based platforms for linking various mobile devices, networks, and applications, users will be able to access various information and keep in touch with others at any time and in any place. Centralized, easy-to-manage access points and highly secure mobile solutions can integrate voice, information, image, and wireless transmission into one infrastructure, overcoming the limitations of conventional communication and enhancing the effect of collaboration. It is known that blurring the boundary between work and personal activities has positive effects on both work productivity and the flexibility of applications in everyday life.

2.5. IoTs Security

The susceptibility of the IoT to all sorts of attacks has increased; incidents such as hacker invasions to store or control IoT equipment or systems have been frequently reported. People can be given a specific level of trust at different parts of the IoTs [35]. By 2020, according to an estimation by Cisco, more than 50 billion IoT-connected devices and objects will exist [36].

The IoTs is mainly composed of various commonly used devices [37]. The security issues here differ because the work model of IoT equipment varies depending on the application scenario [37]. The International Telecommunication Union Telecommunication Standardization Sector established the Internet of Things Global Standards Initiative and the Focus Group on Machine-to-Machine Service Layer for optimizing IoT special applications based on the international network communication standards protocol. OneM2M, a machine-to-machine (M2M) and IoT-focused international standard organization under the Telecommunications Standards Institute, was set up to handle various IoT applications, including heterogeneous networks and device networking management, data exchange, and information securities. Furthermore, OneM2M defines interface specifications and the data format of various applications to facilitate cross-equipment and cross-application interconnection.

For M2M communication in the IoT domain, each item of equipment "knows" how trustworthy each machine is for important or sensitive information transmission [36]. Trust can be defined using three approaches: determining how many machines can be trusted by a user, determining how trustworthy each other device is, and determining how trustworthy a user is for the device.

The Open web Application Security Project (OWASP) proposed the OWASP Internet of Things Top 10 [38], which lists the 10 major vulnerabilities of and risks to the IoT that should be taken seriously and complied with by industries. Most recent cases of distributed denial-of-service attacks have been mixed attacks; thus, IoT security design will definitely pose certain levels of threats and challenges to smart city information security [39].

3. Constructing Taiwan's Smart City Information Security

Digitalizing the information security industry is one key direction for Taiwan's industry development. The government has requested each critical infrastructure-related competent authority to establish its own industry-related information sharing and analysis center, security operation center, and computer emergency response team, which are the three critical infrastructure platforms of information security. In addition to centralizing the nation's security information, the Executive Yuan set up the Taiwan Computer Emergency Response Team/Coordination Center, which is in charge of integrating nongovernmental information security intelligence and reporting related information security incidents. Mr. Liao Chih-Ming, Director of the aforementioned center, stated that the value of information intelligence lies in data integration.

3.1. Taiwan's Smart City Information Security

The Personal Data Protection Act, which has been promulgated and implemented since October 2012 in Taiwan, is the core of information security. Due to the severe penalties, government units and enterprises at all levels have vigorously implemented and introduced various international standards, such as ISO27001, ITIL, etc. in order to objectively and effectively assist information security management, information security technology, and information security operation. In the smart city information security safety framework, there are three main information security axes requiring pluralistic consideration. These three domains are information security management, information security technology, and information security operations, and they are essential for achieving long-term information security. Take Taipei City as an example: the smart city construction there has information security at its core, which is encompassed by smart education, smart transportation, smart innovation, smart health care, smart payment, smart public housing, and other smart applications. Participants must follow the government's unified standards and regulations to share the platform and information (see Figure 3) [40].

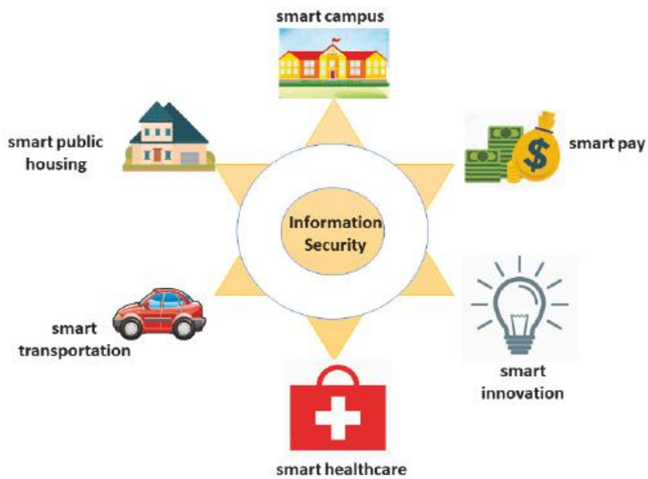

Figure 3. Information security-centered smart city.

3.2. Information Security Investment

According to Cisco's 2017 report [41], more than 55% of enterprises had their information security budget included under their IT budget, whereas 36% of enterprises had information security budgeted under IT. Only 9% of enterprises budgeted security independently (see Table 4). Most enterprises had information security accounting for 11% to 25% of their IT budget. As high as 10% of enterprises did not allocate any budget to information security. In Taiwan, most industries allocate their information security budget to their IT budget, however it is difficult to access such information. These data are often confidential, and enterprises are reluctant to provide detailed information.

Table 4. Percentages of enterprises' information security budgeted under IT.

Security Budget under IT Budget	2014 (Effective Number of Samples, n = 1673)	2015 (Effective Number of Samples, n = 2374)	2016 (Effective Number of Samples, n = 2828)
Fully under IT	61%	58%	55%
Partially under IT	33%	33%	36%
Completely independent	6%	9%	9%

Source: Cisco's 2017 Security Capabilities Benchmark Survey [41].

3.2.1. Investment

According to Gartner's latest forecast (August 2018) [42], the total global expenses of information security products and services will exceed US$114 billion in 2018, which is a 12.4% increase from 2017. It is anticipated that in 2019, the market will undergo a steady growth of 8.7%, reaching US$124 billion. Taiwan's 2018 information security expenses are anticipated to increase by 13.9%, reaching NT$21.8 billion, and information security service expenses will reach NT$9.7 billion. Among various types of product, information security products are the fastest growing, having seen a 21.5% increase, which is equal to approximately NT$1.2 billion. Siddharth Deshpande, Gartner's Research Director, indicated that information security officers are striving to achieve the safe use of technology platforms for their companies to increase their competitiveness and to drive sales. The ongoing technological shortages and the reform of laws and regulations, such as the European Union's General Data Protection Regulation, are driving the steady growth of the information security service market.

According to Taiwan's iThome survey on the percentages and distribution of money invested in information security, all industries in Taiwan have placed significantly more emphasis on information security than ever before [43]. The annual growth rate of the overall information security investment in 2018 has reached 73%. As for key investment items, IT infrastructure protection ranked top (see Figure 4), and authorization, end-points, and data-related control were also high on the list. Unexpectedly, boosting employee information security awareness ranked second, with a percentage of investment reaching 47.9%. This finding suggests that because the government has put much effort into advocating the importance of information security, companies have come to recognize that relying on information security products alone for threat prevention is no longer adequate; personnel information security awareness education and training are required.

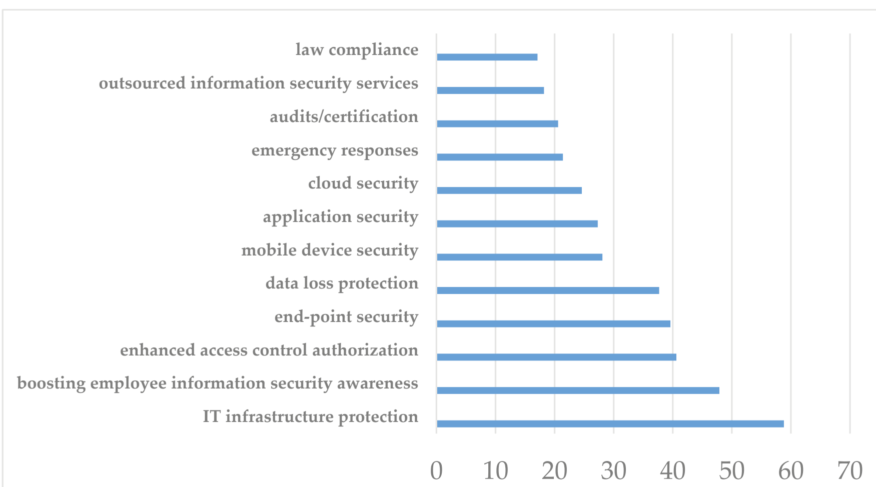

Figure 4. Taiwan's 2018 key corporate information security investment ranking. Source: iThome (2018) [43].

3.2.2. Threats to Information Security

Information security threats are detrimental for enterprises. According to iThome's survey [43], nearly 80% of Taiwanese enterprises that were surveyed experienced information security incidents in 2017, and 15.3% of them had experienced more than 50 information security incidents in that year. In terms of the sources of these information security threats, most were outsider threats: 55.3% were from hackers, 14.7% were related to organized crime, and 7.2% were state-level attacks by foreign countries. Figure 5 shows the sources of major information security attacks in 2017, in which hackers and internal personnel are seen to pose a certain degree of threat to enterprises in Taiwan.

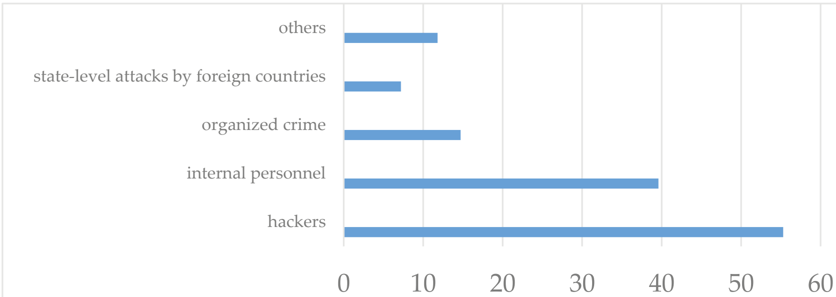

Figure 5. Major sources of information security attacks in 2017. Source: iThome(2018) [43].

Although the threat of external attacks remains, enterprises should also pay attention to insider threats. This survey revealed that among all enterprise information security incidents that occurred in 2017, 39.6% could be attributed to employees. In other words, internal personnel form another major source of threats to corporate information security.

3.2.3. Information Security Obstacles

Cisco's 2018 global survey [41] summarized the 11 largest obstacles to the adoption of advanced security processes and technology (see Table 5, Column A1, A2); each obstacle was organized by the percentage for each country and each region. Among all obstacles, budget constraints ranked first (34%), and compatibility issues with legal systems, certification requirements, and lack of trained personnel ranked joint-second (27%). Organization is not a high-value target for attacks and security is not an executive-level priority ranked in last place. This finding matched the trends of the last two years; first, senior management support is necessary for successful information security operations, and second, hacker organizations have become profit-oriented.

According to data from Taiwan's iThome 2018 Enterprise Information Security Survey [43], employees' lack of knowledge of advanced security processes and technology ranked top (63.1%), budget constraints ranked second (29.9%), compatibility issues with legal systems, certification requirements, and lack of trained personnel ranked joint-third (25–29%), and organization culture of/attitude to security and reluctance to purchase until proven in the market ranked last.

In this study, data from Taiwan's iThome 2018 enterprise information security survey report were reclassified according to items from Cisco's 11 advanced security procedures and technological obstacles (Table 5, Column B) to make comparisons between the two sources. Four items were found to be similar between Taiwan's and Cisco's global averages (with an error rate below 2%). A radar chart was used to compare Taiwan's figures with global averages, and general performance trends were expressed using the advanced security procedure and technological obstacles (see Figure 6). The percentage of employees lacking information security knowledge reached 63.1% (Table 5, Column B), indicating that Taiwanese enterprises in general valued information security, which was a result of the government's efforts. In terms of budget constraints, those of Taiwan were slightly lower than the global average; although Taiwan's information security budget increased, it was still not sufficient. In terms of compatibility issues with legal systems, certification requirements, and lack of trained personnel, Taiwan's values were similar to the global averages; in general, all were inadequate. Regarding reluctance to purchase until proven in the market (9%, Table 5, Column B), organizational culture/attitude (5%, Table 5, Column B) and security is not an executive-level priority (9%, Table 5, Column B), Taiwan had superior performance compared with the global averages, which can be attributed to the government's information security policies.

Table 5. Obstacles blocking the adoption of advanced security procedures or technology (defense weakening).

Item	Global: 2018 Cisco Global Survey		Taiwan: 2018 iThome Survey
	Column A1 2016 (Effective Number of Samples, n = 2912)	Column A2 2017 (Effective Number of Samples, n = 3651)	Column B 2017 (Effective Number of Samples, n = 462)
Budget constraints	35%	34%	30%
Compatibility issues with legal systems	28%	27%	26%
Certification requirements	25%	27%	29%
Lack of trained personnel	25%	27%	27%
Competing priorities	24%	24%	18%
Current workload too heavy to take on new responsibilities	23%	22%	16%
Lack of knowledge about advanced security processes and technology	22%	23%	63%
Reluctant to purchase until they are proven in the market	22%	22%	9%
Organizational culture/attitude about security	22%	23%	5%
Organization is not a high-value target for attacks	18%	18%	19%
Security is not an executive-level priority	17%	17%	9%

Source: cisco.com/go/acr2018 [41] and iThome [43].

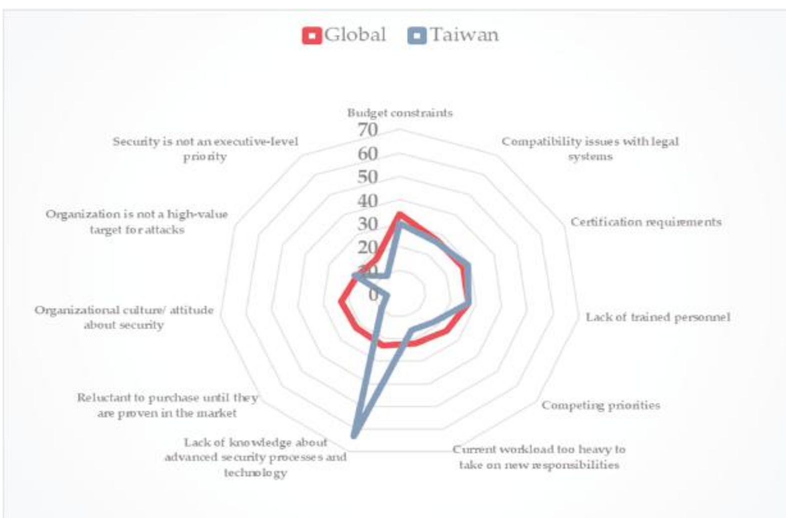

Figure 6. Obstacles blocking the adoption of advanced security procedures and technology: Taiwan vs. global averages [41,43].

3.2.4. Information Security Risks

The 2018 iThome chief information officer (CIO) survey results for Taiwan's corporate information security risk rankings are shown in Table 6 [44]. It can be observed that for CIOs, in addition to the invasion of malicious viruses, employee negligence and lack of information security awareness (which was as high as 56.7%) elicited the highest level of concern. This finding resonates with the information in Table 2 in that employees generally lack information security awareness. Moreover, this is what

Taiwanese enterprises have been striving to improve. As for virus attacks, according to 2017 statistics by Symantec on the increasing annual rates of global viruses, the types of attacks in descending order were malware (92%), phishing emails (71%), junk mail (55%), mobile device usage (54%), blackmail software (46%), and potential vulnerabilities for attacks or damage (13%). This result matched the list of information security risks that cause the greatest concern among Taiwanese CIOs.

Internal employees' negligence and lack of information security awareness pose threats to information security. It is also a great hidden risk for Taiwanese enterprises. Moreover, 56.7% of enterprises considered employees' negligence and lack of information security awareness to be the greatest information security risk and, thus, even more severe than that of phishing emails, malware, or blackmail software.

Table 6. Information security risks of greatest concern to Taiwanese CIOs by percentage as well as increasing annual rates of global viruses from Symantec's 2018 Internet Security Threat Report (ISTR) survey.

Risks	Information Security Risks of Greatest Concern to Taiwanese CIOs (Chief Information Officers) by Percentage (Effective Number of Samples, n = 462)	Increasing Annual Rates of Corresponding Types of Global Virus according to an ISTR 2017 Survey (Effective Number of Samples, n = 15,000)
Phishing emails	50.8%	71%
Malware	46.3%	92%
Blackmail software	45.2%	46%
Junk mail	35%	55%
Using mobile devices	23%	54%
Potential vulnerabilities for possible attacks or damage	18.7%	13%

Source: iThome CIO 2018 [44], ISTR 2018 Survey [39].

4. Conclusions

Information security will become a focus of corporate investment as impacts from information security threats intensify. This study integrated domestic and foreign survey data and drew conclusions regarding information security approaches for building smart cities in Taiwan from the aspects of information security manpower, information security threats, and information security management.

First, in terms of information security manpower, enterprises in Taiwan have started to hire more information security personnel than ever before because of the accentuated information security threats. According to iThome survey [43,44], enterprises on average had 3.5 information security staff members, and among all industries, those in the financial industry had the highest number of information security staff members (10 on average). Nonetheless, there was still a shortage in information security manpower. In 2018, 21% of enterprises would like to employ information security personnel, and in the financial industry, 62.5% of enterprises have information security job openings. Thus, 2018 can be said to be the year of information security manpower training and the beginning of the war for obtaining information security talents. In terms of security management, information security personnel have budgets, interconnection, and personnel as the critical limiting factors. With the development of machine learning, big data, intelligence threats, end-point detection and response, and changes in threat situations, how to acquire capabilities for in-process detection and quick threat response is a practical consideration for all enterprises. Therefore, managed detection responses and security services have become critical because they can resolve the problems of insufficient manpower and technology and, thus, have been adopted by many enterprises.

Second, regarding information security threats, because of extensively used digital equipment and applications, advancing ICT, AI-based information security, and AI technology-boosted future information security defense systems, information security will be more critical than ever before because of the development of smart IoT devices. Information security incidents occurred frequently in 2017, and the types of attack have become increasingly complex and difficult to prevent. Moreover, with the boom of the IoT, even more conventional industries will have to implement an information security system. In the future, AI technology will be integrated into information security to enhance defense systems (e.g., a smart collaborative defense system) [45]. This is an area that is worthy of attention, and some key points include enhancing the precision of intelligence analysis, analyzing abnormality readings based on behavior, enhancing efficiency through identity certification, sandbox testing, and system vulnerability detection and fixing will be critical [40].

Third, regarding information security management, after several major information security incidents hit international headlines, Taiwan's competent authorities finally began to request that companies set up directors and divisions that are responsible specifically for information security. Whether this measure will affect the future trend is worthy of investigation. Known as the most stringent data protection law in history, the latest version of the General Data Protection Regulation of the European Union has caused great pressure for many enterprises worldwide because the penalty for breaching this regulation is the highest in the world: up to 4% of the global revenue of the enterprise. As a result, compliance with laws and regulations will be critical; enterprises in Taiwan must improve rapidly in this area to catch up. This year, the Executive Yuan proposed six sub-bills stipulating new information and communication security responsibility levels under the Capital Security Management Act. Government agencies will be required to take responsibility for the information security of their business domains. These bills will form a new set of unified information security management standards, similar to the information security operating standards of ISO27001, for Taiwan's government agencies. Sooner or later, this new set of standards will be applied to Taiwanese enterprises.

For people-oriented smart city development, all participating individuals and companies must take security and privacy seriously. For information security issues involving smart applications, adopting an appropriate information security approach is crucial. Network attacks are gradually shifting their target to critical infrastructures and strategic industries. In the worst-case scenario, network attacks may paralyze the social operating system [18,39]. When running a smart city, it is crucial to recognize that network attacks will inevitably and successfully break through the defenses [46]. In this era of fast network technology development, expansion, and popularization, network information security problems must be formally and cautiously handled and prevented by companies, the government, health and medical institutions, and schools of all sizes. In addition, insurance companies are responsible for assisting corporate legal personnel in risk prevention in advance and helping them with damage compensation restoration after the attacks to reduce losses. In this new era of network technology, the government should actively amend relevant laws to ensure that all companies fulfill their corporate responsibility to improve network information security [47].

The development of the new generation of information and communication technologies, such as Cloud computing, Big Data, Mobile Network, IoTs, etc., has brought vigorous business opportunities to smart cities [48] and has also brought new threats to information security. In the development of people-oriented smart cities, information security is a serious issue that must be confronted.

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sustainability

MDPI

Article

Towards a Smart and Sustainable City with the Involvement of Public Participation—The Case of Wroclaw

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Abstract: The purpose of this article is to identify the directions and scope of inclusion of the residents' participation into the concept of city's sustainable development and the smart city concept, taking into account national and international conditions, on the basis of Wroclaw's practices in 1998–2018. Many researchers have emphasized the necessity of including residents' participation in both the smart city concept and the sustainable city development concept, but they do not focus on a coherent linking of these activities during evolution toward a sustainable smart city (SSC). The in-depth case study analysis considered, i.e., three subsequent Wroclaw development strategies (1998–2018) and implementation of the smart city concept in Wroclaw (2015–2018) with particular emphasis on the issue of public participation and sustainable development of the city. The results of study show that in the case of the developments in the activities of smart city and sustainable city development carried out by Wroclaw, it is possible to identify two different approaches to residents' participation in city activities. In Wroclaw, 'residents' participation' in the framework of the sustainable city development activities currently covers all theoretical levels of participation, while within the smart city activities it focuses mainly on the participatory budget and the limited use of ICT. The conducted research indicates that for the implementation of the SSC concept it would be important to integrate these approaches in order to ensure the full range of residents' participation in accordance with theoretical postulates. The conducted analysis therefore covers mostly unexplored area of research, which is important from the point of view of a city's evolution toward becoming a sustainable smart city. The conclusions from the research are also an empirical contribution to the analysis of the changes of cities towards SSC and indicate the need for further, extended research on the undertaken problem.

Keywords: city sustainable development; smart city implementation concept; residents' participation; participatory budgeting; Wroclaw 1998–2018

1. Introduction

Public participation with the use of participatory budget as one of the 'tools' has become, in the recent years, a very important element of the decision-making process in the scope of activities aimed at improving the quality of city residents' life, in developing countries, as well as in developed countries [1–6]. In the 1990s, the need to use public participation was indicated in the scope of shaping public spending directions. Litvack and Seddon indicated that "local referendums, permanent public-private councils, and other institutional structures are other easily identifiable conditions that may improve the ability of local governments to identify and act on citizen preferences" [7] (p. 16). The public participation itself may include a very wide range of activities focused on various stakeholders [8–10] (i.e., residents, non-profits, businesses) and their roles (e.g., as advisory boards for social issues or development in planning, in supporting city management, in design new apps or trough participating in public decisions) in supporting smartization process [11], however in this work the focus will be placed on the consistency of the residents' participation (with particular emphasis on participatory budgeting (PB) with the concept of smart city and sustainable development (SD) of city on the example of Wroclaw. The reason for undertaking this research problem is on the one hand the observed in Poland's adaptation of public participation, particularly PB, to the urban development strategies (usually strongly embedded in the purposes of sustainable development), and on the other hand, a small number of publications analyzing this last problem [12–15]. Literature devoted to the public participation in the context of sustainable urban development usually includes selected elements of areas of the sustainable development (equity and social justice, economic development, environmental protection, urban governance) [12,16–21]. Examples of holistic approach to the issue of SD in the cities include among others: collective work of the *Public Participation in Sustainability Science: A Handbook* [22], Campbell's *Planner's Triangle Model* [23] indicating possible conflicts and ways to solve them (also with the inclusion of the negotiations and referendums with social groups), or the article by Weymouth and Hartz-Karp [24]. The literature emphasizes the role of public participation in the aspect of governance [25–29], while the analysis of the significance of public participation in the smart city concept cannot be found so often [13,30,31]. Also noteworthy is the concept of deliberative collaborative governance (DCG) and PB is one of its elements [27]. The purpose of this article is to try to identify the directions and scope of inclusion of the public participation into the concept of city's sustainable development and the smart city concept, taking into account national and international conditions, on the basis of Wroclaw's practices in 1998–2018. The time frames were determined by the dates of adopting subsequent development strategies by the city. This attempt is important due to the fact that in Polish conditions, the activities undertaken by cities aimed at harmonious combination of actions oriented to sustainable city development with the implementation of the smart city concept, have not been analyzed so far, particularly taking into account public participation in these two areas. In this context, the case of Wroclaw may constitute a relatively modest supplementation of the existing achievements of science associated with the sustainable smart city concept. The conducted analysis, apart from explaining the conditions of evolution in the approach to public participation and sustainable development from the perspective of creating and implementing city development strategies, contributes to the determination of the possibilities and limitations of adapting these actions into the practical implementation of the sustainable smart city concept. Simultaneously, the additional effect of the conducted analysis is the indication of the relations between the implementation of smart city solutions and sustainable city development. It also contributes to the sustainable and smart cities debate by adding empirical support to sustainable smart city concept and points out a largely unexplored area of research.

2. State of the Art

2.1. The Concept and Sources of Sustainable Development

Sustainable development (SD) is the main concept of global environmental policy [32–36]. Its main assumption is to ensure the possibility of society interaction with the environment, while reducing the risk of damaging the resource for the future. One of the most cited definitions of SD has been formulated in the report of the World Life Issues on Environment and Development (WCED) Commission led by G.H. Brundtland and entitled *Our Common Future* [37]. This commission indicated that "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" [37] (p. 16). It was also indicated here that economic and ecological goals should be linked to social goals. The latter are defined as fair opportunities of access to natural resources. As a result of noticed "failures of 'development' and failures in the management of our human environment", as well as "environmental trends that threaten to radically alter the planet" [37] (p. 10), the commission (among others) has been authorized to raise the levels of understanding and commitment to action of individuals, voluntary organizations, businesses, institutes, and governments.

From the point of view of this article, it is significant that this report indicates seven critical objectives connected with sustainable development [37] (p. 46): reviving growth; changing the quality of growth; meeting essential needs for jobs, food, energy, water, and sanitation; ensuring a sustainable level of population; conserving and enhancing the resource base: reorienting technology and managing risk; and merging environment and economics in decision making. In the commentary regarding the last objectives, the role of civil society participation was emphasized. It was indicated that "sustainability requires the enforcement of wider responsibilities for the impacts of decisions. This requires changes in the legal and institutional frameworks that will enforce the common interest (. . .). The law alone cannot enforce the common interest. It principally needs community knowledge and support, which entails greater public participation in the decisions that affect the environment. This is best secured by decentralizing the management of resources upon which local communities depend, and giving these communities an effective say over the use of these resources. It will also require promoting citizens' initiatives, empowering people's organizations, and strengthening local democracy" [37] (p. 56). Additionally, it may be indicated that "when the environmental impact of a proposed project is particularly high, public scrutiny of the case should be mandatory and, wherever feasible, the decision should be subject to prior public approval, perhaps by referendum". In the conclusion regarding Chapter 2: Towards Sustainable Development, as the first element conditioning the pursuit of sustainable development, a political system that secures effective citizen participation in decision making is listed, which more clearly emphasized the significance of public participation in sustainable development.

The above-mentioned report has become one of the reasons for organizing the United Nations Conference on Environment and Development (Rio Earth Summit, 1992), during which the issues regarding SD were fundamental in the discussions. One of the effects of Rio Earth Summit was the development of *Agenda 21* [38]—as the final document in which it was indicated that "sustainable development should become a priority item on the agenda of the international community" [38] (Chapter 2, sec.1). *Agenda 21* also recommends that national strategies be developed to address economic, social and environmental aspects of sustainable development. In the SD context, at the local (also urban) level in the Chapter 28, Local authorities' initiatives in support of *Agenda 21* (called also "local Agenda"), the issue of important role of local authorities is undertaken in the scope of fulfilling *Agenda 21* objectives "because so many of the problems and solutions being addressed by Agenda 21 have their roots in local activities" [38] (Chapt. 28, sect. 1). This results from the fact that local authorities' competences include a number of tasks associated with the "constructing, operating and maintaining economic, social and environmental infrastructure, overseeing planning processes, establishing local environmental policies and regulations, and assisting in the implementation of national and subnational environmental policies". It is important to point out that the role of local authorities (and therefore also cities) was emphasized as the level of governance closest to the people, which should play a key role in influencing, through educating, mobilizing and responding to the public, on building a positive SD reception among citizens. The assumption is that the local authorities should use the dialogue with citizens and other local entities, which through consultation and consensus-building will enable to develop local development strategies adapted to the specificity of local communities that will be consisted with a local *Agenda 21*. It should be noted that during this period, we had early experiences in the scope of participatory budget (PB) (period of trials between 1989 and 1997, which highlighted the initiatives in Porto Alegre in Brazil, and Montevideo in Uruguay [39]), therefore, due to the low significance of PB in this period, it was not indicated as one of the SD instruments at the local level. Due to the fact that in the 90s of the XX century, the main partner of authorities, which enabled "participatory democracy" consisted of non-governmental organizations, it was decided that formal and informal organizations, as well as grass-roots movements, should be recognized as partners in the implementation of *Agenda 21* [38].

As a consequence of the problems undertaken in the *Agenda 21*, the Millennium Development Goals (MDG) were adopted at the UN forum in 2000 [40]. The eight Millennium Goals were a commitment of the international community to (1) eradicate extreme poverty and hunger; (2) achieve universal primary education; (3) promote gender equality and empower women; (4) reduce child mortality; (5) improve maternal health; (6) combat HIV/AIDS, malaria and other diseases; (7) ensure environmental sustainability; and (8) develop a global partnership for development. The UN has set 18 targets and 48 indicators corresponding to these goals in order to monitor the implementation of MDGs at global, national and local levels [41]. It is easy to notice that the above-mentioned goals, targets, and indicators do not take into account the idea of civil society and its participation in activities for the benefit of sustainable development.

The literature indicates that the main area of *Agenda 21* consisted of the environmental aspects of SD [42]. The conclusion of this focus on environmental aspects was the change, postulated by Drexhage and Murphy report [42], which is important from the viewpoint of this work, using partnerships between government, business and civil society to identify and test new approaches, and to scale up promising approaches [42]. Noticed dysfunctions in the implementation of *Agenda 21* are associated with directing the implementation of activities to the environmental aspect (focus on the "environmental box"). During the summit entitled *2002 World Summit on Sustainable Development* (WSSD), the main emphasis has been placed on the social and economic development [43]. Redclif [44] indicated that SD after the first Earth Summit (1992), focused on rights, rather than needs, as the principal line of enquiry. In this context, the question arises whether PB in the scope of SD is a tool associated more with the implementation of rights or the improvement of the quality of life, thus satisfaction of the needs.

Along with the arising criticism of MDG and *Agenda 21*, the UN has undertaken actions in order to introduce a new development strategy *Transforming Our World: the 2030 Agenda for Sustainable Development* [45]. The Development Agenda replaces the Millennium Development Goals adopted in 2000. Development of the Agenda assumptions was carried out through international negotiations coordinated within the United Nations by the High Level Panel (HLP) on the *Post-2015 Development Agenda*. HLP announced recommendation for the next global development plan, taking into account results of the report entitled *A New Global Partnership: Eradicate Poverty and Transform Economies through Sustainable Development* [46]. The agenda contains 17 Sustainable Development Goals and 169 targets associated with them, which are monitored with appropriate indicators. From the viewpoint of this article, it is important to indicate that within the *Agenda 2030*, "Make cities and human settlements inclusive, safe, resilient and sustainable" was distinguished as one of the goals (goal 11). Noticing the significant increase in the role of cities in the settlement network and the association problems, the UN indicated that within goal 11, apart from targets that are a kind of continuation of MDGs [41,45], the target 11.3 was indicated, which is supposed to enhance inclusive and sustainable urbanization and capacity for participatory, integrated, and sustainable human settlement planning and management in all countries. One of the indicators of this target is the proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically. This means that, compared to earlier solutions, the role of citizens' participation in sustainable development has been emphasized in *Agenda 2030*.

2.2. Sustainable Development of Cities

In the context of cities, SD has no single definition and it is understood in a very different way, depending on the approach presented by the researchers [47]. Considering SD from the viewpoint of subject issues of this article, it may be assumed that the essence of SD in relation to cities recognizes that "a sustainable city is one which succeeds in balancing economic, environmental, and socio-cultural progress through processes of active citizen participation" [48] (p. 2). At the same time, it is indicated that "a 'sustainable city' is organised so as to enable all its citizens to meet their own needs and to enhance their well-being without damaging the natural world or endangering the living conditions of other people, now or in the future." [49] (p. 13). It is also necessary to emphasize that from this viewpoint, the urban form "must be of a form and scale appropriate to walking, cycling and efficient public transport, and with a compactness that encourages social interaction" [50] (p. 12). A very important aspect emphasized in relation to the achievement of SD in cities is the assumption that it should be "[a] development that does not require resources beyond its environmental capacity, is equitable, promotes social justice, and is created through inclusive decision-making procedures" [51] (p. 3). At the European level, the concept of SD was also defined assuming that "sustainable development is development that delivers basic environmental, social and economic services to all residents of a community without threatening the viability of the natural, built and social systems upon which the delivery of these services depends." [52] (p. 8). Such approach results from noticing that sustainable development is much boarder concept than environmental protection. In the *European Sustainable Cities—Report of the Expert Group on the Urban Environment*, it was indicated that "it embraces concerns for the quality of life, for equity between people in the present, for inter-generational equity, and for the social and ethical dimensions of human welfare." [52] (p. 8). In conclusion regarding the report, it is emphasized that "the sustainable development agenda provides new challenges for urban policy integration within holistic frameworks" [52] (p. 8).

In the context of sustainable development of cities, it is also necessary to indicate that measures have been taken within the EU in order to determine the principles and strategies of urban development policy. *The Leipzig Charter* is usually considered to be the key (although not the only) document [53]. According to the preamble of the above-mentioned charter: The "Leipzig Charter on Sustainable European Cities" is a document of the Member States which has been drawn up with the broad and transparent participation of European Stakeholders." [53] (p. 1). Two key objectives have been determined within the Charter: (1) making greater use of integrated urban development policy approaches; (2) putting emphasis on deprived neighborhoods within the context of the city as a whole. Target-specific strategies have been defined for each goal. An overview of selected EU activities in the area of sustainable development is presented in the Table 1.

Table 1. Selected EU measures in the scope of sustainable development of cities.

Year	Document	Main Topics
2007	*The Leipzig Charter*	The use of an integrated approach to urban development policy on a larger scale; creating and providing high-quality public spaces; modernization of infrastructure networks and improvement of energy efficiency; active innovation and education policy; drawing attention to the poorest districts in the context of the city as a whole; implementation of the quality strategy of the physical environment; strengthening the local economy and labor market policy; planning an efficient and cheap urban transport.
2010	*The Toledo Declaration*	A holistic approach, horizontal networking within and vertical networking between all levels involved, strategic planning at a city-wide level by means of an integrated urban development concept, linking the integrated approach to an area-based/spatial perspective, and linking the integrated approach to the aim of inclusion
2010	*Europe 2020 Strategy*	Smart, sustainable, and inclusive growth—(in the areas of employment, innovation, education, poverty reduction, and climate/energy)
2011	*Territorial Agenda (TA 2020)*	To build an inclusive, smart and sustainable Europe of diverse regions. It promotes place-based policy-making, which includes working in an integrated manner and multi-level dialogue, instead of single-sector and top-down approaches.
2011	*Cities of Tomorrow*	Report emphasises the importance of an integrated approach in order to achieve sustainable urban development (also need for governance)
2015	*Urban Agenda for the EU*	The inclusion of migrants and refugees, air quality, urban poverty, housing, circular economy, jobs and skills in the local economy, climate adaptation, energy transition, the sustainable use of land and nature-based solutions, urban mobility, digital transition, and innovative and responsible public procurement
2016	*The Pact of Amsterdam*	As in UA for EU 2010 and effective urban governance, including citizens' participation and new models of governance; governance across administrative boundaries and inter-municipal cooperation: urban–rural, urban–urban, and cross-border cooperation; link with territorial development and the Territorial Agenda 2020 (well-balanced territorial development);

Source: own elaboration based on [54].

2.3. Sustainable Development in Polish Cities in the Context of Selected Government Activities

In the course of implementing the assumptions of *Agenda 2030*, Poland created in 2017 *The Strategy for Responsible Development* (SRD), which is supposed to reflect the national approach to the issues of sustainable and responsible economic development. This approach was determined as "responsible development". According to the provisions of this strategy, it means "one which, in the process of strengthening competitiveness by means of new growth factors, allows the participation of and provides benefits to all social groups living in various parts of our country [...]. The focus is not solely on the total size of GDP, but rather on its quality as well as the perception of the development processes in the context of their importance for citizens" [55] (p. 27). The main goal of SRD was "to create conditions that foster income growth for all residents of Poland, while also increasing social, economic, environmental and territorial cohesion" [55] (p. 43). In the scope of this Strategy, three specific objectives related to individual goals of SDG were determined (Table 2).

Table 2. Main assumptions of SRD.

Main Objective of the SRD		
Specific Objective I	**Specific Objective II**	**Specific Objective III**
Sustainable economic growth increasingly driven by knowledge, data, and organizational excellence	Socially sensitive and territorially sustainable development	Effective state and economic institutions contributing to growth as well as social and economic inclusion
SDG: 2, 3, 4, 7, 8, 9, 10, 11, 12, 13, 16, 17	SDG: 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 16	SDG: 3, 8, 9, 11, 16, 17
Achieved through: The use of existing advantages and parallel creation of new ones in areas generating high added value, with greater and better use of knowledge and capital, as well as rational/effective use of resources.	Achieved through: Regional policy that promotes sustainable, lasting and self-maintaining development, in the scope of social policy, economic and financial instruments and differentiated approach to development (various types of territories, social groups).	Achieved through: Improving the quality of functioning of the state and institutions contributing to the development, including elimination of bureaucracy. Good management of the country and state assets, involving various entities, integrating different public policies and taking into account the specific conditions and needs of various territories, as well as based on the principle of open governing.

Source: own elaboration based on [55].

One of the intervention areas indicated in the SRD assumptions was (within specific objective II) strengthening of urban area development management, among others through developing and disseminating the principles of social participation in the management process, and also, in the case of areas threatened by marginalization, support for local initiatives and stimulation of activity of local communities at the commune level, in the scope of building a civil society and supporting local leaders (initiatives within the Sołecki Fund (Community Fund), participatory budgets, local crowdfunding programs), development of social participation in the process of local development management (e.g., the promotion of good practices) [56]. In the report entitled *Implementation of the Sustainable Development Goals in Poland* [57], the national SDG achievement priorities were indicated. The basic goals include in this case, among others, switching from an administration system to governance. Also, the analysis of convergence of the SRD priority areas with the goals and targets of the 2030 Agenda was carried out. The following areas were recognized as the ones with the highest convergence: education, participation, social inclusion, GDP growth, financial services, infrastructure, research and development, economic innovation, entrepreneurship, employment, sustainable agriculture, industry, adaptation to climate change, and pollution. Activities in the scope of urban policy in Poland are focused on the improvement of the development conditions of Polish cities, and the first of them is the dissemination of the principles of public participation in decision-making and management of cities and their functional areas. The above-mentioned activities include the project initiated by the Ministry of Development entitled Human Smart Cities—smart cities co-created by the inhabitants [58]. Among others, this project includes the thematic area defined as "Innovative solutions aimed at supporting the social participation, as an element necessary for an intelligent city co-created by the inhabitants (3.0 Human Smart City)" [59].

The above-mentioned activities are consisted with the priorities of a *National Urban Policy 2023* (NUP) [60], created in 2015, where the necessity of public participation (including municipal-level dialogue and public consultations in the development process) is one of the highlighted thematic areas. The goal of the NUP is to strengthen the capacity of cities and urbanized areas for sustainable development and job creation, as well as improving the quality of life of the residents. Five specific objectives relating to the basic issue areas and contributing to the achievement of the strategic objective have been indicated [60]: (1) efficient (creating conditions for efficient, effective and partner management of development in urban areas, including especially in metropolitan areas); (2) compact and sustainable (supporting sustainable development of urban centers, including counteracting negative phenomena of uncontrolled suburbanization); (3) coherent (reconstruction of the development potential by regeneration of socially, economically and physically degraded urban areas); (4) competitive (improved competitiveness and potential to create development, growth and jobs of major urban centers); (5) strong (support for development of subregional and local urban centers, primarily in problem areas of regional policy (and in certain rural areas) by strengthening their functions and counteracting their economic collapse).

It should be emphasized that the NUP very strongly underlines the importance of public participation in the implementation of each of these goals, while its importance in the first goal is emphasized in the strongest manner. In regard to the participation, the consultations with citizens are indicated as the main process—where the following are recognized as the basic tools: participative budgets, civic legislative initiative, activating measures (picnics, cultural activities etc.), survey research, study works (workshops, laboratories, joint projects, PPGIS), on-line consultations).

From the viewpoint of this work, it is necessary to note the connection indicated in the NUP between the proposed urban policy and the smart city concept. NUP's authors directly indicate that the main idea of NUP "can be naturally identified with the concept of smart cities in its broadest, not narrow, industry understanding" [60] (p. 15). It is also emphasized here that the technological sphere must be accompanied by "intelligent" activities in other spheres of functioning, while "wisdom" of the city is expressed in an integrated approach to planning and transforming the city, as well as managing it. In accordance with the provisions of NUP, the cities should actively seek and then apply solutions enabling the rationalization of expenses, more effective management of various aspects of the city's functioning, as well as more precise and faster reacting to the diagnosed problems. In the opinion of NUP's authors, only such view of the 'learning' city allows to qualify the city as a smart city. This approach also indicates the method for measuring success—the primary measure will be the constantly increasing quality of the residents' life.

2.4. The Concept of Smart City and Smart Sustainable City

The concept of a smart city appeared in 1997 (Graham and Aurigi [61,62]), along with the increase in the possibility of using ICT tools for communicating with residents, collecting data or using this data to manage the city. It is difficult to indicate one universal definition of the concept of a smart city. In 2000, Hall et al. indicated that "a city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizen" [63] (p. 1). Therefore, 'smart city' in this definition was associated with the use of ICT to support the delivery of public services. In Komninos' definition from 2006 (cited quite often) a smart city is defined as "territories with high capacity for learning and innovation, which is built—in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management" [64] (p. 13). The idea of 'smart city' in the report entitled *Smart Cities—Ranking of European Medium-Sized Cities* is defined quite differently (more broadly), because it indicates that smart city is a city well performing in a forward-looking way in [..] six characteristics [economy, people, governance, mobility, environment, and living], built on the smart combination of endowments and activities of self-decisive, independent and aware citizen" [65] (p. 11). Caragliu et al. identifies smart city with the situation "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance." [66] (p. 71). The above-mentioned definition is largely based on the aforementioned six characteristics of smart city. It should be noted that the concept of participatory governance appears here in the context of smart city. Most definitions emphasize the importance of ICT in defining smart cities. Moreover, in practice, the multitude of approaches is visible similar to the concept of smart city, which translates into the use of alternative concepts resulting from highlighting the most important implementation areas in a given city. Anthopoulos and Fitsilis [67] separated seven groups of cities, apart from smart cities: (1) web (virtual) cities (focused mainly on provision of information, on-line communication capabilities and cyberspace); (2) knowledge cities (digital public repositories with crowd sourcing options accessible via ICT); (3) broadband cities/metropolies (with ultra-high speed networks in the urban area); (4) mobile cities (with wireless broadband networks accessible across the city); (5) digital/information cities (with ICT environment across the city for support of local needs and transactions, building local information society and creating sustainable local development); (6) ubiquitous cities (extension of the digital or information city in enabling ubiquitous service provision and data flow from anywhere to everyone, due to the use of chips or sensors built-in urban infrastructure); (7) eco cities (as ubiquitous cities focused on sustainable growth and for environmental protection). It is also worth noting that the definition used by the International Organization for Standardization [68] (p. 3), which indicates that smart city is "a new concept and a new model, which applies the new generation of information technologies, such as the internet of things, cloud computing, big data and space/geographical information integration, to facilitate the planning, construction, management and smart services of cities". At the same time, the following goals of smart city are emphasized [68]: convenience of the public services; delicacy of city management; liability of living environment; smartness of infrastructure; long-term effectiveness of network security. Analysis of smart city evolution was carried out by Cohen [69], who distinguished its three generations. In the smart city of the third generation, the initiative is taken over by city residents. The city authorities play the role of an assistant, observer or they support the process of communication.

From the viewpoint of this article, it should be noted that the concept of smart city can be also considered in terms of research issues undertaken by scientists. A holistic and interdisciplinary approach to the issue of SC research in the cities and villages is presented in papers of Visvizi and Lytras [70–72] . They argue [71] (p. 134) "that smart cities research needs to be based on real tangible experiences of individuals inhabiting rural and urban space and that it also needs to mirror and feed into policy-design and policymaking processes". Visvizi and Lytras notice also that [72] (p. 1) "the application and usability of ICT in the context of a village remained underdiscussed in the literature" introducing the idea of the 'smart village' into the debate. Annapoulos et al. [73] carried out a review and comparison of the smart city conceptualization models, indicating architecture, governance, planning and management, data and knowledge, facilities, services, people, and finally environment as occurring directions of conceptualization. It should be emphasized that the occurrence of a trend in the literature, which binds the smart city with governance, indicated in [73], due to the capacity of the governance concept may refer to various issues, depending on the author. The concept of governance is defined, for example, as "the process by which we collectively solve our problems and meet our society's needs" [74] (p. 24), while Pierre defines governance as "the process through which local authorities, in concert with private interests, seek to enhance collective goals. It is a process shaped by those systems of political, economic and social values from which the urban regime derives its legitimacy" [75] (p. 373). Stoker [76] (p. 18) indicated that it is possible to distinguish the following aspects of governance: (1) it refers to a set of institutions and actors that are drawn from but also beyond government; (2) it identifies the blurring of boundaries and responsibilities for tackling social and economic issues; (3) it identifies the power dependence involved in the relationships between institutions involved in collective action; (4) it is about autonomous self-governing networks of actors; (5) it recognizes the capacity to get things done which does not rest on the power of government to command or use its authority. It sees government as able to use new tools and techniques to steer and guide. It is noticeable that citizen participation appears in the context of governance. There are many analyses that take into account the role of participatory governance (PG) and citizen involvement in the concept of smart city [65,77–80]. The PG itself may apply to many areas. For example, based on the review of literature dealing with the topics of PG mechanisms in developing countries, Speer [81] identified four main strands to use for partitioning the literature: (1) the democratic decentralization strand, (2) the deliberative democracy strand, (3) the empowerment strand, (4) the self-governance strand. As a consequence, the inclusion of the governance area in the concept of smart city may, among others due to participation, support the process of good governance by making it more efficient, fair, transparent, and legal. In accordance with the UN concept, the good governance is supposed to be characterized by the following eight basic characteristics: participatory, consensus oriented, accountable, transparent, responsive, effective and efficient, equitable and inclusive and follows the rule of law [82]. In 2008, the Council of Europe [83] identified 12 principles of good governance at local level. They include: fair conduct of elections, representation, and participation; responsiveness; efficiency and effectiveness; openness and transparency; rule of law; ethical conduct; competence and capacity; innovation and openness to change; sustainability and long-term orientation; sound financial management; human rights; cultural diversity and social cohesion; accountability. The implementation of most of the above-mentioned principles can be supported, which is easy to notice, due to implementation of the concept of smart city. It should be also noted that by many researchers recognized the implementation of good governance as one of the conditions of successful economic development [84].

The concept of smart sustainable cities appears in the source literature as an effect of parallel occurrence in practice, within one city of activities in the framework of sustainable city development and the adoption of solutions in the scope of smart city [30,85–89]. The problem in defining a smart sustainable city lies primarily in the lack of coherence within both concepts, as well as in the fact that they are overlapping. UN Economic Comission and ITU define smart sustainable city as innovative city "that uses information and communication technologies (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" [90]. Sometimes, the role of smart city in sustainable development is also indicated—"the smart city with its digitally mediated, efficient and integrated infrastructure is positioned as a facilitator of sustainable development by aligning the aims of environmental protection, social equity and economic development" [91] (p. 271). Whereas, Bibri [92] indicated that the concept of 'smart sustainable city' is used to describe a city that is supported by the pervasive presence and massive use of advanced ICT, which, in connection with various urban systems and domains and how these intricately interrelate and are coordinated respectively, enable the city to control available resources safely, sustainably, and efficiently to improve economic and societal outcomes. Höjer and Wangel [93] (p. 344) point out that "cities can be made sustainable without the use of smart (ICT) technology, and smart technologies can be used in cities without contributing to sustainable development. [. . .]. It is only when all these three aspects are combined, when smart technologies are used for making cities more sustainable, that we can speak of Smart Sustainable Cities". On the other side, in a recent in-depth literature review D'Auria and co-authors [94] (p. 11) indicate that in the literature "often [. . .] the sustainable city is considered an evolution or an advanced version of the smart city". Authors underline that smart city conception is an evolution of a digital city concept (by adding to ICT and innovation "human features of city life") and next they define the sustainable city concept as "a new approach [to smart city] through the filter of a new philosophy" [94]. The main change is inclusion of an "equitable and balanced setting of goals in line with the principles of sustainable development" [94]. D'Auria et al. point that there are different elements of change and expected goals and that evolution from a digital city to the sustainable city should be described more as a "change" ("because it represents a suitable way to describe the evolution that cities have experienced in recent years, regardless of the perspective" [94]). They also notice that a smart city can be considered as a base for creating activities ensuring city sustainable development and that smartization process significantly supports "sustainable urban development" and improves "quality of life".

On the basis of conducted analyses, Dhingra and Chattopadhyay [95] (p. 551) indicate that it is possible to recognize a city as a smart sustainable city (SSC), when one of the seven important goals is "achieved in an adaptable, reliable, scalable, accessible and resilient manner". These goals include: (1) improve quality of life of its citizens; (2) ensure economic growth with better employment opportunities; (3) improve well-being of its citizens by ensuring access to social and community services; (4) establish an environmentally responsible and sustainable approach to development; (5) ensure efficient service delivery of basic services and infrastructure such as public transportation, water supply and drainage, telecommunication, and other utilities; (6) ability to address climate change and environmental issues; (7) provide an effective regulatory and local governance mechanism ensuring equitable policies.

In this context, the diagnosis of the SSC term's origin proposed by Nam and co-authors seems to be interesting [79]. Adding the word "smart" to sustainable city indicates that SSC "is required to adapt itself to the user needs and to provide customized interfaces" [79] (p. 283). The idea of using the (neoliberal) concept of a smart city in order to achieve sustainable development it is not uncritically accepted. It is subjected to criticism more and more often, because the possible tensions between SD and SC are indicated, which may include [91]: (1) reinforcing neoliberal economic growth; (2) focusing on more affluent populations; (3) disempowering and marginalizing citizens; (4) neglecting environmental protection; and, (5) failing to challenge prevailing consumerist cultures. Martin, Evans, and Karvonen indicate that in the some studies, there are doubts reported whether digitization can actually deliver sustainability, especially from the perspective of environmental protection and social equity [91]. From the viewpoint of this article, the third tension is significant—because an allegation appears in the literature that "rather than being empowered to participate in the smart city, citizens are instrumentalised as another efficient component of the digital infrastructure" [91] (after [96]). The authors of the above-mentioned analysis also indicated that increase in the role of "smart engagement could marginalise citizens further from practices of urban governance as global technology companies take responsibility for services previously provided by local government [91] (after [86,97].). This may result from the fact notices by the researchers that "digital innovations have been designed based on the assumption that structural problems can be resolved through changes in the behaviour of individual citizens" [91] (p. 273). On the other hand, the analysis conducted by them indicates the communes' growing interest in regard to the use of ICT, in order to empower citizens and increase citizen inclusion in urban governance, whereas it should be noted that other innovations in the scope of citizen participation were also used within the smart city initiatives [91]. This is important, because it confirms that the concept of smart city is currently defined not only through the prism of using ICT.

2.5. Participation and Participatory Budget

Growth of the interest in public (citizen) participation since 1989 [39] is often associated with the hope of using various forms of cooperation between local authorities and residents, in order to better adapt public services to the needs reported by the residents [1,12,20,84,98–102]. Other goals of participation consist of social goals, such as [103]: (1) educating the public; (2) incorporating public values, assumptions, and preferences into decision making; (3) increasing the substantive quality of decisions; (4) fostering trust in institutions; (5) reducing conflict; and (6) making decisions cost-effectively. In the case of the last goal, it should be noted that it is a measure of the legitimacy of individual forms of social participation. Juxtaposition of the costs of individual types of participation with achievable or expected effects often provide the possibility of choosing a more favorable form of participation. In the context of this article, the concept of public participation will refer in a wide sense to enabling citizens to participate in the activities of public administration entities. However, the literature indicates a large variety of forms of such engagement of the citizens [104]. It is necessary to refer here to one of the first and most frequently cited method for determining the essence of social participation, proposed by Sherry R. Arnstein in 1969 [105]. In this concept, the participation refers to the influence of "minorities" on the decision of those who manage. The typology of participation types has been arranged hierarchically here, along with the increase of the decision-making power of stakeholders. Arnstein divided the participation levels into three groups. Firstly, nonparticipation (manipulation and therapy rungs); secondly, tokenism (information, consultation and placation); thirdly, citizen power (partnership, delegated power, citizen control). The lowest levels of this 'ladder'—manipulation and therapy do not constitute the real participation, because they are aimed at shaping attitudes of stakeholders by those who manage ('illusory participation'). Subsequent levels of participation—information, consultation, and placation—constitute only a small part of proper participation, because besides getting information about the implemented task, citizens are not able to influence their form (informing) or, despite listening to stakeholders, collecting surveys, conducting other studies, the authorities do not undertake actions aimed at implementing the collected suggestions (consultations) or there is no possibility of influencing the actual actions of the authorities by the representatives of stakeholders participating in the planning and implementation of tasks [106]. In the Arnstein's opinion, only from the level of partnership, through the delegation of power to the taking over of control over the actions, we will be dealing with real participation. Thus, in the case of partnership, in the process of negotiation and co-responsibility, the stakeholders are able to influence the decisions of those who govern. In turn, when introducing elements of delegating power, the stakeholders will mainly decide about the shape of a given project. Whereas, the full participation will mean taking control over a part of government activities in the relevant area. Classification proposed by Arnstein contributed to Connor's considerations, who proposed a new ladder of citizen participation in 1988 [107], indicating two groups of participants—general public and leaders. The essence of this approach was to consider a ladder of participation in terms of the possibility to mitigate the tensions/conflicts associated with the selection of a given project. In the case of this division, it should be pointed out that the division of participation levels into individual groups has been clearly identified. The general public participates through participation in education (the lowest level), information feedback, and consultation. In Connor's opinion, this means (which seems to be logical) that only few from this group will become leaders (analogically as in, e.g., politics, science, or sport), who will get the possibility of joint planning ("one window approach"), mediation, litigation and resolution/prevention. On the other hand, Wilcox [108] describes the problem of participation in three dimensions: levels of participation (information, consultation, deciding together, acting together, and supporting independent community initiatives), phases of participation (initiation, preparation, participation, and continuation), and the people involved (local groups, businesses, residents, activists, officers, politicians). In this approach, the actual participation of stakeholders may mean joint decision-making in the case of most people, as well as initiating or preparing actions in the case of 'leaders'. Different approach to participation is presented by Creighton [109]. Definition adopted by Creighton emphasizes that that public participation is a process by which public concerns, needs and values are incorporated into governmental and corporate decision-making procedures; it is a two-way communication and interaction that is guided by one general goal—better decisions supported by the public opinion [109]. Creighton emphasizes the continuity of communication process with the stakeholders, associated with its subsequent stages, usually following one after another (inform the public, listen to the public, engage in problem solving, develop agreements). Rowe and Frewer [110] also highlight the aspect of the flow of information between participants and sponsors (e.g., governmental or regulatory agency), distinguishing public communication (one-way information flow and no involvement of the public), public consultation (a process initiated by the sponsor and there is a public feedback understood as public opinion concerning a given issue), and public participation (information is exchanged between members of the public and the sponsors, dialogue and negotiations occur). A frequently cited division of participation is the division defined by the International Association of Public Participation (IAP2) [111], which distinguishes five levels of participation (inform, consult, involve, collaborate and empower), however it is necessary to indicate here the core values for public participation defined by IAP2. From our viewpoint, the following two are the most important: "public participation includes the promise that the public's contribution will influence the decision" and [it] "promotes sustainable decisions by recognizing and communicating the needs and interests of all participants, including decision makers" [111].

Depending on the participation level, different tools may be used. At the lowest levels, the following may be used for the purposes of informing: act sheets, websites, open house, exhibitions, leaflets, or participatory innovation platforms [112–115]. Along with the increase in the demand for feedback, the following may be used: public comment, focus groups, surveys, public meetings up to the forms, in which the citizens have the possibility of direct influence through citizen advisory committees, participatory decision-making (budgets), citizen juries etc. The participatory budget can be considered to be one of the most fully consistent participation tools in regard to the concept of governance. In the introduction to the book entitled *Hope for Democracy: 30 Years of Participatory Budgeting Worldwide* [5] (p. 3), Dias indicated, on the basis of observation from over 30 countries all over the world, that participatory budgeting processes: (1) emerged and developed in contexts of multiple crises and, in some cases, as a response to these crises (lack of trust in institutions and political elites, conflicts of various kinds, disasters, etc.) [. . .]; (2) have a capacity for action and production of impacts proportional to their own dimension, which, in most cases, is limited or circumstantial; (3) have a "methodological and conceptual elasticity" that has allowed their adaptation to different contexts and for different purposes, residing in this particular one of the main success factors for a territorial extension as vast as the one recorded so far. Wampler [116] defines participatory budgeting as a decision-making process, in which residents/citizens discuss and negotiate the method of distribution of public funds. Goldfrank [117] notices that this process is open to any citizen, who wants to participate in it. It combines the forms of indirect and direct democracy, requires discussion and contributes to the redistribution of resources. While introducing us to the topic of PB, Shah [118] (p. 1) indicates that "it is a tool for educating, engaging, and empowering citizens and strengthening demand for good governance. The enhanced transparency and accountability that participatory budgeting creates can help reduce government inefficiency and curb clientelism, patronage, and corruption". A similar approach is indicated by Sintomer, Herzberg, and Rocke [3], who identify the key issues for PB: (1) there has to be discussion of the financial and/or budgetary dimension; (2) participation of those responsible for budgeting policy administration; (3) it has to be a repeated process (e.g., every year); (4) it must include some form of public deliberation; (5) some accountability on the output is required.

Usually, the following characteristics are indicated in the case of participatory budget in Poland [98,106,119]: basis for the functioning of PB is the local (commune) law, the initiator of such activities consists of local authorities, it is supposed to improve the quality of life through the implementation of actions reported and selected by residents, it is a continuous, cyclical process with a long-term horizon, involving a wide groups of residents and having an educational aspect. In 2018, it became a mandatory activity of large cities in Poland under national law. Article 5a of the *Local Government Act* (LGA) [120] determines that "local legislative bodies have the power to consult with local residents on major issues for the municipality". This results in the possibility of communes introducing social consultations, among others, concerning the directions, scale and methods of spending public funds. Unfortunately, the general nature of this regulation resulted in the fact that the introduction of PB in Poland encountered major problems, which include [119]: (1) total freedom of the local authorities in undertaking decisions on the conduct of consultations (of any kind); (2) great freedom of the local authorities as to the choice of formula of consultations; (3) lack of necessity to realize the selected by residents budgetary tasks for realization in the framework of the budget; (4) diverse scale of bottom-up disbursement of funds; (5) lack of formal separation of the participatory budget from the entity budget; (6) indication (selection) of the authorized participants of the consultation procedures; (7) pre-defined by local government authorities areas of expenditure. This resulted in an extensive diversification of scales and forms of the PB introduction as a participation form in the cities.

3. Materials and Methods

In this paper, the authors decided to analyze the role of public participation in the context of the development of the smart city concept, as well as the sustainable city concept with the use of Wroclaw qualitative single-case study. Bansal [121] (p. 127) indicates that "qualitative research is based on textual data, drawn from researchers' observations, interviews, analyses of archival manuscripts, and other similar sources". In the literature, case study is usually perceived as a research method that serves an in-depth examination of a single example of a class of phenomena. There is a dispute as to the meaning and possibility of using case study method in social sciences [122], but in order to understand a complex issue of a different approach to residents' participation, in-depth case-study research was necessary. The premise for undertaking research, was observed by the authors changes and differences in approaches to residents' participation in the strategies of sustainable city development and in the area of smart city implementation.

Wroclaw is situated in southwest part of Poland, between Berlin (300 km), Warsaw (300 km), and Prague (220 km). It is a capital of Lower Silesia voivodeship (region, NUTS-2). It is one of the medium-sized cities in Europe with a population of about 635,000 and it is also one of "second tier cities" [123]. Wroclaw covers an area of 293 km^2 (more: [124]). Also, it is one of the main communication nodes of the south-western Poland (E-30 railway line, A4 motorway, S-5 and S-8 roads) and important communication artery of Europe. It is a city of science and education—there are 13 universities located here, including several of the highest national rank, as well as many significant cultural institutions, and it is a center of economic development, placed by analysts in the forefront of the most developing cities in Poland, while having the image of the center of growth area with European importance, as well as a city of diversified economy, various industries, rapidly growing sector of financial services, entrepreneurial services, and extensive transport services. The reason for selecting Wroclaw as the case of research is that the city met the following conditions:

- The existence of a city development strategy that takes into account sustainable development of the city and participation of residents;
- Undertaking by the city the activities in the smart city area within the framework of a policy defined by the city (not individual actions detached from each other), including the role and forms of participation of residents and sustainable development of the city;
- The existence of defined different forms of participation within both areas;
- Relatively long period of co-existence of strategy, smart city activities, and participation of residents, allowing observation of the effects of the implemented solutions.

The selected city is an example of a city, which is evolving towards a smart and sustainable city, whereas the belief of Wroclaw authorities about the important role of public participation in the development of the city has been increasing since the 1990s. This results in the increase in the role of public participation indicated in strategic documents, which results in practical merging of Wroclaw's activities carried out in the scope of smart city and sustainable city development, i.e., striving to become a smart sustainable city. From the point of view of the contribution to the field of research on sustainable and smart cities, it should be noted that the case of Wroclaw can be treated as a catalyst or starting point for research on the coherence of public participation solutions in sustainable city development and smart city programs in regional centers in Poland and Europe.

The structure of presented article reflects the course of performed research works. This article is divided into three main parts. The first one is devoted to the analysis of the scientific achievements in the scope of undertaken research problem and the analysis of national and international action plans, particularly:

- Firstly, in order to embed the case study in the broader context, the authors reviewed literature on sustainable development, sustainable urban development and main United Nations (UN) program documents in the scope of sustainable development, taking into account urban development in the context of the role and forms of public participation indicated in these documents.
- Secondly, the authors reviewed national regulations concerning sustainable development and urban development corresponding to the UN strategies and documents, also taking into account the role of public participation indicated in them.
- Thirdly, the authors analyzed the literature regarding the concept of smart cities, taking into account the importance and scope of public participation of this concept, as well as carried out the analysis of connections of the concept of smart city with the concept of sustainable development, particularly in the area of public participation.

The second part was devoted to the analysis of the case study, which included:

- Firstly, the analysis of three subsequent city strategies (1998, 2006, 2018) in the context of participation and sustainable development.
- Secondly, the analysis of implementation of the smart city concept in Wroclaw (2015–2018), taking into account the significance of participation and sustainable development was done.
- In addition, the work involved analysis of data concerning the participation of residents in subsequent editions of the participatory budget of Wroclaw.

As a consequence, an attempt was made to identify the directions and scope of inclusion of public participation in the concept of sustainable city development, as well as the concept of smart cities, taking into account the national and international conditions.

4. Analysis of Wroclaw's Strategy from the Years 1998–2018 in the Context of Evolution of the Participation and Sustainable Development

20 years have passed from the moment of preparation and implementation of the Wroclaw's first development strategy. During this time, two subsequent strategies were developed and adopted, constituting a response to the dynamically changing conditions of the city's functioning. In 1998, less than a year after the flood, which destroyed a large part of the city, the Wroclaw City Council adopted the development strategy entitled *Strategy—Wroclaw 2000 Plus* [125], which was supposed to be a medium-term document, with the horizon of the first decade of the century. In 2006, the Wroclaw City Council adopted a resolution concerning the update of city's development strategy—*Strategy—Wroclaw in the 2020 Plus Perspective* [126]. It was mainly focused on the implementation of extensive infrastructure undertakings. This strategy was adopted shortly after Poland's accession to the European Union, therefore the possibility of obtaining EU subsidies had a considerable impact on its shape. The development directions that during that time seemed the most attractive, required verification over time. The answer was the development and adoption of the *Development Strategy for the City of Wroclaw until 2030* [127], which occurred in 2018.

In the last 20 years, the above-mentioned documents determined the desired directions of Wroclaw's development, indicating the most important goals that the city faced in this regard, as well as the methods of their implementation. In the context of this study, the emphasis should be mainly placed on two issues—evolution of the significance of the participation in subsequent strategies of Wroclaw and their consideration of issues associated with the sustainable development of the city (Figure S1: Timeline of case study).

4.1. Wroclaw's Development Strategy Strategy—Wroclaw 2000 Plus

Wroclaw's development directions defined based on the diagnosed challenges (demographic, political, economic, health, ecological, infrastructural, institutional, to cultural or psychosocial), among others, focused on: increase in the number of residents up to approx. one million in the perspective of 2050, taking into account the care for a new generation of Wroclaw residents; supporting economic development; maintaining a significant position in the scope of culture, science and art; development of urban space, including solving communication problems in the city through repair, investment and organizational measures that reconcile the needs of transit and local traffic, as well as individual and collective communication; improving the quality of residents' life, taking into account the issue of the condition of natural environment, health, safety, education, and level of participation in social life, including the actual impact on decisions regarding individual and collective life; changes in the ownership structure; building a sense of identity, belonging and co-responsibility of residents for the city's development, as well as efficient functioning of city authorities.

The above-mentioned directions have been included in the city's mission: "Wroclaw is a meeting place—it is a city that unites", referring to the idea of exchange of values, goods, services, and concepts. The implementation of such formulated mission required the pursuit of six strategic goals:

- developing the Wroclaw's urban functions as a regional metropolis and the center of meetings and exchanges of European significance;
- building the Wroclaw's identity and improving the identification of residents with the city, particularly through science and art;
- creating conditions for the broader economic, civic, and social activity of the residents;
- adapting the urban structures to the aspirations of residents, as well as the specificity of districts and housing estates;
- developing the social fabric of the city, as well as its institutional reconstruction;
- developing the city's technical infrastructure.

Within the *Strategy—Wroclaw 2000 Plus* [125], a series of strategic programs was formulated, which concerned infrastructure, as well as social problems. One of them was the program entitled "Decentralization", which was aimed at unblocking civic activity through decentralization of the city management and supporting the implementation of local development goals. Among others, this program assumed the following by 2002: (a) changing the city's constitutional concept as a single commune by dividing the city into the city center and other local centers, adapting the functioning of auxiliary units of the city council and city management to such division, granting maximum competences to the neighborhood councils; (b) supporting the emergence process of local activists; (c) opening the city to the initiatives of various groups and communities, aimed at the development of local communities and achievement of group goals; (d) increasing the possibilities of inclusion of various groups into activities for the development of local communities and the city (among others through the revival of committees, councils and organizations, creation of information networks regarding their functioning and a forum for exchanging experiences).

In relation to the challenges associated with striving for sustainable development of Wroclaw, the program entitled "Traffic Jam Elimination in Wrocław" was formulated and it was aimed at creating conditions for efficient, safe and environmentally-friendly transport of people and goods. Among others, the program assumed the following by 2010: construction of the Wroclaw motorway bypass, creation of P&R parking system on the outskirts of Wroclaw, which was supposed to reduce the car traffic in the city center, modernization of the tramway system and construction of new connections. Equally important was the program entitled "city on the river" aimed at creating the spatial identity of Wroclaw as a city associated with the Oder and its tributaries. Among others, this program focused on: reconstruction and expansion of the Oder boulevards, as well as associated infrastructure of walking routes, implementation of the program transforming the great island (housing estates located on the island) into the area of ecological development and recreation center. The program entitled "Quality of Life" was also extremely important and it focused on the continuous improvement of the quality of life of residents through ecologically motivated investment activities, as well as appropriate social policy. Among other things, it envisioned extension of the spatial offer for recreation, reliability of installation and supply of clean drinking water, completion of the city's essential sewerage investments, improvement of city cleanliness, creation of a child-friendly city.

4.2. Strategy—Wroclaw in the 2020 Plus Perspective

Mission in the new city strategy has not changed, remaining the unchanged axis of actions. It was indicated that its maintenance is equal to the focus on building a city that provides the possibilities for meetings and exchange of ideas, goods and services, which is attractive and friendly for the residents and visitors, conducive to understanding, responsible, and responsive to the challenges of the future, open to friendly interaction of various cultures and views. The *Wroclaw 2020 plus* strategy defined the fundamental recommendations and directions of the city's development from a perspective of:

- people (being: health, safety, housing, education: educating citizens, training specialists, work: city's economic policy, places of work, employees, self-fulfilment);
- community (Wroclaw residents: symbolic community, families, neighborhoods and housing estates, academic sphere, culture sphere, social organizations and civic movements, visitors and immigrants);
- external communities;
- space (housing, public, economic, recreation, information, communication);
- self-government (thinking, governing, inspiring, public service).

The above-mentioned areas cover strategic questions concerning the development dilemmas, guidelines regarding changes and proposals for undertaking that support implementation of the strategy.

In relation to the significance of participation in the city's development, the area of 'community' was extremely important, particularly the scope of 'symbolic community', where the following were recognized, among others, as the appropriate directions of actions:

- informing citizens; providing them with knowledge regarding the choices the city is facing;
- developing civic attitudes via debates concerning common issues, promoting the city directed inwards, participation of media focused on discussion;
- positive response to civic initiatives, directing resources in the first place, where you can count on the participation of residents.

However, for such a broadly defined range of indications, the strategy did not determine specific proposals for actions that would enable their effective implementation.

The scopes of 'neighborhoods, housing estates' and 'social organizations and civic movements', which were distinguished in the same area, seem to be equally significant. The first of them formulates the postulates of supporting grassroots initiatives, increasing neighborhood self-governance, building a reciprocal relations between the cities and neighboring communities, maintaining the primacy of the common good over the particular good. The tool aimed at enabling their implementation was supposed to be, among others, a pilot program for the autonomy of the selected housing estate. The second area focused on the possibilities of using the potential of social organizations and civic movements by the city. Among others, it took into account: development of civic self-defense movements and organization of free time, as well as appreciation of initiative groups created for the implementation of a specific project for the common good. Actions that were supposed to enable this in accordance with the strategy, include: preparation and updating a 'map' of civic activity, making public spaces available for civic activity of residents, promoting social and civic activities, particularly among young people.

Despite the lack of a clear placement of the suggested directions of action in the concept of sustainable development, the content analysis allows to identify the adequate recommendations at least in two areas. The first one consists of is 'space':

- in the scope of communication space, the recommendations concerned, among others: relieving the city from transit traffic, elimination of heavy transport from the city center, enforcing environmental standards (noise, exhaust gases), soft elimination of passenger cars from the city center, creation of numerous pedestrian zones;

- in the scope of terms of housing space, among others: inhibition of urban sprawl processes, revalorization of tenement houses, revalorization of housing estates on the outskirts of the city, comprehensive improvement of city cleanliness and aesthetics;
- in the scope of public space, among others: caring for historical, representative buildings (sacral, cultural, academic, official), care for incorporating into the city the location and aesthetics of large objects of consumer culture, communication, and architectural adaptation of the city to the needs of people with disabilities;
- in the scope of information space, among others: construction of information environment, deepening intergenerational dialogue, widespread use of Internet techniques in administration, law enforcement, trade, promotion, etc.

At the same time, in the 'self-government' area, the strategy clearly emphasized the responsibility of the authorities and residents for the future of the city, which is characteristic for the idea of sustainable development—"The city is a deposit of the past for the future. It is necessary to look after it and enrich it, as well as prepare it for the next generation to take over. It is prohibited to ruin and incapacitate the successors by incurring too far-reaching commitments on their behalf" [126]. It is also worth to note that recommendations concerning the strategy include, among others: indication regarding the need to build a social understanding and support for the city's transformations described in it, as well as promote a culture of civic participation.

4.3. Strategy Wroclaw 2030

The strategy formulated (for the first time) a vision of the city—"Sustainable development based on the high value of life of the current and future residents, as well as creativity, innovation and entrepreneurship". It was also inspired by the residents, who in the above-mentioned pools determined the preferred priorities of the authorities for the next 10 years. These included: pro-ecological policy, including air protection and increasing the area of green areas (45.2% of respondents), revitalization of degraded city areas (44.9%), development of public transport (43.6%) and supporting local entrepreneurship (32.4%) [127]. The main components of this vision include:

- sustainable development—focusing not only on economic development, but also on social and environmental issues, also in the context of future generations;
- high quality of life—safety, health, comfort of the current and future residents;
- economy based on knowledge—creativity, innovation and entrepreneurship

The overriding goal of the current strategy is the strengthening of solidarity and creativity, increase in the quality of life throughout the city and improvement the Wroclaw's position in the global networks—among others through actions aimed at achieving the status of one of the green capitals of Europe. Verification of the implementation of such formulated strategic goal required the development of a set of measurable indicators. This group includes: life expectancy, results of secondary school final examinations at extended level, place of universities in rankings, GDP per one resident as a percentage of the EU average, place in the Globalization and World Cities Ranking, turnout in neighborhood elections, turnout in local elections, number of days in the year for which the PM10 particulate matter standard is exceeded and the average annual $PM_{2.5}$ concentration level, percentage of population living up to 300 m from any green areas.

Actions planned in the strategy have been divided into seven priorities (while maintaining their compliance with the appropriate partial strategies of the city):

- mobility—among others, cohesive public transport system, limiting car traffic in the city center, promoting sustainable mobility, supporting ecological freight transport, developing river transport, developing the agglomeration rail system, developing shared transport systems;

- quality of the environment and urban space—among others, reduction of CO_2 emissions by 30% by 2030, investing in environmentally friendly technologies, investing in renewable energy sources on the roofs of public buildings, effective activities aimed at reducing smog, protecting environmentally valuable areas, promoting space sharing, increasing safety in public areas;
- entrepreneurship—e.g., strengthening the position of local enterprises, supporting and promoting local and regional products;
- creative and innovative economy connected with science—e.g., supporting the development of high-tech start-ups, supporting cluster initiatives;
- healthy and active residents—among others, elimination of architectural barriers for people with limited mobility, supporting actions aimed at extending the lives of Wroclaw residents, creating zones of active recreation, expanding the offer in the scope of education, culture, sport and recreation;
- governance—creation of an integrated system for managing urban strategies and urban programs, implementation of recommendations of the functional analysis of Wroclaw housing estates (organic development of grassroots democracy), harmonization of Wroclaw self-government cooperation with the government administration, implementation of the tools of self-government cooperation with non-governmental organizations, further development of the tools of self-government cooperation with universities, increasing the share of residents in city governance (among others through the development and implementation of Wroclaw's participation strategy), developing sub-local (neighborhood) self-government, applying innovative methods of consultation that strengthen civil society, supporting the participation of sub-local self-governments in urban policy consultations, introduction of the new tools for managing urban policies within e-administration (taking into account civil technology, i.e., grassroots civic technologies);
- open city—increasing the access to public services, including the excluded people into the city life, promoting tourist attractions of the city.

From the viewpoint of the purpose of this work, particularly important are the tasks set for the city in the scope of mobility, environmental quality, health of residents, open city and—above all—governance.

4.4. Smart City Wroclaw

The idea of creating a modern and responsible city found its expression in the Wroclaw's implementation of the concept of smart city in 2015. The following areas have become its pillars: governance, economy, lifestyle, people, education, mobility, infrastructure and environment (Table 3). The indicated scopes are based on the previously described set of areas highlighted in the report entitled *Smart Cities—Ranking of European Medium-Sized Cities* [65], which in the case of Wroclaw was extended to include education and infrastructure. They are treated equally and focused on Wroclaw's development in a sustainable manner, while becoming a more and more smart city. In the context of Poland, Wroclaw is not only the one of the precursors of the smart city concept, but also one of the leaders in its implementation.

Efficiency of implementation of the smart city concept has been repeatedly confirmed by awards granted to the city [128]: in 2015—the CINEV Smart Mobility in Smart City award received in Hong Kong for the integration of public transport, in 2016—City of the year over 500,000 residents—award presented during the Smart City Forum for the vision of building Wroclaw as a smart city based on such pillars as: strategy, residents and communication with them, attractiveness of life, as well as development and creation, manifesting among others in openness of data and promotion of start-ups' environment, also in 2016—Public incentives in transport—award presented during the Euro-China Smart Mobility Conference in Shenzhen for modern transport solutions encouraging residents to travel by public transport, in 2016 and 2017—IPMA—award for the Project Management Office for the best managed social project in Poland in the Polish Project Excellence Award competition, in 2018—city of the year over 500,000 residents—award within Smart City Forum for innovative solutions in the scope of electromobility and non-cash smart payments, also in 2018—the Green&Smart City Awards in the Top Level Design category, presented at Smart City Expo in China.

Table 3. Pillars of smart city Wroclaw.

Pillars	Description	No. of Programs
Governance	Smart-governance includes three elements: policies and strategies, e-office, and open self-government. Role of the authorities is to organize and integrate individual elements of smart city.	11
Economy	Searching for solutions in the scope of stimulating entrepreneurship and innovation, increasing productivity and combining local markets with global markets.	6
Lifestyle	Initiatives focusing on the needs of present and future generations, ensuring safe and healthy life, rich cultural, entertainment and housing offer, wide access to educational, communication, and service infrastructure.	6
People	One of the most important aspects of smart city—committed, creative, and resourceful society, which understands the essence of everyday sustainable life, constitutes its essential foundation.	6
Education	Investments in education and knowledge, including education of older people, elimination of e-excluded and education of entrepreneurship.	6
Mobility	Mobility consists of three elements: integrated transport system, ICT, and supporting green transport.	16
Infrastructure	Modern solutions in the scope of infrastructure are the key to further development of the city.	4
Environment	Sustainable development of the city through appropriate management of resources, investments in green technologies, public transport, and pedestrian transport.	3

Source: Own elaboration based on [128].

4.5. Participation as an Element of the Concept of Smart City Wroclaw

The key issue of the concept is the interaction between city authorities and citizens, falling within the scope of the "people" area. The active participation of residents, companies and organizations which, in accordance with the smart city 3.0 concept, will be the co-creators of the city, not just passive consumers, was perceived as essential in creating smart Wroclaw. In practice, the idea of participation is implemented in two key programs—"Wroclaw Talks" [129] and Wroclaw Citizen Budget (WBO) [130]. The first of these is a platform that allows conducting broad social consultations, as well as facilitating local meetings with residents, focusing on specific problems. Social consultations between residents and officials allow the former to express their own opinions, better understand the needs of other residents, as well as to ask questions to officials and experts. So far, the following has been carried out within the projects: consultations regarding land development, plan for sustainable urban mobility, location of 'park and ride' parking lots, system of Wroclaw housing estates, the action of making the Wroclaw streets green, city strategy, as well as the Wroclaw Study, forms and principles of WBO operation. The "Wroclaw Talks" website enables the use of free legal assistance, customer guide of the Wroclaw City Hall, but also it allows e.g., to submit a petition or application under within the Micro-grants program, which is a citywide support program for grassroots local initiatives, implemented by residents in cooperation with the Wroclaw Culture Zone and the Umbrella Foundation within one of three paths (for individuals and informal groups, for non-governmental organizations, for informal youth groups). Within this program, the Social Dialogue Groups (GDS) were also created, the idea of which consists of talking, making diagnosis, solving problems and improving the efficiency of activity and cooperation of various groups (residents, NGOs, employees of Wroclaw City Office) in various areas of social life in Wroclaw.

Compared to other countries, Poland has little experience with using the participatory budget as a governance tool. The first solution, in the form of a pilot project based on the grassroots activities of the Sopot Development Initiative (SIR), was implemented in Sopot in 2011 [103]. In subsequent years, PB began to be implemented in other cities, which resulted in an increase from approximately 50 PB in 2013 to over 250 in 2018 [104]. Wroclaw was one of the cities that implemented the idea of participatory budget already in 2013. The actual use of PB in Wroclaw as a smart city tool conducive to city sustainable development can be discussed, along with the extension of available financial resources and development of PB procedures allowing the actual wide participation of residents. The very form of participatory budget in Wroclaw has evolved adapting (in subsequent editions of the WBO) to the changing needs of residents and in response to the revealed shortcomings of the earlier solutions [12] (Table 4).

The consequence of the first two years of PB implementation in Wroclaw was the shaping of a PB model that tried to take into account, through the division of neighborhood/regional/area projects, the demographic diversity occurring in the city and resulting in the selection of projects focused only on areas with high population density or concerning larger groups of residents (parents of children attending one school, cyclists). At the same time, by taking into account the submitted proposals in the scope of necessity of supporting small projects within the framework of the PB, mainly regarding the area of improving the quality of life and security, the gradation of the size of projects was introduced. It is also possible to distinguish the important role of leaders as initiators of projects (formally—because a project for PB can be created by a group of residents). In the framework of procedure, a system of consultations and supporting of groups by specialists was developed, as well as discussions regarding the possibility of changes in subsequent editions (evaluations)(Table S1: Participatory budget process in Wroclaw—timeline).

The analysis of data (Table 5) concerning the amount of funds allocated for the participatory budget in 2014–2019 (funds planned for one year in advance) indicates their nominal increase in the studied period, but at the same time a decrease in their share in total city expenditure is visible. There is a very significant increase in the total expenditure of the city per capita visible, which is the result of an active investment policy in subsequent years. After the first period of involvement in PB (2014–2015), also a decline in the interest in voting is visible (particularly, the number of voters aged 18–30 has dropped over 70%, from around 55,000 (2015) to 15,000 (2018)).

From the viewpoint of the directions of use of PB in the city's activities, it should be pointed out that the majority of tasks adopted for implementation were to improve the safety and quality of life of the inhabitants in the broad sense. In subsequent participatory budgets, the city tried to classify projects selected by the residents for implementation into several thematic groups, due to the subject of the project. The classification criteria themselves, and thus assignment of the project to a given group, were not very transparent, however the concept proposed by the city was used in the analysis. In subsequent years, the classification was changed and therefore the presented data constitute a certain unification of used divisions, due to the specificity of financed tasks (Figure 1). At the same time, a database containing a list of selected projects, along with the costs assigned to them, within particular groups of expenditure directions, was not made available.

Table 4. Evolution of PB in Wroclaw.

	2013	2014	2015	2016	2017	2018
Pool of funds mln PLN	3	20	20	25	25	25 + 2.5 Green WBO + 0.25 monuments
Restriction on project value	Medium	Small, medium, big	Small, medium, big	Small, medium, big (entire city)	Small, medium, big (entire city)	Very small (monuments), small, medium, big (entire city)
Entities authorized for submission of applications	Groups of inhabitants, NGOs	Leaders	Leaders	Leaders	Leaders	Leaders
Number of votes possible to be used per 1 inhabitant	5	3	3 (one for each cost threshold)	4 including one per small and medium (for areas)	4 including one per small and medium (for areas)	5 including one per very small and one per small and medium (for areas)
Territorial area of voting	Entire city	Entire city	Entire city	14 areas/districts/and entire city	14 areas/districts/and entire city	14 areas/districts/and entire city
Minimum number of votes per project	None	None	100	100	100	100

Source: Own elaboration based on [13,130].

Table 5. Share of PB in the city's expenditure (Euro) in subsequent editions of WPB (WBO).

	2013	2014	2015	2016	2017	2018
% of total expenditures	0.08%	0.51%	0.51%	0.59%	0.55%	0.57%
Expenditures per capita	867.75	904.13	919.44	979.26	1048.81	1115.58
PB expenditures per capita	1.10	7.32	7.29	9.10	9.09	9.99
Number of PB voters	50,000 *	153,666	168,278	104,884	97,043	68,670
% of inhabitants	8% *	24%	26%	16%	15%	11%

* estimated; Source: own elaboration based on [130].

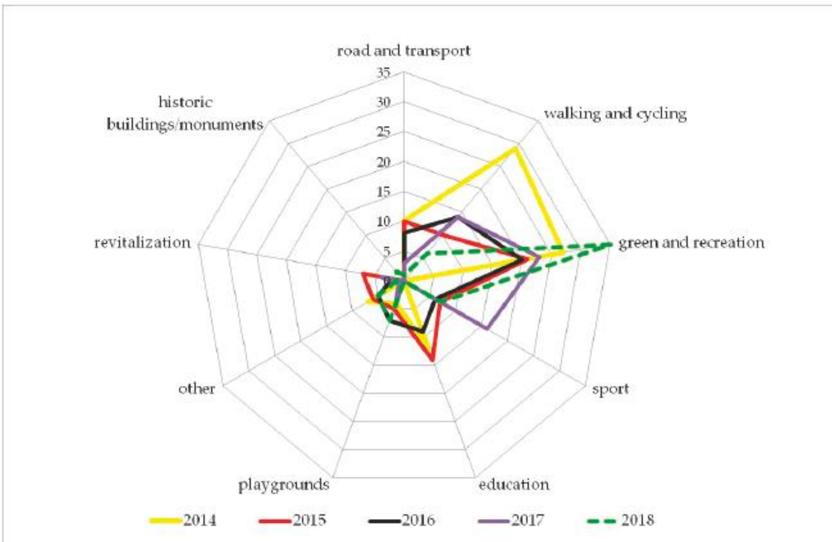

Figure 1. Number of projects selected for implementation due to the direction of expenditure.

Analysis of the value structure of the projects was conducted based on the categorization used by the city authorities [130] (Figure 1). The most numerous group of projects are housing estates projects (in which the pool of funds amounted to over 80% of the total planned PB), however their number in subsequent years has been constantly decreasing, since the introduction of the division of PB into housing estates—from 77 in 2015 to 59 in 2018. Based on the data concerning the projects selected in the voting, it can be noted that as far as the number of projects is concerned, by far the largest number of selected projects each year concern urban greenery and recreation—i.e., area associated with the improvement of environmental conditions (parks, squares, gardens, plantings). The second group consists of projects associated with the communication system—walking and cycling, as well as road and transport. In this case, the emphasis is put on improving safety by limiting the capacity of streets, as well as by introducing 'green solutions' (bicycle paths, P&R etc.). Until 2016, the city enabled the financing of generally available public sports facilities of schools and educational institutions, which often translated into initiatives of the residents of housing estates supporting the construction of sports grounds and playgrounds on school grounds.

The last of the frequent directions of PB's investments is the sports infrastructure. To sum up, it can be indicated that the implementation of PB in Wroclaw is focused on satisfying local needs reported by residents in the scope of infrastructure supporting the improvement of the quality of life in the city (green areas, road safety and transport, sport and recreation).

4.6. Sustainable Development as an Element of the Concept of Smart City Wroclaw

Wroclaw functioning according to the smart idea is by definition a city developing in a sustainable manner, in essential areas, such as energy management, mobility, health and its protection, infrastructure, etc. This is reflected in the programs implemented in the city. They can be systematized according to the assignment to individual parts forming the concept of smart city:

- In the 'people' area, it is e.g., the 'city in form' program that promotes a healthy lifestyle and health education of residents. Its goal is to shape pro-health attitudes among the local community. Among others, the educational offer includes: events, conferences, workshops, trainings, physical activities, competitions, and regular initiatives—Health Day in Wroclaw, Wroclaw Days of Health Promotion and Week of Movement. In the framework of this program, a BMI calculator, as well as water demand calculator and calorie-burning calculator were made available to the residents.
- In the 'environment' area, particular importance is assigned to the investments supporting the improvement of energy efficiency, generation of low-emission energy, modernization of infrastructure and education in this scope. The main goal is to govern the city in an ecological, modern, economical, and effective manner. Two main programs include: (1) "KAWKA"—financial support for the replacement of coal furnace and boiler room with ecological heating; (2) Low Emission Economy Plan (PGN)—strategic document developed for the Wroclaw functional area—Wroclaw and 14 communes.
- In the 'mobility' area, the priority is to move in a convenient, quick and safe manner, with the use of modern technologies, but at the same time in a sustainable manner, i.e., with care for the natural environment. In this area, there is a long list of projects, among others: (1) pilot project 'smart parking', whose aim is to design, install, calibrate and test the system of identification of free parking spaces in the selected area of Wroclaw; (2) Wroclaw System for Charging Electric Vehicles (2011); (3) Wroclaw Challenge—Mobility—a project promoting changes in the behavior of residents in the scope of sustainable urban transport; (4) Smart Trip—the purpose of this project is to conduct research and development works aimed at optimizing the use of transport resources. This program consists of mobile application, functional applications, system for selling tickets of collective transport, parking charging system, loyalty system, big data, sale of tickets to municipal institutions and system for recognizing occupancy of parking spaces; (5) Municipal rental of electric cars in Wroclaw Vozilla—car-sharing system; (6) Wroclaw City Bike (WRM)—self-service urban bike rental system launched in 2011, the first 20 min of rental is free.
- In the 'infrastructure' area, there are two key projects: (1) MAN Wroclaw—project that has been implemented since 2007. It assumed the construction of a public telecommunications network and the construction of a fiber-optic network; (2) Urban Internet—program initiated in 2004, when the first steps associated with the construction of infrastructure allowing free access to the Internet using a radio network were undertaken.

It is necessary to emphasize the compliance of the above-mentioned activities with those declared by Wroclaw residents in the studies on the assumptions of the Wroclaw 2030 Strategy, desirable directions of the government's activities over the next decade, which mainly consisted of urban goals (indicated by nearly 45% of respondents), i.e., pro-ecological policy, including better air protection and increasing the green areas, revitalization of degraded areas of the city and development of public transport [131]. Such formulated goals emphasize the role of the common good in the scope of creating the quality of residents' life. The second direction of activities, which was indicated by 18–32% of respondents, were the goals of social development and cohesion, associated with supporting local entrepreneurship, social policy, development of social dialogue, and education [131].

5. Discussion and Conclusions

During the studied period, the Wroclaw city authorities developed three strategies for the city development. The conditions such as political, social, demographic situation, resources and growing problems of the city had a strong impact on the final shape of the subsequent strategies and guidelines for the action directions. The first strategy was created and adopted during the liquidation of losses after the flood, which occurred in July 1997. Thus, it was dominated by the current problems of the city. Adoption of this strategy at that time had a pragmatic dimension—removal of damages was connected with modernization of the city, whose direction was determined by the strategy, while the strategy became an important tool for gaining the necessary funds for the city, as well as attracting investors. From the viewpoint of this work, it is worth noting several important factors in them. Firstly, a clearly formulated trend of growing citizens' interest in the participation in decision-making processes appeared in the area of political challenges, especially at the local level, with the simultaneous increase in the competences of territorial self-government and its strength in the scope of coordination of local activities. The possibility and necessity to use a computer network to consult, discuss local problems, and even to resolve them through a referendum were also noticed. The second important element appeared in the area of health and ecological challenges—it was noticed that there's a necessity to create a local program of the city's sustainable development, based on the *Principles of Wroclaw Ecological Policy*, taking into account: environmental protection, active impact on the preservation and reconstruction of diverse ecological systems within the city and its surroundings, shaping the aesthetic urban landscape, preventing the degradation of agricultural land, pro-ecological changes in the residents' lifestyle, taking into account the educational programs, protection against the effects of natural and ecological disasters. Moreover, it was indicated that there is a need to determine a standard of the quality of life for residents and to make it a tool used to carry out local policy. The third important category was psychosocial challenges associated with the need to increase the satisfaction of the Wroclaw's residents from living in their city. Fourthly, in the scope of demographic challenges, the issue appeared concerning the potential problems associated with creating life perspectives for the youth of baby boomers.

Strategy—*Wroclaw in the 2020 Plus* perspective was de facto an update of the previous strategy, necessary due to the approaching end of the time scope covered by the 1998 strategy, as well as new possibilities resulting from Poland's accession to the European Union. Limiting only to the update resulted from a positive assessment of the activities implemented and continued as part of the previous strategy. As its strategic goal, the new strategy adopted the hand-over of the city to the next generation in a state good enough for it to be the entity and not the subject in the processes of global competition, while human and social capital was indicated as the fundamental factor of the city's development.

Contrary to the previous strategy, the second strategy of Wroclaw did not include any clear indication of determinants associated with the potential of residents to co-decide about its development. There was also no clear indication of the need to include in the city's strategy issues associated with its sustainable development. The potential of residents to participate in the development of the city was indirectly indicated in the group of factors containing the competences and genius loci—there is a reference here to the residents' ability to self-organize and demonstrate initiative, as well as to spontaneous cooperation aimed at the common good.

Dynamic changes in the surroundings resulted in the need to undertake works on a new strategy for Wroclaw. The analysis included in the report entitled *Diagnosis of Wroclaw* [131] demonstrated that the following cities will have better chances of survival in the future:

- learning cities that will put emphasis on knowledge and development of people (human capital);
- cities that bind strategy of many management areas with the city's main strategy (intellectual capital);
- cities that care about trust (trust capital) and communication (relationship capital) between all users of urban space;
- innovative cities—changing their functional profiles in order to improve the quality of life and to reduce costs, as well as to find new profit opportunities [131].

While using information about trends in the future, the city authorities started the works on the draft of a new strategy *Wroclaw 2030* in 2015. The new philosophy of operation was already visible at the stage of strategy planning—residents were included in its creation. Firstly, during the period X.2015-VI.2016, 12 open thematic forums were organized, where everyone could expressed their opinion. Secondly—a series of meetings with committees of the city council, neighborhood councils and candidates for councilman were organized. Thirdly—public opinion polls were carried out in 2016 regarding the future of Wroclaw, thus including residents in the process of strategy creation. The results of these polls, proposals collected during forums and determinations of diagnoses were included in its development.

A new mission has become a key element of the strategy—"Wroclaw is a beautiful, wise and rich city—a city that unites and inspires." The priority values included in it were inspired by the results of polls conducted in 2016. By indicating the preferred future profile of the city, the respondents stated that it is particularly important for them that Wroclaw should be the leading center of science and culture, one of the most beautiful cities in Europe, the "Silicon Valley" of Central Europe, a city that attracts tourists and investors, one of the most important transport ports. This new mission also resulted from the analysis of conditions of the city's functioning, among which the key ones included: increasing expectations of residents regarding the quality of life and their impact on decisions, problems associated with the air quality, demography, and aggravating global political situation, probability of a significant reduction in the access to EU funds, probability of changes in the functioning of city self-governments, effective implementation of the previous mission with accompanying increase in GDP and reduction in unemployment (Figure S2: Wroclaw 2030 Strategy goals).

Based on the analysis of including the participation into Wroclaw's development strategies, which is the subject of the study, a clear evolution of the degree and scope of its use can be observed—from single, simple, and unconnected solutions, to separation of governance as one of the priorities of strategic activities and including the participation in its scope.

- The first strategy emphasized the need to support inclusion of groups and environments in social development, however the proposed programs were limited to creating information networks and platforms for exchanging experiences, supporting the process of emergence of the local activists and reviving committees, councils and other organizations in order to support the development of local communities.
- *Wroclaw 2020 Strategy* indicated three directions of supporting participation: informing citizens, developing citizen and social attitudes and supporting citizen initiatives. However, in practice, the proposed actions were again selective in nature and they were not treated comprehensively.
- A radical change took place in the Wroclaw's third development strategy, in which the main goal was to improve the quality of resident's life, including by increasing their participation in making decisions about the city, in which they live. Unlike the previous ones, *Wroclaw 2030 Strategy* also emphasized the necessity to create an integrated system of management of urban programs strategies, as well as the role of organic development of grassroots democracy. The proposed programs harmoniously cooperated with these assumptions—they included the planned implementation of the Wroclaw participation strategy, which clearly signals the idea of comprehensive planning and implementation of activities aimed at long-term goals. The change has also occurred in the perception of the necessary instruments—the strategy puts emphasis on the need to use innovative consultation methods and introducing new tools within e-administration (e.g., civil technology).

Analyzing the place of participation in Wroclaw's development strategies in the context of evolution of the participation significance in the analyzed subsequent UN program documents, it can be noticed that there's a high degree of compliance of changes in the meaning of participation and the role of governance between them.

The key moment for the development of public participation in Wroclaw consisted of the years 2013–2015—in this period, the Wroclaw participatory budget (WBO) was launched for the first time, and then the city began to intensely implement the concept of smart city (3.0), making WBO one of its key instruments. Within the smart city, two important areas—governance and people—were distinguished. The participatory budget was put in the 'people' area, instead of—in compliance with the theoretical approach—in the 'governance' area. The reasons for this action can be found in the low level of use of ICT in the whole PB procedure—where the main area of ICT use was voting and providing information to residents. ICT was not used to visualize or consult the developed projects. Another form of using ICT in PB was to provide open data regarding the detailed voting results.

The issue of intensifying participation of the Wroclaw residents seems to be significant, because in the studies [131] preceding the formulation of the Wroclaw 2030 strategy, it was diagnosed that 57.9% of respondents showed the lack of social activity (index of interest in the matters of residence region and the city, as well as activities for the housing estate and the city), while 11.9% demonstrated the lack of civic activity (covering participation in the last national and European parliament elections, participation in self-government elections and in the municipal referendum). On the other hand, the same studies indicate the significant potential of Wroclaw residents in the scope of activities for the common good—51.2% of respondents declared their willingness to engage in activities carried out with other residents, 48%—willingness to be subject to greater rigors and limitations in using cars in urban transport and 46.1%—willingness to be subject to greater rigors and limitations in order to improve the natural environment in the city.

Public participation is an important element of the city's sustainable development (in accordance with the results of literature analysis and the presented research results), as well as significant part of the concept of smart city, which engages the residents in the process of smart co-management (Figure 2).

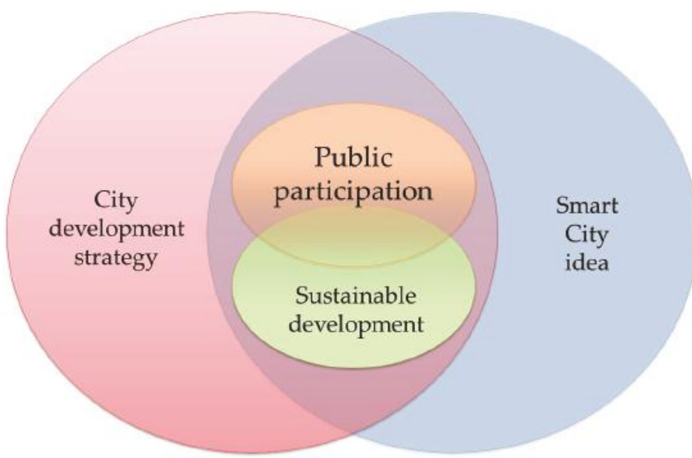

Figure 2. Relationships between Wroclaw development strategy, smart city idea, sustainable development, and public participation.

An important difference is the perception of the scope of participation—in the case of implementation of the city's sustainable development, all of its forms appear (in accordance with the Arnstein's participation ladder), while in the case of smart city the main significance is assigned to the most developed one that provides the residents with a tool for the actual possibilities of co-decision. In the case of Wroclaw, WBO is such tool, however it is worth to consider the wider use of ICT within its framework, which despite the five-year functioning of the budget is still used to a very limited extent. The analysis of Wroclaw's strategic documents from the last 20 years indicates the changing attitude of policy makers towards the city's sustainable development. The first strategy proposed the creation of a local program of sustainable development and it also proposed the programs covering the issues of ecology, transport and quality of life. It can be clearly seen that it is characterized by the inclusion of the residents' participation in the scope of programs associated with the sustainable development of the city. During the same period, participation was one of the signalled (but marginalized) elements of *Agenda 21*. In the second strategy of Wroclaw, there was no indication of the need to include sustainable development issues in it. However, it indicated the directions and activities clearly belonging to this scope (transport, ecology, responsibility for the city's future, encouraging residents to participate in local politics). In the case of the last strategy, sustainable development was included in the vision of the city and became one of the three main directions of activity. Environmental, social, transport, ecological, educational, and health issues gained the rank of priorities, whereas the sustainable development has become one of the elements of the vision and one of the key values for the city.

By comparing the scopes and directions of activities determined by the current Wroclaw development strategy and separately implemented smart city idea, the existence of common areas can be seen associated with the public participation and sustainable development of the city. Having in mind the separation of activities in the scope of smart city and city development strategies among various organizational units, it is necessary to indicate the potential threat of a lack of proper coordination of the activities. Therefore, the communication between decision-making units becomes extremely important (or establishment of a superior unit responsible for the given area), as well as the consistency of documents regulating both issues. The solution adopted by Wroclaw includes two such activities: firstly, it is clearly indicated in the current strategy, with which legal acts and strategies each of the priority areas should be consistent (e.g., governance with conclusions from the Functional Analysis of Wroclaw's Housing Estates of 2017, municipal strategy of participation and strategy of cooperation of the city authorities with non-governmental organizations), secondly—two units were established—Department of Sustainable Development responsible for coordinating urban tasks of design, program or strategic nature, in accordance with the idea of sustainable development, and the Office for Social Participation that carries out and coordinates all activities in the scope of social participation of the city's residents.

The last issue is the decreasing percentage of residents participating in the participatory budgeting process. The results of subsequent editions of WBO indicated that the engagement of residents is decreasing in the scope of creating ideas and participating in voting, particularly in the group of young people (Millennials). The subsequent research should try to diagnose the causes for this state of affairs. The results of previous research [106,132,133] concerning the low inclination of Poles to participate in activities for the benefit of society and low sense of impact on the social matters (Millennials achieved the worst results), let us hypothesize that the potential cause is lack of education in the scope of participation, which translates into the barrier hindering any action ("I do not know, so I do not do") and/or insufficient communication policy, informing and encouraging to participate in the activities of the commune. The participatory budget procedure in Wroclaw is heavily extended in time. The time between submitting the first proposal, revision of it, voting and implementing may take up to two years. Discouragement may be also caused by a significant percentage of projects verified negatively by authorities at the stage of submission. There is also the problem of the extremely small number of consultations with residents concerning submitted (and positively verified) projects.

A number of potential limitations need to be considered. Firstly, the current paper was undoubtedly limited by the complexity of the undertaken problem. The most important limitation lies in the lack of a uniform structure of all strategies, their scope and methods of creation. This could lead to the subjective systematization of gathered information and the possibility of non-intentional omitting or generalizing some less relevant information. Secondly, another limitation was the use of documents mainly generated by one stakeholder in the process—the city, which can result in a distortion of the actual picture of the situation. Thirdly, some of the activities related to the participation of residents in the city activities from before 2015 are not included, either in the analyzed documents or in the information made available by the city, which could have resulted in omitting them in the analysis. Further research should be undertaken to explore, among others, the reasons for participation or non-participation of residents in municipal affairs, methods of communication with city-residents and their effectiveness in the governance process, comparative studies with other cities implementing residents' participation both in the smart city projects and sustainable development strategies.

Despite limitations, the conducted research indicates that for the implementation of the SSC concept it would be important to integrate these approaches in order to ensure the full range of residents' participation in accordance with theoretical postulates. The conducted analysis covers, therefore, the mostly unexplored area of research, which is important from the point of view of cities evolution toward a sustainable smart city. The conclusions from the research are also an empirical contribution to the analysis of the changes of cities towards SSC and indicate the need for further, extended research on the problem.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/2/332/s1, Figure S1: Timeline of case study, Figure S2: Wroclaw 2030 Strategy goals, Table S1: Participatory budget process in Wroclaw—timeline.

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Detection and Localization of Water Leaks in Water Nets Supported by an ICT System with Artificial Intelligence Methods as a Way Forward for Smart Cities

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Abstract: The last decade has seen the development of complex IT systems to support city management, i.e., the creation of so-called intelligent cities. These systems include modules dedicated to particular branches of municipal economy, such as urban transport, heating systems, energy systems, telecommunications, and finally water and sewage management. In turn, with regard to the latter branch, IT systems supporting the management of water supply and sewage networks and sewage treatment plants are being developed. This paper deals with the system concerning the urban water supply network, and in particular, with the subsystem for detecting and locating leakages on the water supply network, including so-called hidden leakages. These leaks cause the greatest water losses in networks, especially in old ones, with a very diverse age and material structure. In the proposed concept of the subsystem consisting of a GIS (Geographical Information System), SCADA (Supervisory Control and Data Acquisition) system and hydraulic model of the water supply network, an algorithm of leak detection and location based on the neural networks' MLP (multi-layer perceptron) and Kohonen was developed. The algorithm has been tested on the hydraulic models of several municipal water supply networks.

Keywords: water supply networks; network modelling; leak detection; artificial neural networks

1. Introduction

In the context of the implementation of modern technologies (including ICT—Information and Communication Technology) the adjective "Smart" is becoming increasingly popular. There is more and more spoken and written about SmartCit, SmartHome, SmartGrid, and SmartMaintenance [1]. When we hear about "smart grids", we most often talk about energy grids, but this term appears more and more often in relation to other industrial networks like water, sewage, or heating networks. The use of artificial intelligence methods allows us to direct the operation of the water supply system towards the development of intelligent cities.

Management of the municipal water supply network is a complex task, in which three main objectives are fulfilled: ensuring proper water quality, ensuring proper pressure in the network user nodes, and elimination of water losses. In this paper, we focus on the elimination of water losses, which in old water supply networks generate the highest operating costs. Water losses are caused by network failures caused by too high water pressure, and in the case of old networks, by the material usage of water pipes. In order to reduce the network failure rate it is necessary to properly control the operation of pumps in source and zone pumping stations and to revitalize the network, the former being computationally demanding due to the need to apply complex optimization algorithms, and the latter is very expensive. Therefore, the third solution is quick detection and location of failures, including above all the so-called hidden leaks, which, when they occur, are not visible, because they rely on the leakage of water into the ground through the gaps created in impaired pipelines. The reduction of losses in water distribution networks represents a challenge for water utilities worldwide. In the world as well as in Poland there is a lot of research on how to solve this problem. Interesting research on leakage detection in water supply networks is presented in papers [2–5]. In [2] three main objectives have been achieved: Firstly, the effectiveness of so-called vibration monitoring for leak detection purposes was assessed providing a positive response; then, a prototypal detection procedure was studied, implemented, and tested on experimental data; finally, the specifications for a prototypal acquisition equipment were also determined. References [3,4] show further studies on leak detection using vibration monitoring and in Reference [5] the suitability of a non-intrusive pipeline surface vibration-based leak detection technique is either confirmed.

Since this problem is also very topical in Poland, many of the emerging works concern its solution [6–12]. The easiest way to solve this problem is to install a sufficiently dense monitoring system on the water supply system, to determine hourly flow and pressure characteristics for each measuring point and to compare the current values of these parameters with the values determined on the relevant characteristics. The observed deviation between the measured value and the determined value signals the occurrence of an abnormal state, including a possible leakage in the environment of a given measuring point. This is a costly way because of the need to install multiple measuring devices in the monitoring system in order to achieve satisfactory detection of emergency conditions. Moreover, in this way, only the area of the network where an unusual event takes place is identified, not a specific point on the network. Another possible way of solving the problem of failure detection is to use a hydraulic model of the water supply system to perform many simulations of leaks in all nodes and pipes of the network, in order to determine and archive the distributions of flows and pressures at monitoring system measurement points corresponding to these leaks and also to the standard network operation state [9]. If the observation of network operation indicates a deviation from standard state, the current distribution of flows and pressures is compared with the distributions from the archive in order to find similar distribution, which will indicate the points of the network where the leakage occurred [7,8,10]. This method of identifying leaks is very time-consuming as it requires calculations of leakage simulations for many different states of network load in order to obtain a set of distributions representing the fullest possible set of potential leaks. The paper presents the third method of leakage location using the monitoring system, hydraulic model of the network, and neural classifier. This way, thanks to the use of neural networks to identify emergencies, is much faster and more accurate than the methods previously mentioned. Numerical algorithms, developed on the basis of the presented concepts of leakage location on the water supply network, have been implemented in an IT system developed by the Institute of System Research of the Polish Academy of Sciences in Warsaw (IBS PAN), as a tool supporting the comprehensive management of the municipal water supply system. The whole system and its individual algorithms have been tested on exemplary models of water supply networks from several Polish water supply companies [10–16].

The research carried out on the detection and location of leakages using artificial intelligence methods is part of the idea of SmartCity, developed worldwide, which undertakes research on the global inclusion in operation of various areas of the functioning of urban infrastructure, including the infrastructure of the water supply system—SmartWater. This philosophy is in line with the improvement of the operation of water supply system operation facilities, which also translates into the quality of decision-making processes [5,17–20]. The SmartWater concept is an innovative approach to supporting the process of managing the operation of the water supply system with the possibility of using the cooperation of variable factors. Cooperation of these factors, taking into account technical and non-technical aspects, significantly broadens the issues of information resources and is an added value in supporting decisions on managing the operation of the water supply system. Inclusion of SmartWater in the processes of managing the operation of facilities in addition to the ability to support the decision of the water supply system with a focus on the use of technical and non-technical information resources of the enterprise enables the use of modern technological solutions (e.g., remote data transmission, remote control of the operation of facilities, or on-line interaction with customers). The algorithm of detection and location of leakages in the water supply network presented in the article is an element of a complex ICT system developed in IBS PAN to support Smart City management, the concept of which was presented at the ICT4S conference in Stockholm in 2014 [21].

2. Water Management and Its Impact on Sustainable Development of a City

Sustainable development is development that meets the basic needs of people today without threatening the ability to meet future needs through integrated economic, environmental, and social activities. The concept of sustainable development has been developed and promoted since the 1990s and is based on the concept of needs to be met and constraints to be taken into account, which are determined by environmental and technical capabilities. In sustainable development, the environment is its foundation, technology is a tool, and the well-being of society an objective. Basic human needs are related to the provision of conditions for a healthy life, which requires healthy food, clean air, and a sufficient amount of clean drinking water. Therefore, sustainable development is achieved primarily by reducing the use of renewable resources, including water, eliminating hazardous and toxic substances from economic processes, and reducing emissions of pollutants into the atmosphere. In this way, the aim is to provide people with a sense of security and prosperity, understood as the creation of conditions conducive to their physical, mental, and social health.

The above shows that clean water, in sufficient quantity, is a key condition and element of sustainable development. The Institute of System Research of the Polish Academy of Sciences in Warsaw has been developing ICT systems supporting the management of water and sewage systems, the aim of which is precisely to provide clean water for urban dwellers and to protect the natural environment by improving sewage treatment. In the case of water, the computational algorithms developed primarily concern the improvement of its quality and economical management of its resources, including, among other things, by reducing water losses.

The problem discussed in the paper focuses on the last aspect of ensuring sustainable development related to the urban area, i.e., limiting water losses in the water supply system through early detection and location of leaks. This is, of course, a small element of a larger whole, but it is very important in the case of old or poorly managed urban networks and very important from the point of view of meeting basic social needs, because water losses leading in extreme cases to a reduction in water supply and an increase in water acquisition costs have a negative impact on calm and social satisfaction.

3. Solution of the Water Leaks Problem

The approach presented below is an extension of the simpler, previously discussed algorithms, one of which was based on the use of a monitoring system installed on a water supply system only, while the other used an additional hydraulic network model. The development of these algorithms consists in the use of neural networks to create a classifier locating leakage sites. Therefore, part of the steps of the new algorithm (Figure 1) is a repetition of the steps of the previous algorithms. All steps of the new algorithm are as follows:

Step 1 of the new algorithm is the same as in the first algorithm and concerns the planning of the SCADA (Supervisory Control and Data Acquisition) monitoring system for the tested water supply network. In this system measuring points should be located in the so-called characteristic points of the network, where the installed measuring probes react to changes in pressure or flow that occur even in distant areas of the network.

Steps 2, 3, and 4 of the algorithm are identical to the steps of the second algorithm and concern the formulation of the hydraulic model of the network, its calibration on the basis of measurements from the monitoring system, and performing multiple calculations of the hydraulic model for leaks simulated in all nodes and pipes of the network and for network operation without leaks. All determined pressure and flow distributions shall be archived in a special distributions database, with the distributions obtained for standard network operation without leaks being later the reference point for all unusual situations occurring on the network.

Step 5 of the algorithm is new and concerns the determination of the neural classifier of leak location based on the data archived in the distributions database.

Step 6 of the algorithm is similar, although not identical, to the next step of the second algorithm. It consists in registering current pressure and flow distributions on the network and comparing them with the distributions of standard network operation. If differences between current and standard values are found at any measuring point, exceeding a preset tolerance threshold, a classifier is activated to select a place on the network, where an emergency condition could have occurred.

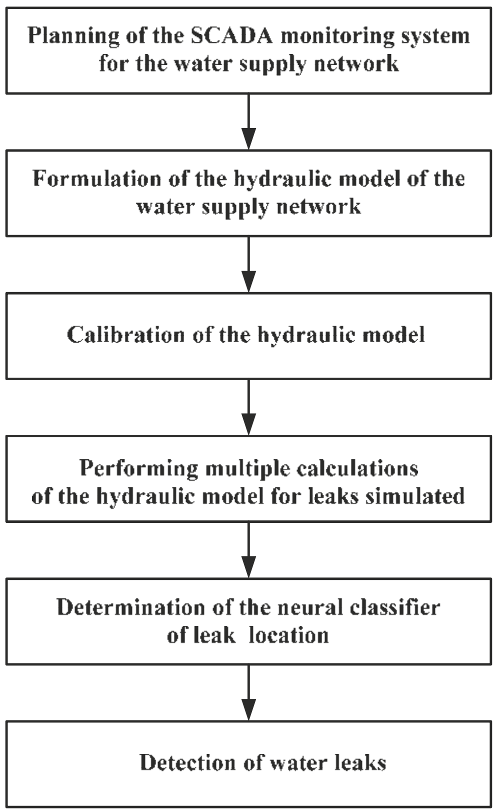

Figure 1. Block diagram of the algorithm for detection and location of hidden leaks.

It should be noted that the key activities of the algorithm are carried out in three steps concerning the planning of an appropriate SCADA system, the calibration of the hydraulic model of the water supply system, and the designation of the classifier. A well-planned monitoring system determines the correct calibration of the hydraulic model of the network and a good model provides reliable results of leakage simulation and determination of the exact location of leakages [22]. The hydraulic model of the network is determined on the basis of direct measurements from the object, while the classifier is determined on the basis of the model calculation results and the accuracy of the model determines the accuracy of the classifier.

At the end of this chapter some questions mentioned above should be clarified and these are as follows:

Supervisory Control and Data Acquisition systems (SCADA) are used commonly in waterworks to measure the pressures and flows on the water net and to control network objects like pump stations or reservoirs based on these data. In the research presented, SCADA means only a data acquisition system collecting the flow and pressure measurements from the selected nodes of the water net which are then used to model the failures classifier.

To select the measuring nodes in the water net, a monitoring system for the investigated network has to be planned. As mentioned earlier, proper planning of a monitoring system is one of the three key actions of the developed algorithm. This problem is a typical task of multi-criteria optimization, because a good monitoring system should cover as many measuring points on the network as possible and at the same time the multiplication of these points increases the costs of the system. The task of optimization would then be to minimize the costs, and thus the number of measurement points of the system, and to maximize the information about the network supplied from these points. In the presented algorithm, the task of planning a monitoring system is solved in a different way, by determining a ranking list of characteristic points of a water supply network, i.e., such points which provide information on changes in the state of network operation taking place even in distant places [23]. The specified point of the network is higher on the ranking list if the area of pressure and flow changes recorded in it are larger. For the purpose of the leak location algorithm, 20 characteristic points, where flow sensors were located, were determined for the tested exemplary water network. The operating experience shows that the observation of flow changes is of decisive importance when detecting leaks, as the associated pressure drops are quickly compensated for by the more intensive operation of the pumps and can be assumed to be negligible.

To elaborate the failures classifier, the calibrated water net hydraulic model is needed, and its calibration is possible after the monitoring system has already been planned. The model calibration has been executed by means of a heuristic algorithm of multi-criteria optimization. In the algorithm two criteria regarding the differences between the calculated values of water flows and pressures and the measured ones in the monitoring points have been used. To calibrate the model, one set of data gained by the monitoring system installed in the waterworks in Rzeszow has been used and another data set was applied to validate the model.

The hydraulic model of water net used in the calculations is a model applied by Straubel in his decisions making system REH (Rechnerunterstuetze EntscheidungsHilfe) and broadly converted by him into practice [24].

4. Acquisition and Processing of Calculation Data

All the calculations testing the algorithm have been done for an exemplary water network shown in Figure 2. The surveyed network concerns the city of Rzeszów in south-eastern Poland. The network is 514.7 km long and consists of mains (49.5 km), distribution network (260.1 km), and home connections (205.1 km). The network was established in 1934 and nowadays almost half of the network is built of 20- and 30-year-old pipes and almost 1/4 of the network consists of pipes whose age exceeds 40 years, which qualifies them for modernization or replacement. Similarly, the material structure of the network is unfavourable and heterogeneous, while approximately 44% of it consists of galvanized steel pipes, 33% consists of cast iron pipes, 14% of steel pipes, and the remaining 9% of asbestos cement, polyethylene, and PVC pipes. The diversified age structure and materials of the network is the reason for its high failure rate, with about 65% of failures related to cast iron pipes and about 30% of failures related to steel and galvanized steel pipes. The main cause of network failures are corrosion of the material and seals at pipe sections connections, in both cases they occur mainly in cast iron pipes.

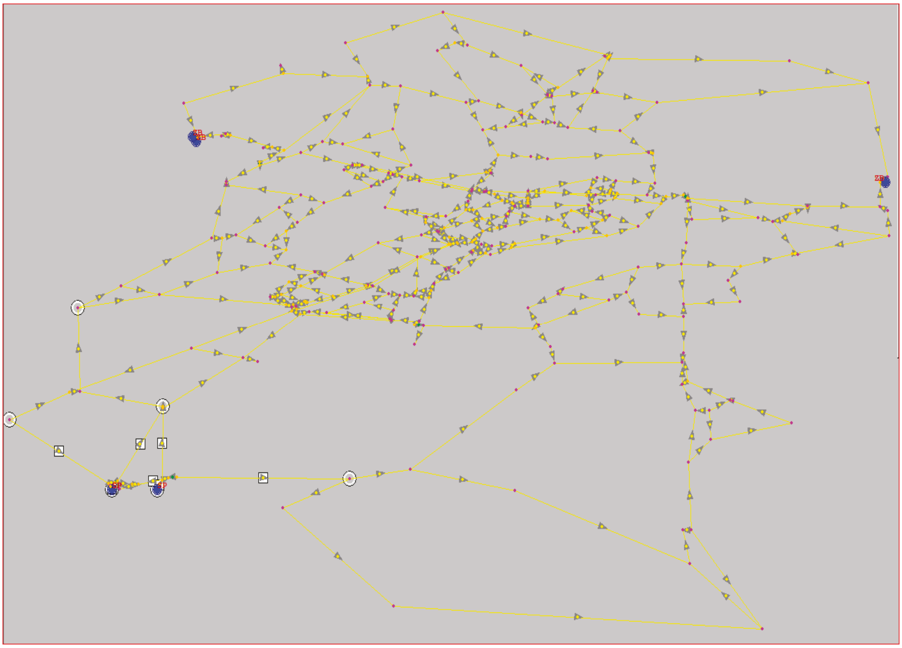

Figure 2. The modelled water network; ZB on the network graph means tank and SP means pumps station.

The failure of the network results in high water losses, reaching up to 30% of production. The tested network model consists of 280 nodes and 398 pipes and on the network three storage tanks are installed and the water is extracted from two deep water intakes; 175 nodes on the network are distribution nodes to which the end users of the network are connected.

Before starting to determine the neuronal classifiers, the network model was calibrated on the basis of measurements from the tested water supply system. Hydraulic calculations of the model showed that among 175 distribution nodes in 154 nodes the pressures are witin the desired range of 2.5–4.0 atm. In 10 nodes they were within the permissible range of 2.0–2.5 atm. and only in 11 nodes (6% of distribution nodes) the pressures were lower than 2 atm.

Simulation of leaks in selected network nodes was performed for leakage values: 15 l/s and 35 l/s. The results of calculations presented in the article concern leaks at the level of 35 l/s.

For development the neuronal classifiers the MLP (multi-layer perceptron) and Kohonen neuronal nets were used. Neural networks, including the relatively simplest and therefore the most popular MLP networks, are used more and more frequently in recent years to solve several technical problems. Also popular and often used are Kohonen networks belonging to the so-called self-organizing networks (SOM, Self Organizing Maps) [25,26]. Comparison of MLP networks with Kohonen networks allowed us to check how these networks behave when solving a real, rather unusual technical problem. A fragment of the data file prepared to designate the classifier on the basis of the data archived in the distributions database is shown in Table 1. The last column of the file, with the exception of its first element, contains the numbers of network nodes in which water leaks were simulated (w0103, w0130, etc.). The first element of this column, symbolically marked with w0, indicates the standard operating state of the network. The first line of the file contains numbers of measurement points of the monitoring system, where flow values were recorded (pp1, pp2, etc.). The second line contains flow values registered in the measurement points for standard network operation and in the following lines the flow values at the same monitoring points are recorded for subsequent leakage simulations at the respective network nodes.

Table 1. Fragment of the learning data file.

PP1	PP2	PP3	PP4	PP5	PP6	PP7	PP8	PP9	PP10	NODE
−0.066	−0.066	0.588	−0.768	0.035	0.166	0.166	2.655	0.886	−0.886	w0
−0.053	−0.053	−2.026	−0.275	0.043	0.134	0.134	1.043	2.023	−2.023	w0103
−0.053	−0.053	−2.024	−0.275	0.043	0.134	0.134	1.034	2.029	−2.029	w0130
−0.053	−0.053	−2.049	−0.264	0.043	0.133	0.133	6.034	1.772	−1.772	w0213
−0.049	−0.049	−2.701	−0.113	0.046	0.123	0.123	0.513	2.442	−2.442	w0252
−0.025	−0.025	−5.327	0.802	0.061	0.058	0.058	13.202	3.733	−3.733	w0259
−0.057	−0.057	−1.287	−0.43	0.041	0.144	0.144	4.881	1.467	−1.467	w0265
−0.03	−0.03	−4.873	0.612	0.058	0.072	0.072	12	3.4	−3.4	w0302
−0.053	−0.053	−2.022	−0.275	0.043	0.134	0.134	1.02	2.039	−2.039	w0353

Algorithm testing was performed for two cases: for a monitoring system consisting of 10 measurement points and 37 randomly selected network nodes where leakages were simulated (Table 1), and for a monitoring system consisting of 20 measurement points and for 44 network nodes with simulated leakages. Data from leakage simulations concerning flow distributions for 10 and 20 measurement points were multiplied in order to obtain data files (cases) for classifiers development, consisting of 368 and 736 records, respectively. In order to teach the neural network correctly, it is necessary to determine the size of the teaching set, i.e., the appropriate number of cases required to teach the neural network. In the case of smaller datasets, it is important to be aware of the fact that such a network will be insufficiently taught due to the lack of the sufficient amount of information in the teaching set required to teach the network satisfactorily. Therefore, the number of cases in the learning set has been multiplied by duplicating them. This gave a sufficient number of cases and the neural network could be sufficiently trained. The obtained data sets were then divided into learning, testing and validation subsets at the ratio of 70:15:15%.

In each of the algorithm testing cases, classifiers were determined using MLP and Kohonen networks. The investigated MLP networks were three-layer, parameterized by selecting the number of neurons on the hidden layer and the number of learning calculation runs (epochs). The number of neurons on the hidden layer was experimentally selected from the range (5–30), while the numbers of epochs in the calculations were set at 200, 500, and 1000. The number of neurons on the input layer of the network corresponded to the number of measurement points, so it was 10 or 20, respectively, depending on the case under study, while the number of neurons on the output layer corresponded to the number of nodes with simulated leaks plus a symbolic node w0, so it was 38 or 45, respectively.

The network output corresponding to the node where the leakage was simulated and a record with the corresponding flow distribution was given to the network input at that moment, assumed the value of 1, while all other outputs assumed the value of 0. Already during the calculations, it turned out that the MLP network with such a large number of output neurons counts for a long time, and therefore its structure was changed and 1 neuron was placed on the output layer, assuming at subsequent moments of calculation values corresponding to the node numbers in which the leakage was simulated at that moment. In this way, the network inputs corresponded to the measurement points on the water net and the network output indicated the water net node where the failure was simulated.

Parameterization of the Kohonen network was done by changing the number of neurons on the topological layer and also by changing the teaching epochs. The number of neurons on the topological layer assumed values of 2×8, 5×5, and 10×10, while the number of epochs assumed values from the range (100–20,000).

Using MLP networks, different activation functions were selected for neurons on the hidden layer from the hyperbolic tangent, linear, logistic or exponential functions, and for neurons on the input layer from the hyperbolic tangent, linear and Softmax functions, where the Softmax function is of the form:

$$\frac{\exp(a_i)}{\sum \exp(a_i)}$$

The network was taught using the BFGS algorithm (Broyden–Fletcher–Goldfarb–Shanno), in which the criteria of stopping calculations were optionally the sum of square function (SOM) and the following cross-entropy function:

$$E_{CE} = -\sum_{i=1}^{N} t_i ln\left(\frac{y_i}{t_i}\right)$$

where: N—number of records in the used data file, y_i—calculated values of outputs in the network model, t_i—actual values of outputs recorded in the data file.

5. Calculation Results

The exemplary results of calculations carried out with the use of MLP networks are shown in Table 2 and Figure 3. Results are shown for the tests carried out for the monitoring system with 10 measurement points and for 38 network nodes where leakages were simulated. For the monitoring system with 20 measurement points and for 45 nodes with simulated leakages, the results were largely similar, although the networks obtained were generally more accurate. The calculations carried out for 10 monitoring points show that network MLP 10-23-1 proved to be the best classifier for MLPs, for which the average quality value (Av-Q) was 85.80% (average of the quality of teaching (Teach), testing (Test), and validation (Valid) runs).

Table 2. The multi-layer perceptron (MLP) nets calculated for 10 monitoring points, network qualities Q calculated in %.

No.	Network Model	Teach-Q	Test-Q	Valid-Q	BFGS	Error Function	Activation Function for Hidden Layer	Activation Function for Output Layer	Av-Q
1	MLP 10-14-1	31.20	43.86	38.60	15	Entropy	Linear	Softmax	37.89
2	MLP 10-20-1	55.26	56.14	54.39	27	Entropy	Linear	Softmax	55.26
3	MLP 10-9-1	46.62	56.14	42.11	83	SOS	Linear	Logistic	48.29
4	MLP 10-14-1	79.70	78.95	75.44	208	SOS	Tanh	Exponential	78.03
5	MLP 10-17-1	52.26	54.39	35.09	30	Entropy	Logistic	Softmax	47.24
6	MLP 10-26-1	55.26	42.11	33.33	97	SOS	Logistic	Tanh	43.57
7	MLP 10-23-1	92.48	84.21	80.70	45	Entropy	Tanh	Softmax	85.80
8	MLP 10-15-1	66.17	47.37	47.37	239	SOS	Exponential	Tanh	53.63
9	MLP 10-25-1	55.26	38.60	36.84	146	SOS	Logistic	Tanh	43.57
10	MLP 10-22-1	46.24	45.61	36.84	21	Entropy	Exponential	Softmax	42.90

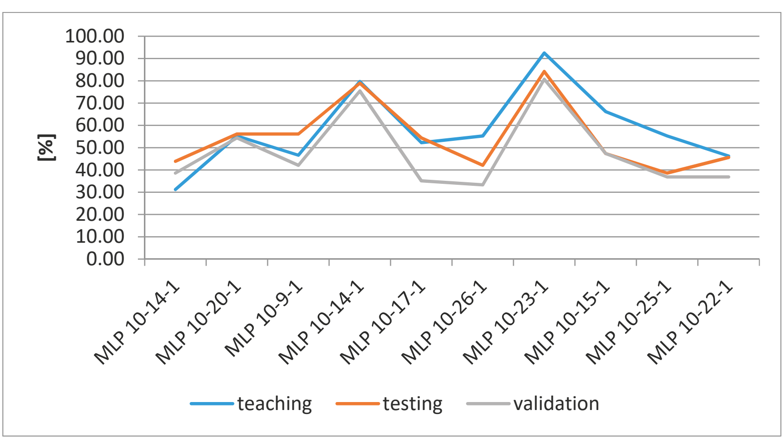

Figure 3. Results of MLP network modelling obtained for 10 measurement points in graphical form.

The quality, or rather the accuracy of the network depends on the number of neurons placed on the hidden layer and on the choice of activation functions between the layers. In the best classifier, the number of hidden neurons was 23, and in general, the network is more accurate as the number of these neurons increases, although exceeding a certain limit, the number of neurons aggravates the modelling results. In turn, the best combination of activation functions selected for the hidden layer and the output layer was the combination of hyperbolic tangent—Softmax, and also good results were obtained for the combination of hyperbolic tangent—exponential function. All other combinations of activation functions were not very effective. In the calculations of the best classifier, the criterion of stopping calculations (error function) was the cross-entropy function.

Examples of results obtained using Kohonen networks also for a monitoring system with 10 measurement points and 38 network nodes where leakages were simulated are shown in Table 3 and Figure 4.

Table 3. Kohonen nets calculated for 10 monitoring points.

Network Model	Teach-Q	Test-Q	Valid-Q	Epochs Number	Av-Q
SOFM 11-100	81.20	78.99	72.85	Kohonen 1000	77.68
SOFM 11-25	40.95	45.38	29.35	Kohonen 1000	38.56
SOFM 11-16	32.97	30.12	28.16	Kohonen 1000	30.42

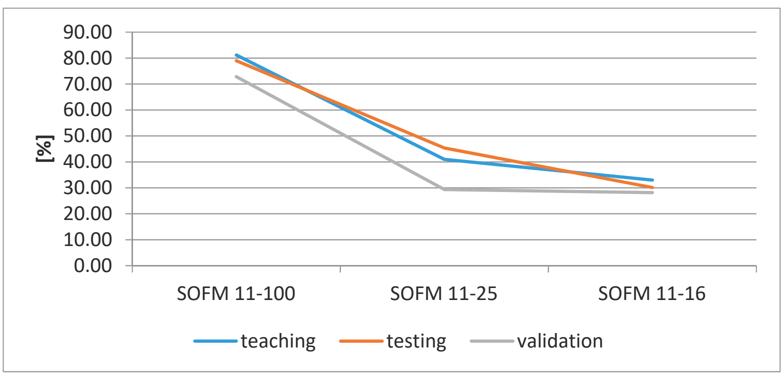

Figure 4. The errors of the Kohonen nets obtained for 10 monitoring points in %.

The accuracy of the model determined depends on the number of neurons on the topological layer of the network, which is similar to the case of MLP networks, whose accuracy depended on the number of neurons on the hidden layer. However, Kohonen models generally gave worse results than MLP models. The best Kohonen classifier was obtained for SOFM 11-100 with 100 neurons on the topological layer (10×10) and for an epochs number of 1000; the average quality of this model is 77.68%, 8% worse than the best MLP model.

Comparison of the results for the best MLP and Kohonen classifiers for the case of 10 measurement points of the monitoring system is shown in Table 4 and Figure 5. At the same time, Table 5 shows the results of modelling for the best MLP and Kohonen classifiers for both calculation cases, i.e., for 10 and 20 measurement points and 38 and 44 network nodes with simulated leaks. The table shows that the MLP network with an increased number of measurement points shows 100% accuracy.

Table 4. The best MLP and Kohonen nets calculated for 10 monitoring points.

Network Model	Average Network Quality
MLP 10-23-1	85.80
SOFM 11-100	77.68

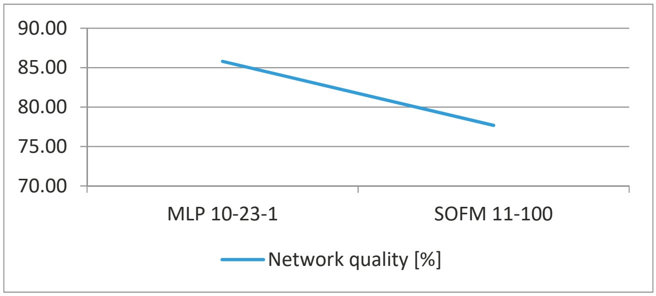

Figure 5. The network qualities for the best MLP and Kohonen nets calculated for 20 monitoring points in %.

Table 5. Results comparison for best MLP and Kohonen nets calculated for 10 and 20 monitoring points.

Network	Calculation Cases	Teaching	Testing	Validation	Total/Average
MLP 10-23-1	Number	258	55	55	368
	Correct results	239	46	44	329
	Incorrect results	19	9	11	39
	Correct results in %	92.48	84.21	80.70	85.80
	Incorrect results in %	7.52	15.79	19.30	14.20
MLP 20-29-1	Number	514	111	111	736
	Correct results	514	111	110	735
	Incorrect results	0	0	1	1
	Correct results in %	100.00	100.00	99.99	100.00
	Incorrect results in %	0.00	0.00	0.01	0.00
SOFM 11-100	Number	258	55	55	368
	Correct results	210	43	40	293
	Incorrect results	48	12	15	75
	Correct results in %	81.20	78.99	72.85	77.68
	Incorrect results in %	18.80	21.01	27.15	22.32
SOFM 21-100	Number	514	111	111	736
	Correct results	422	82	78	582
	Incorrect results	92	29	33	154
	Correct results in %	82.13	74.16	70.24	75.51
	Incorrect results in %	17.87	25.84	29.76	24.49

The classifier algorithm checks for leakage accurately, i.e., the correct identification of leakage is accepted if the classifier indicates precisely the point at which the leak was simulated. Indication of another point, even close to the simulated leakage point, means an incorrect solution which is not taken into account in the assessment of the percentage of the quality of the classifier at each phase of the calculation: learning, testing, and validation. This means that MLP 20-29-1 network has correctly identified all simulated leaks, i.e., it locates exactly all network nodes where the simulated leakage occurred.

Kohonen's network gives much worse results and increasing the number of measuring points not only does not improve, but even worsens the model. It is interesting that the Kohonenan network, as more sophisticated, seemed to be more accurate than the simpler MLP network.

An exemplary graph of the learning rate for MLP network (MLP 20-29-1) is shown in Figure 6.

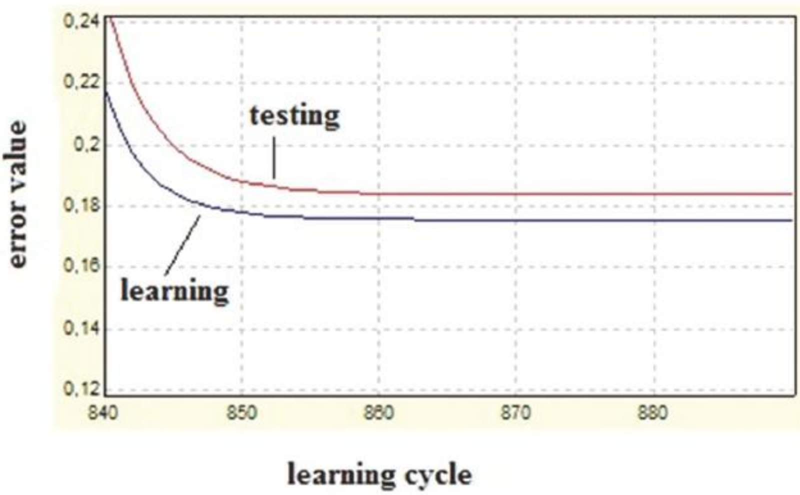

Figure 6. Graph of the learning rate for MLP 20-29-1.

Neural network models were calculated using the StatSoft STATISTICA Data mining package.

6. Discussion and Conclusions

The calculations performed show that neural networks can be a useful and convenient tool for solving the task of detecting and locating hidden leakages in the water supply network, as one of the most important problems related to the complex management of an urban water supply company. The developed algorithm is an element of a complex IT system developed and tested in IBS PAN.

The article examines in detail the different types and structures of neural networks used, which has not been done so far. Simpler mentioned algorithms of failure detection using only SCADA system or additionally hydraulic models of water supply systems were also studied by the authors and the results obtained were worse than those obtained with the use of the MLP 20-29-1 classifier designated in the article.

An interesting observation found during the research is that the MLP networks are more useful for solving this type of task, and simpler in design and calculations than the Kohonen networks. This means that in the problem of location of leaks, a simpler network gives better results than a more complex network. It is possible that if the structure of the Kohonen network had become more complex and the number of epochs had increased, the results would have been better, but there was no point in complicating the Kohonen network if satisfactory results had been obtained through the MLP network.

To solve the problem of detection and localization of water leaks in water nets three components of such the IT system must be disposable: an appropriate designed monitoring system, an exactly calibrated water net model, and a neuronal failures classifier. Using the data from the monitoring system, the hydraulic model of the network can be calibrated and with this model the failures classifier can be erected. By means of the monitoring system the detection of possible water leaks can be then noted and the following use of the neuronal classifier shall lead to recognition of the leaks localization.

The calculation results presented here have been conducted with the use of the real data concerning the water net but the programs used for calculations were not tested in the real operational conditions of the waterworks. Such an approach shall be done in the future in the frame of a research project realized with a waterworks in Poland.

The aim of this paper was to check whether the neuronal nets could be at all useful tools for solving the problems of finding out the water leaks. The results received testify the supposition and the next investigation planned could focus on the development of better algorithms to identify leakage points in the water supply networks where monitoring systems are poor in measurement points, as was the case in the calculation carried out for 10 points.

The innovativeness of the presented research consists mainly in the fact that the presented algorithm of detection and location of leaks is not a single program, but an element of a complex IT system, and its launching requires cooperation of several elements of this system: GIS program, SCADA monitoring system and water meter monitoring system, hydraulic model of water supply network, automatic calibration algorithm of the hydraulic model, SCADA system planning algorithm, and finally neural networks. Previous attempts to solve the leakage detection task were limited to using only the SCADA system or SCADA system and the hydraulic model calibrated only manually and not automatically, which is made possible by the IT system developed by IBS PAN.

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A Study on the Public Landscape Order of Xinye Village

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Abstract: In the modernization process since China's reform and liberalization, urban and village space design is reflected in the characteristics of Western cultures. The idea of Western space design has a profound influence on China, but the piecemeal individuation of art design, the disorderly public art modeling and concept, not only interferes with the aesthetic sense of urban and village public space itself, but also seriously affected the landscape order of public space. In fact, Chinese traditional settlement landscape excels in abundant landscape design and spatial sequence. This paper, using the methods of literature discussion, field research and spatial analysis, takes the typical traditional landscape settlement "Xinye Village" (新葉村) in the south of the Yangtze River as an example, and explores its public landscape order as a whole, and finds its spatial structure based on the "Five Elements and Nine Divisions (五行九宮)" cultural schemata. In the process of development, it has experienced the competition of public space, thus forming a stable and sustainable spatial order form. The purpose is to explore the cultural schema of the public landscape from the traditional Chinese settlement, and to put forward the possibility of "constructing the public landscape order based on culture" in future urban and village landscape design.

Keywords: settlement; culture; public landscape; landscape order; Xinye Village

1. Introduction

With its continuing reform and liberalization, China has been going through a rapid development of urban construction with accelerating rural urbanization. Meanwhile, there are also over-crowded large cities, ubiquitous commercialization in public space, and disorderly environmental landscapes. The stress of urban life is suffocating and even causing an increasing ratio of depression. By contrast, some villages in China still preserve a traditional public landscape order. Therefore, in their spare time, far away from the cold concrete jungle and heavy traffic flow, more and more people go to the countryside to travel and enjoy the natural or traditional cultural landscape. The crisis of public space has a direct impact on the construction of public landscape order. On the one hand, public space is affected by social and economic benefits, and more complex factors have appeared, which leads to the increase of the instability of public landscape. On the other hand, public space is divorced from the organic connection of nature and lacks the spirit of place that embodies culture; the sustainability of public landscape order is challenged.

Public space and public life form public landscape, and show the relationship of dialectical development. The change of public space and public life will also cause the change of public landscape. Public landscape maintains the stability and sustainable development of public space. In the countryside, Chinese people have long depended on their families for survival. Their living space contains the "public culture" of the ethnic group and dominates the public landscape consciousness of settlement. In order to meet the functional or symbolic demands of public space, the authority of ethnic groups, the consensus of ethnic groups and the spirit of stabilizing ethnic groups are established, and the interests of families and the relations between families are maintained. In the public space of settlements, the unique landscape artistic conception and landscape order are created by combining cultural beliefs. At the same time, the public landscape of settlements contains wisdom about living space and living resources, and shapes the relationship between human beings, culture and nature: it regulates the relationship between humans and the environment, the relationship between people and others, and the relationship between human and themselves, emphasizes the harmonious relationship between humans, nature and society, and then creates the stability and sustainability of the public landscape.

As *Lao Zi* (老子) put it, "Human follows the earth, the earth follows heaven, heaven follows Dao (道), and Dao follows nature" [1]. Kay Milton (2007) [2] said: "Culture is a medium for human interaction with the environment. Culture is an indispensable part of human beings. Because if there is no culture, human beings cannot obtain the material and social resources from which they depend." These two perspectives together illustrate that space is organized through the operation of cultural, natural or social processes, which is best represented by Xinye Village (新葉村).

The design of the village is centered on "water" and based on "five elements and nine divisions (五行九宮)". It is a typical settlement with the traditional design philosophy. "Five Elements and Nine Divisions" is a method of simulating celestial phenomena and astronomy to create space order [3]. "A symbol of the sky and comply with the geography" is an important concept of Chinese space culture. *The Book of Changes* (易經): "When people know the law of the formation and operation of the sky, they understand the forming principle of the landscape of the mountains and rivers on the ground" [4]. Public landscape sequence is a spatial form that reflects and merges current nature functions, social culture, politics and economic environment [5]. The Xinye Village lies in the hilly and mountainous areas of the west of Zhejiang Province. It integrates culture and living resources, creating space order in which the natural and tranquil landscape can be felt.

Taking Xinye Village as an example, this paper discusses its public landscape order based on the "Five Elements and Nine Divisions." According to the literature research and field investigation, the analysis and empirical research of public space and ritual behavior landscape are carried out with the help of geographical information and literature data. The purpose is to explore the landscape pattern of Chinese traditional culture and the public landscape order it creates, so as to provide reference for future innovation of urban public landscape order.

2. Literature Review

Local literature is the basic information source of this study, which mainly focuses on public space construction, local emotion, spirit and culture. For example, Zhihan Wang (2006) [6] discussed the three-month festival of Xinye Village; written by Jianliang Ye and Zhichang Chen (2011) [7], A Taste of Xinye featured the austere local spirit and emotion. Qiuxiang Li (2007) [8] studied the cultural belief and landscape construction of Xinye Village. Weinan Liang and Li'na Zhao (2016) [9] explored the elements of public space, the characteristics of public space, and the relationship between public space and behavior in Xinye Village.

Study on settlement landscape in China was based on material spatial study in the early stage and moved on to a broader discussion on divisions and places of historical interests in line with dynasties. Take Dunzhen Liu's (1984) [10] *History of Ancient Chinese Architecture* as an example. Reading through this book offered a communication trend from the north to the south of the design concepts of Chinese public landscape sequences and the settlement trend based on water in Jiangnan after the Southern Song Dynasty. The current study of the public landscape sequence in rural areas, however, inclines us to expand to the overall settlement system, and focuses on the psychology, spirit, cosmological culture, regional characteristics and social life. For instance, Zhihua Chen and Qiuxiang Li (2011) [11] discussed in the "Chinese Heritage· Countryside Architecture: Xinye Village", from the perspective of history and culture, uncovered the intact village structure within the settlement life circle by means of dynamic development and comparative association. In "Chinese Domestic Architecture: Analysis of Traditional Residential Architecture", Senlin Liu (2009) [12] researched the impact of settlement residents' psychology and mentality upon the environmental space and analyzed domestic architecture and mentality, domestic architecture and the cosmic system, and the public mentality of auspicious choice. In Report of Mountain Area Development in China, Guojie Chen, Yiping Fang, Yong Chen, et al. (2007) [13] examined the macro, medium and micro patterns of mountain area settlement distribution. Haiqing Wu (2011) [14] in the "Formation of Jiangnan Scenery and Chinese Aesthetic Culture" held that intellectuals all aspired to a picturesque residential space due to the fact that the Southern Song Dynasty was content to retain sovereignty in Jiangnan. Baode Han (2006) [15] in Fengshui and Environment revealed environmental features from the perspective of Fengshui. In terms of the cognitive model of the cosmos in Chinese tradition, Lizhen Lv (1990) [16] in the "Outline of Neo-Confucianism" puts forward the "Chinese traditional cognitive model of the universe," and analyzed the relationship among heaven, people and the society in the space.

The current public landscape research focuses on the relationship between public art, place spirit and social life. For example, Jinchang Liu (2016) [17], analyzed the significance of space field and how the art, culture and environment can be connected. Pi-Fen Wang, Ming-Chyuan Ho (2012) [18] explored practice and types of sacred space to construct a preliminary conceptual model for designing sacred space. Xuzheng Zeng (2014) [19] put forward the basic subject of building community public life and public space. Yin-Jen Chen, Su-Hsin Lee (2016) [20] believed that "Public Space" becomes the most important landscape connecting indigenous interactive activities and public relationships within their daily life. Chu-joe Hsia (2007) [21] argues the historical dialogue between cities to discuss the cultures of Chinese cities, the building of public space, and the meanings of public arts.

The related foreign literature goes as follows: Reginald G. Golledge and J. Stimson (2003) [22] analyzed spatial behavior from a geographic perspective. Grant W. Reid (1994) [23] argued the scenery from thought to form. Bryan Lawson (2013) [24] researched spatial language from multiple angles. Christopher Alexander (1991) discussed the eternity of architecture and spatial model. Francis D.K. Ching (2015) [5] comprehensively researched architectural design and the relationship between space and sequence. Jacinta Francis, Billie Giles-Corti, Lisa Wood, Matthew Knuiman (2012) [25] discussed "Creating sense of community: The role of public space". Maryam Ziyaee (2018) [26] assessed urban characteristics through cultural landscape matrix. R. Altin and C. Minca (2017) [27] wrote "Exopolis reloaded: fragmented landscapes and no human's lands in a North-Eastern Italian border region." A. Höglhammer, A. Muhar, P. Stokowski, T. Schauppenlehner and R. Eder (2018) [28] present the results show that public open spaces are not regarded as important leisure spaces but rather private areas for leisure purposes.

Settlement public landscape can symbolize the unique identity of the settlement, and improve the residents' and tourists' memory of spatial characteristics in the environment. Settlement is a space identity through the combination of landscape and culture, and in the description of the location, different settlement landscape elements have different functions. This paper attempts to describe the cultural identity of the settlements by linking them with natural resources, cultural beliefs and social life. With the help of geographic information such as public landscape orientation, orientation and layout, combined with local culture and ethnic life, the composition of public landscape is analyzed. It will also discuss the links between public landscapes, the interaction between the public landscape and human beings, as well as the spatial order constructed by settlement public landscape.

3. Method

This paper uses the methods of literature discussion, field investigation and spatial analysis. In spatial analysis, schema cognition and spatial analysis are used as specific research methods. Schema cognition has been an important method of cognitive space-time in China since ancient times, such as the typical cognitive space tool in the Han Dynasty (漢代); The Eight Trigrams (八卦) symbols in the book of changes are presented in the form of schema; Yin Yang (陰陽) Tai Chi (太極) and the five elements (五行) can interpret the operation rules of the universe through schemata. In the West, schema first appeared in the philosophical works of Immanuel Kant (1724–1804). Gestalt psychology was the first to attach theoretical importance to schema. Jean Piaget (1896–1980), a famous Swiss psychologist, believed that "schema refers to the structure or organization of action." Spatial analysis refers to the technique of studying things in geometry or geographical properties. Spatial analysis is also used as a tool to verify the occultation length [29]. Therefore, we will draw lessons from the traditional Chinese spatial schema cognitive method combined with the current geospatial analysis methods. We designed detailed research steps, in-depth research framework in order to carry out this study.

3.1. Research Steps

3.1.1. Data Collection

The data in this paper come from comprehensive literatures, which include seeking the cooperation of settlement residents, local governments and scholars, and collecting various relevant information through historical documents and field surveys of settlement, searching local literatures, investigating the landscape layout of settlement, and statistical data of public open space and geographical environment. Participatory observation on the spot helped us understand the basic situation of village cases, collect genealogy, local literature and local cultural relics departments, with regard to the "Village Historic Architecture and Cultural Conservation Planning" and other information, compared the location of "public space" and its historical rise and decline with the sample data obtained from field trips.

3.1.2. Research Design

The prerequisite for establishing analytical methods is to design a research framework, in order to help better integrate research methods and content in the process of research, to explore the relevant elements of public landscapes and the basic cultural framework they comprise, and to better assist spatial content analysis in the process of research. The construction of "public landscape order" is put forward as a result.

3.1.3. Research Analysis

Through taking the public landscape of Xinye Village as a case study, collating the local literature and sample obtained from field interviews, comparing the location of "public space" on the map and its landscape construction, using chart cognition and spatial analysis, and making the systematic analysis of the related spatial theory, this paper discusses the public landscape order system of settlement: the connection between the public spatial landscape, and the exploration of the potential spatial culture, The spatial position, distribution, shape, orientation, and topological relation of the common landscape of settlement are analyzed.

3.1.4. Research Discussion

With the help of the viewpoint of competition theory and geospatial information, the competition hypothesis of "public space" is put forward by means of graphical cognitive analysis. We can find detailed descriptions of all variables related to public activities and public space, compare and study the "competition" between public spaces, study the changes of public space in the development process of villages, and compare the crisis, decline or sustainable development of "public space." This paper evaluates the frequency, variables and vitality of public space through discussion, and concludes the "competition" law between "public space" and puts forward the dynamic development pattern of public space and the relatively stable field construction mode.

3.2. Research Framework

This paper takes the public space of "Xinye Village" as an example. The "public space" of the village is constructed and developed on the basis of Xishan Temple. It presents a unique landscape form and creates a public space landscape pattern and order of the "Five Elements and Nine Palaces". The contradiction between population expansion and limited resources has gradually emerged. Each branch has formed a competitive relationship between space and life, leading to ethnic differentiation (Figure 1).

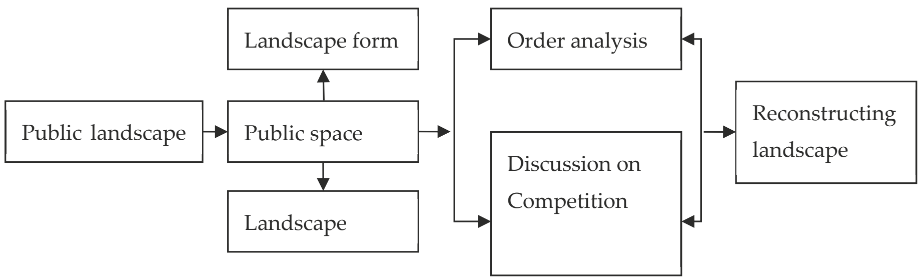

Figure 1. Exploring public landscape order.

4. Construction of Settlement Public Space

4.1. Spatial Design of XinyeVillage Settlement

As was written in the Genealogy of the Yuhua Ye Family: "the Family had been living in Hucen (湖岑) of Shouchang (壽昌) region for generations but moved to the west of Yuhua in 1208. Since the first generation in Xinye Village, the Family has stayed away from wars, natural disasters and man-made misfortunes, maintained the cohesion of a consanguineous settlement, developed into a huge clan, and thus gradually achieved a systemic spatial design at macro, medium and micro levels. The landscape planning of Xinye Village has expanded to the surrounding rural areas, which is in line with what was described in *Er Ya · Shi Di · Wu Fang* (《爾雅●釋地●五方》) by Guo, Pu (郭璞), a Fengshui master: "Rural areas are basically areas outside cities, pastures are the areas outside rural areas, fields outside pastures, forests outside fields, Shang outside forests." As was portrayed in *Meng Zi · Li Lou Shang* (《孟子●離婁上》): "To increase geopotential height, one must depend on hills and mountains; to decrease geopotential height, one must rely on rivers and lakes." Located along the upstream section of Qiantang River, Xinye Village falls in the typical lower mountain and hill area to the south of Yangtze River. It is within the northern limits of the subtropical monsoon climate, featuring warm and humid weather, abundant rainfall and plentiful river branches, four distinct seasons and ample sunshine. It has a history of over 800 years since the first generation of the Yuhua Ye Family came to settle here and went through the Song Dynasty, the Yuan Dynasty, the Ming Dynasty, the Qing Dynasty and the Republic of China. The descendants of the Ye Family have kept the structure and spatial landscape of this village [11]. Zhu Lianfa (2007) [30] mentioned that "Jin Renshan (金仁山), a neo-Confucian philosopher in the Yuan Dynasty, selected the location for Xinye Village during Jiande Period, and Ye Tianxiang and Ye Yuqing, the descendants of Ye Family in the Ming Dynasty designed its layout and spatial landscape. Based on the nine I Ching hexagrams of Yin and Yang unifying Heaven and Earth, and the essence of hexagrams that in the end all are in a cycle that returns to the beginning," they built around100 intersecting streets and alleys, forming a unity of Qian (Heaven) and Kun (Earth). The Construction of "Five Elements and Nine Divisions" Public Landscape order based on the system of number and principle, the spatial system was developed delicately and sophisticatedly layer by layer.

Due to the Chinese philosophical notion that "Tao follows nature", the pursuit of open space and semi-open space outweighs the pursuit of confined space and the open public space naturally forms a public landscape sequence [31]. Through the observation, analysis and research of the site selection and development of Xinye Village, it is found that its public space sequence is based on "Five Elements and Nine Divisions," which is both connected and separated from the inside out and from the outside in. From dots to lines to surfaces to three-dimensional space via pavilions, Towers, roads, alleys, rivers, ponds, halls and temples, these landscape models have been wholly shaped into a systematic landscape sequence. The pattern not only fits the interior landscape of the settlement, but also links the exterior space of the settlement. As it belongs to every villager, the public landscape has been able to foster a secured and orderly residential space. Security, with relevant factors such as physical condition, will, values, judgments, imagination and self-realization, is the inherent function of traditional Chinese settlement landscape. The sense of environmental security is also related to power [32], in that a specific location clarifies the status of human being [33].

4.2. The Model of Settlement's Public Landscape

Table 1 "Five Elements and Nine Divisions" means that the combination of "Five Elements" and "Nine Divisions" can create a unique spatial order. The "Five Elements," namely wood, fire, metal, water and earth, symbolizes the five spatial positions of east, south, west, north and middle respectively. The spatial arrangement of "Nine Divisions" combined with "Luo Shu (洛書)" and "the eight Trigrams of the later heavenly order (後天八卦)," and has given a number sequence from one to nine, azimuth layout, color symbol and so on. Therefore, the integration of "Five elements", "Nine Divisions", "the Eight Trigrams (八卦)" and "Luo Shu" to form the overall space order of "Five Elements and Nine Divisions"(Table 1, Figure 2): "1" is "Kan (坎宮)", which belongs to "water," white, located in the "north"; "2"is "Kun (坤宮)" belongs to "soil," black, located in the"southwest";"3" is "Zhen (震宮)", belong to wood, Virid (碧), located in the "east";"4"is "Xun (巽宮)", belong to "wood", green, located in the "southeast"; "5" is the "Zhonggong", belongs to "the soil", ranks in the "center"; "6" is "Qian Palace (乾宮)". It belongs to "metal", white, located in the "northwest"; "7" is "Dui (兑宮)", belong to "metal", red color, located in the "west"; "8" for "Gen (艮宮)", belong to "earth", white, located in the "northeast"; "9" is "Li (离宮)", belongs to "fire", purple, located in the "south" [3].

Table 1. Historical origin of the settlement.

Number	Five Elements	Nine Divisions	Direction	Color	Main Function Area
1	Water	☵坎(Kan)	South	White	Yongxi Hall and Xuanqin Hall
2	Soil	☷坤(Kun)	Northeast	Black	Xiaxinwu Residential Area and Sifangtang
3	Wood	☳震(Zhen)	West	Virid	Residential Area of Rongren Hall and Banyuetang
4	Wood	☴巽(Xun)	Northwest	Green	Residential Area of Shangdaoyuan
5	Soil	中宫(Zhonggong)	Center	Yellow	Central Palace and Youxu Hall
6	Metal	☰乾(Qian)	Southeast	White	Residential Area of Xuanqin Hall
7	Metal	☱兑(Dui)	East	Red	Jinshidi, Rongshou Hall and Residential Area of Jiedushang
8	Soil	☶艮(Gen)	Southwest	White	Residential Area of Dahou Mountain
9	Fire	☲离(Li)	North	Purple	Qiangang Mountain, Country field, Qing'gang, Wangjing, Daofeng Mountian

Specifically, Xinye Village is a settlement space centered on "Water" in the Chinese traditional philosophy of "Five Elements". The whole settlement is built surrounding the semi-circular pool "Nantang" and the "Youxu Hall." With intersecting streets and alleys, "Metal, Wood, Fire and Earth" have integrated the architecture, the space and the landscape into an organic and intact space, and eventually developed into the pattern of "Five Elements and Nine Divisions" (Table 1) that indicated oneness between nature and humans to showcase a mysterious three-dimensional image and shape into a public landscape sequence. Also, the public ceremony of Xinye Village settlement is conducted in accordance with the spatial structure of "Five Elements and Nine Divisions." For instance, the route of the parade is consistent with the public landscape sequence. The public ceremony in its unique way further highlights such public landscape sequence.

☴ 4 巽(Xun) Green Wood Southeast	☲ 9 離(Li) Purple Fire South	☷ 2 坤(Kun) Black Soil Southwest
☳ 3 震(Zhen) Virid Wood East	5 Yellow Soil Center	☱ 7 兑(Dui) Red Metal West
☶ 8 艮(Gen) White Soil Northeast	☵ 1 坎(Kan) White Water North	☰ 6 乾(Qian) White Metal Northwest

Figure 2. Pattern of Five Elements and Nine Divisions.

4.3. Landscape Construction of Public Space

The existence of landscape all covers broad factors such as geography, countries, nations, and culture, thereby being created on the earth featuring certain traits with specified forms and materials [31]. As Xinye Village is located in the mountain area in the west of Zhejiang, an area where the trans-communication of Form School (形勢派) and Compass School (理氣派) prevails from Fengshui (風水), local residents value the impact of psychology and spirit upon the environment and pursue austere world views. Since the universe derives from its own rules that humans believe in and strive to understand, there came symbols of the universe in human cognition and a close-knit corresponding system, and even a rational condition of knowledge that has the power of influence, invention and creation [31]. Xinye Village lays a stress on proper site selection which combines the form and momentum of the mountains and rivers, and also, a world view and a survival philosophy that conforms to and integrate nature and create a multidimensional public landscape (Figure 3).

Figure 3. Landscape of Xinye Village.

In line with the traditional Chinese world view, the site selection for Xinye Village also took into account the forms and momentum of the mountains and the rivers, thereby creating unique public landscape (Figure 2). The ancient doctrines of “Five Elements” in China hold that all creatures in the universe originated from Water, Wood, Metal, Fire and Earth [34]. The German philosopher Martin Heidegger (1889–1976) also argued that Heaven, Earth, Human and God integrate into a quadruple entirety in China. The ancestors of Xinye Village emphasized the materials and the shapes of the nature (the mountains and the rivers) at the very start of its village planning, with four directions of the settlement towards: east- A. Lion Mountain, south- B. Elephant Mountain, west- C. Yuhua Mountain, north- D. Daofeng Mountain and the settlement centers- E. Nantang. The structure of "form and momentum" in Fengshui carries profound connotations of "the human world". The observation of nature by the Chinese is not purely objective, but rather out of human-oriented humanistic thinking [15]. The whole settlement of Xinye Village imitates the Nine Divisions of Yin and Yang (Figure 4): with D. Daofeng Mountain as Chao Shan (far front hill), C. Yuhua Mountain as Zu Shan (background hill), and two in-village canals "aided on the left and supported on the right," mountains start from the west C. and the north D., and water all flows into the east A. and the south B. In this way, it fosters a natural space landscape that secures wind and auspicious fortune, with A. Lion Mountain and B. Elephant Mountain symbolizing gatekeepers. The artistic imagery of the whole space goes with what is illustrated in Zhuangzi: people will achieve true satisfaction if they bear no desire. Located at the center of the village, E. Nantang, a still water landscape, implies the philosophy of non-interference that settles people's soul. The simple semicircular shape of E. Nantang offers people a sense of unity, and meanwhile symbolizes the combination of a static state and a dynamic state [22]. Changes will happen naturally if no action is taken other than adhering to the Tao; the society will be stable if it is managed in a calm way [35].

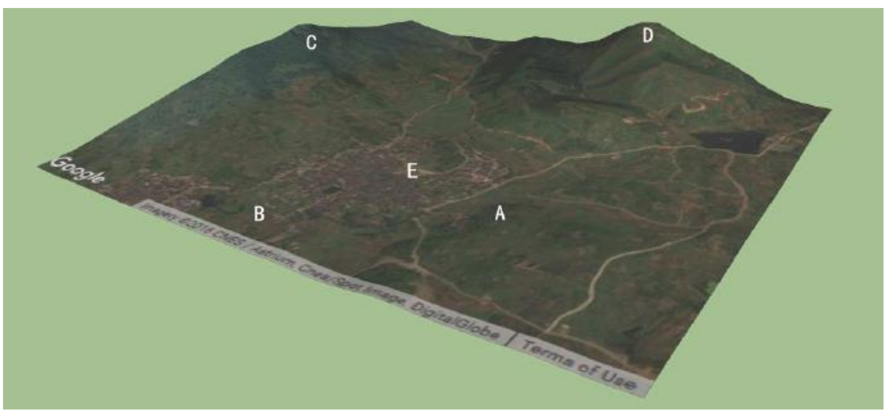

Figure 4. Google solid scene map of Xinye Village.

4.3.1. Public Space landscape

The existing public space in Xinye Village includes the landscape of local culture, such as Fengshui, religion and ancestor belief. These public landscapes determine the spatial orientation, landscape form and order of the settlement. With the development of history and times, there have been many changes in the public space of settlements. The existing public space landscape mainly includes ancestral hall, pool, pavilion, tower, temple and surrounding landscape, as shown in Figure 5, after sorting out the existing public space layout, we found that:

The declining of ethnic groups whose "ancestral Halls" are small, declining, abandoned or even extinct; the powerful of ethnic groups whose "ancestral Halls" are flourishing and gradually differentiate into new branches of ancestral Halls. These families with strong economic strength often build stage in the ancestral Hall, such as Youxun Hall, Rongren Hall, Xuanqing Hall, Rongshou Hall and Rongzhi Hall, etc. In order to meet the three aspects of landscape, daily water and Fengshui, in front of the larger public space, a square and a pond be built, and a solemn and comfortable environment is created. In the existing 13 ancestral temples, such as Youxu Hall, Rongren Hall, Rongshou Hall, Changshu Hall, Tongxin Hall, Changzhu Hall, and the ancestral temple of Xishan, there is always an independent pond within the Hall; in addition, there is a pond shared by Yongxi

Hall and Youxu Hall, a pond for planting lotus flowers in front of Wenchang Pavilion, and there is a pond beside the Tuányun Tower. There are large squares built in the large public spaces of the settlement, such as Wenchang pavilion, Tuányun tower, Xishan ancestral hall and Yuquan temple etc.

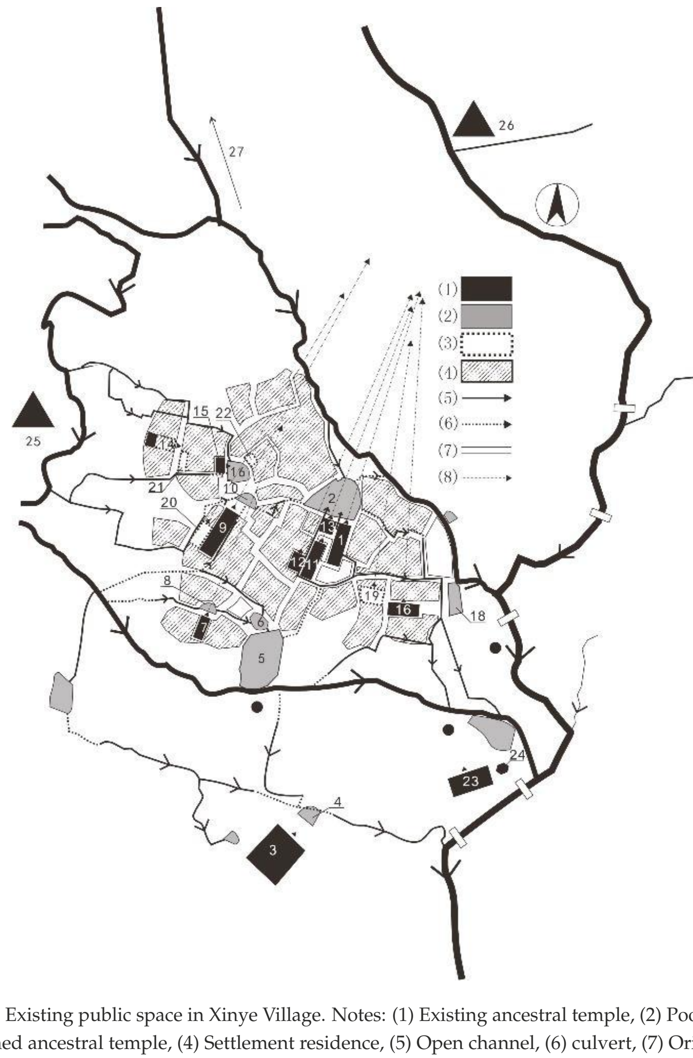

Figure 5. Existing public space in Xinye Village. Notes: (1) Existing ancestral temple, (2) Pool space, (3) Abandoned ancestral temple, (4) Settlement residence, (5) Open channel, (6) culvert, (7) Original path, (8) Mountain orientation; 1 Youxun Hall, 2 Nantang, 3 The ancestral temple in the West Mountain, 4 Pond of the ancestral temple in the West Mountain, 5 Stone pond, 6 Li pond, 7 Cunxin Hall, 8 Pond of Cunxin Hall, 9 Chongren Hall, 10 Pond of half-moon, 11 Xuanqing Hall, 12 Youyi Hall, 13 Yongxi Tang, 14 Yongmu Hall, 15 Youzu Hall, 16 Xicao Hall, 17 Rongrou Hall, 18 Pond of Sifang, 19 Qiyou Hall, 20 Shiliu Hall, 21 Shizi Hall, 22 ZhenMei Hall, 23 Wenchang Pavilion, 24 Tuányun Tower, 25 Yuhua Mountain, 26 Daofeng Mountain, 27 The way to Yuquan Temple.

4.3.2. Public Behavior Landscape

The public behavior landscape in Xinye Village is very rich, which embodies the interaction between human and public space. At the same time, public behavior is regulated and restricted by the public space, and the organic public landscape system is created as a whole. The public behavior landscape mainly includes production activities, daily life, festival entertainment and religious ceremonies.

Productive behavior activity: the behavior landscape of organizational production in Xinye Village includes the process of producing, harvesting, collecting, or celebrating the harvest, and eventually converges into the "ancestral group" of the public space and makes an overall arrangement and sharing. In this process, we can see that the continuation of life and the inheritance of farming culture can bring about rich material changes in the texture of public space.

Daily life activities: the life behavior landscape of Xinye Village mainly takes place in the public space of the village, which has a relatively open square and pond, forming an open landscape. In other words, the village residents will participate in public collective activities to different degrees, forming a kind of daily life landscape.

Festival entertainment and ceremony: the traditional festival celebrations and entertainment are closely related to public space, such as the local customs held in ancestral halls: marriage, birthday banquet, and relocation. All these activities can bring people a special sense of life and promote the inheritance of settlement spirit.

5. Analysis and Discussion of Public Landscape Order

5.1. Analysis of Landscape Order in Public Space

The landscape of public space endows space with value, creating a cultural schema of "public space" and its corresponding functions such as life, production, sacrifice, festivals and entertainment. It embodies the public landscape order of settlement. The landscape of public behavior strengthens the space culture, and the daily communication, festival activity and belief in public space, the "place spirit" of the settlement can be presented. In Xinye Village, the public space pattern created by temples, towers, ancestral temples and "water" provides the villagers with places for worship, gathering, living and entertainment, which stimulates public activities, condenses the emotions and spirits of the village, and forms a holistic and systematic landscape order from material space to spiritual life. The historical evolution process of public landscape shows that public space maintains the sustainability of public landscape in the competition.

5.1.1. Landscape Order of "Five Elements and Nine Divisions"

When the fundamental component units are assembled together in the space, there seems to be more diverse aspects than individual parts, shaping the architectural space and exterior public space [5]. Surrounding Xinye Village settlement are eight mountains standing in the south and facing north. Situated beside a river at the foot of the mountains, the setting of the whole settlement is just like the image of Eight Trigrams and Nine Divisions with the geometry of a spider's web (Figure 6, Table 1): located at the center, Nantang, together with Youxu Hall to its south, directly faces Daofeng Mountain. As it's forbidden to build houses in front of Youxu Hall, all houses in the village are scattered to its east, south and west, forming the most spacious public landscape in the central part of the settlement. The semicircular Nantang pond combined with central point, along with the extending line, creates the fundamental structure of public landscape. The semicircular Nantang is the center of the Eight–Diagram image with its western half reflecting mountains and its eastern half reflecting the brightness of the sky, altogether forming an image of Yin (陰) and Yang (陽) in Tai Chi. Qian (乾)and Kun (坤) in the eight Trigrams are exactly like residential architecture in three rows [7].

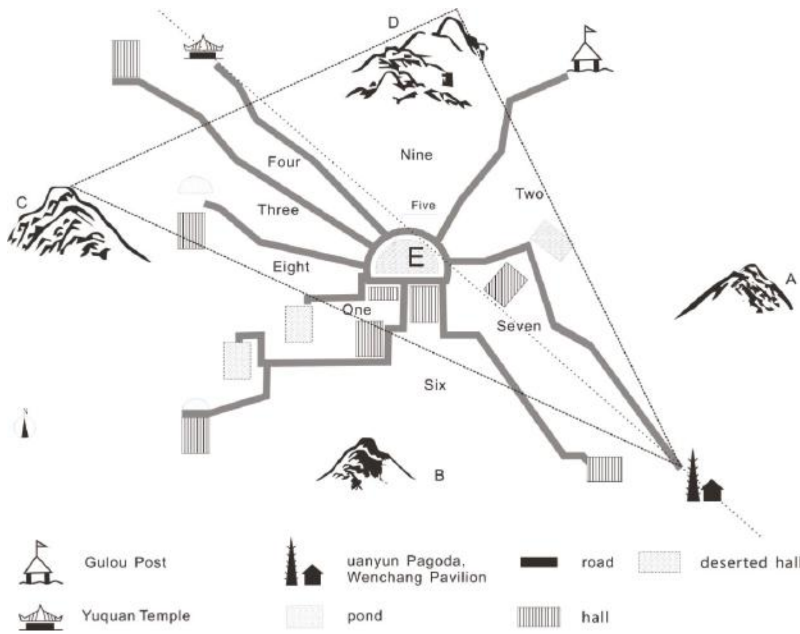

Figure 6. Public landscape sequence of Five Elements and Nine Divisions.

Analyzing Xinye Village from a philosophical perspective, its public landscape sequence conveys in-depth traditional Chinese philosophy, ritual thinking and environmental ecological values. The "Space of the Settlement" presents: five out of eight paths are connected to public space of "ancestral halls", such as Chongren Hall, Chongzhi Hall, Rongshou Hall, Yongxi Hall, Cunxin Hall and Xuanqing Hall. Youxu Hall is a public Hall shared by the whole clan. Gradually with time, the patriarchal clan in the village was divided into several branches with each one building its own hall and having its residential houses surround the Hall except for the front side. So, the setting of the settlement showcases multiple layers and groups. Each element in the public space of the settlement, collectively or separately, exists in irregular communities.

During late Warring States Period, the concept of "Five Elements" prevailed in China and greatly dominated all the spatial concepts of Han people and even all forms of settlements. As a symbol, "Five Elements and Nine Divisions", indicated in the Public Landscape Sequence of "Five Elements and Nine Divisions" offers a unique spatial perspective and enhances spatial mystery to interpret different landscape connotations. According to the essence of hexagrams that "in the end all are in a circle that returns to the beginning" (Figure 6, Table 1), to create a unit of space and public landscape, people adopted numerology to link various spatial elements to better command them all as a whole and gain a sense of wholeness. With the village facing Daofeng Mountain, the narrow and deep streets and alleys on the two sides of the settlement disperse to all directions and the old houses are arranged row after row in terms of their ranking on two sides and the back side with its spreading spatial structure sequentially in its construction.

The existence in the world is an essential natural system of its very existence, Xinye Village planned its layout based on "Five Elements and Nine Divisions" with a classification system of its five elements accounting for part of the cosmology and constituting a simplified cosmic order [16]. Things in the world are those that remain and they decompose this world out of materialization. Traditional Chinese culture holds that all in the universe are made up of five elements including metal, wood, water, fire and earth, and everything that develops and changes in the nature is the result of the ever-changing and ever-influencing five elements [12]. The public landscape layout of Xinye Village is exactly what is described in *The Great Meaning of the Five Elements* (《五行大義》) (Figure 6, Table 1): wood in the east stands for the color of green that symbolizes the creation of all and the color of sprouting buds; fire in the south is the color of red that demonstrates the scorching summer; earth in the center stands for the color of yellow that represents the color of soil and that is why there is a saying that the sky is dark and the earth is yellow in essence; metal in the west is the color of white, which signifies death as autumn bears a somber and desolate sense and the Solar Term of White Dew leads to frost; water in the north is the color of black. Daofeng Mountain in Xinye Village belongs to the element of "Fire" that the ancestors in the village dug the semicircular Nantang particularly to offset "Fire" with "Water." In a word, Xinye Village takes "Five Elements and Nine Divisions" as a spatial schema, forming a unique public landscape order.

5.1.2. Order Imagination of Public Landscape

Wenchang Pavilion and Tudi Temple were built in concert with Tuányun Tower to convey the spirit of local culture. This Tower of Fengshui is called Tuányun Tower, originating from *Zhuangzi· Xiao Yao You* (《莊子●逍遙遊》): "soar straightly above nine thousand miles" [35]. The Tower that soars into the sky can compensate for the disadvantage of the high geopotential of the northwestern area and the low geopotential of the southern area of Xinye Village, creating a "tripartite confrontation" (Figure 6) situation together with Yuhua Mountain and Daofeng Mountain based on Nantang as the center. Vertical elements such as mountains and towers that can form special points in the air literally are able to define invisible opaque in the space. Villagers hold that landscape of "tripartite confrontation," which was adopted "analogy" in landscape design. It will form a visual effect of upstanding height and balance the spatial landscape despite its inconsistence to the basic effect of mountains in nature. It can be seen that the landscape construction of the traditional Chinese public space not only respect the nature as a whole, but also adjust spatial balance from the situation and momentum of the landscape. The "tripartite confrontation" landscape of Xinye Village fulfills people's needs to settle their souls.

As was mentioned by Baode Han in his (2006) [15] edition of *Lectures on Chinese Architecture Culture*, there has been no such spatial culture as that of China that has put so much emphasis on the concept of principal axis that often decides spatial planning and reflects a persistent awareness of cosmic balance by the Chinese [32]. As Jiangnan was a big aggregation of men of letter since the Southern Song Dynasty, the pursuit of success and fame of traditional Fengshui had an underlying impact on Xinye Village (Figure 6): Youxu Hall decides the choice of the location and the orientation of residencies and Halls in Xinye Village so that Tuányun Tower, Youxu Hall and Yuquan Temple are all connected into one axis that bisects the connecting line between Daofeng Mountain and Yuhua Mountain. The whole spatial layout echoes with a larger natural environment in a succinct style, shaping a unique public landscape sequence. The curve path in Xinye Village enables the visitors to enjoy changing landscape as they walk around. For instance, the grey line in Figure 5 shows the current visiting path to the village landscape. Horizontally viewed, the winding space extends beyond the façade and vertical elements, partly hidden, partly visible and alluring.

5.2. Discussion on the Spatial Competition of Public Landscape

Public space and public life form an interdependent relationship. Specific public life requires a specific structure of public space. The pluralistic way of life and culture will split the public space, make it full of conflicts and competition fields, and the competition for public space will lead to the change of the public landscape. With the development of Xinye Village, clan differentiation has appeared since the Ming Dynasty. The living space around the branches of the ancestral hall forms a "mass" of public landscape characteristics. The differentiated ancestral hall construction has planning significance for the layout of the public landscape. According to the Yuhua Ye genealogy, there are 22 ancestral halls in Xinye Village based on ethnic groups, and 11 of them are still in existence. It not only creates the sacrificial, festival and entertainment space for the settlement, but also creates the unique public landscape. In the whole process of development and change, the public space creates competition with each other, breaking through the original space order of "five elements and nine palaces," and constantly reconstructing its new public landscape order.

5.2.1. Competition in the Public Space

In Chinese culture, there is a kind of ethnic "cultural circle", which emphasizes the unequal relationship between "not my ethnic" and "my ethnic" [36]; therefore, after ethnic differentiation, there will inevitably be a "competition". In traditional Chinese military law, there is much wisdom about "competition". It points out the reasons of the competition, that is, striving for fame and fortune, accumulating contradictions, producing civil strife and striving for living resources. The important reason for the "competition" of public space is the competition between power and economy. For villages, the "competition" between ancestral halls is the main way to fight for survival power and living resources. For example (Table 2), the existing public space in Xinye Village includes religion, culture and ancestral belief space. There is a persistent competition between these public spaces. The scale of stable public space is larger than that of unstable public space: for ethnic groups with small power, their ancestral halls are usually small in scale, easy to decay, abandon or have even collapsed. Ancestral halls of powerful ethnic groups are flourishing and have gradually differentiated into new branch ancestral halls. In addition to the orderly hall, Rongren Hall, Luoqing Hall, Rongshou Hall and Rongzhi Hall in Sanshitian village all have drama stages. In front of the powerful ancestral hall of the family, there are open space with squares and ponds, and the environment will be solemn and comfortable. Among the 13 existing ancestral halls, there are ponds in front of Youxu Hall, Rongren Hall, Rongshou Hall, Changzhu Hall, Chunxin Hall, Changzhu Hall and Xishan Temple. In addition, Yongxi Hall and Youxu Hall share the "South Pond". There are lotus ponds in front of Wenchang Pavilion and ponds beside Tuányun Tower. The more stable public spaces—Wenchang Pavilion, Tuányun Tower, Xishan Temple and Yuquan Temple—have very large squares.

Table 2. A public space that changes in competition.

Public Space	Construction and Change of Public Landscape				
	Time of Construction	Relocation or Reconstruction	Incidental Pond	Incidental Square	Storage and Waste Status
Xi Shan ancestral hall	Early Yuan Dynasty	△	√	√	√
Youxu Hall	Beginning of Yuan Dynasty	△	√	×	√
Yongmu Hall	Ming Dynasty	○	×	×	√
Chongxin Hall	○	○	○	○	○
Chongzhi Hall	Ming Dynasty	○	×	×	√
Chongli Hall	○	○	○	○	○
Chongyi Hall	○	○	○	○	○
Chongren Hall	Ming Luanda period	○	√	×	√
Rongshou Hall	○	○	○	○	○
Yongxi Hall	Ming Dynasty	×	√	×	√
Storage Hall	Ming Jiajing period	○	√	×	√
Yuqing Hall	○	○	○	○	○
Yuyi Hall	Ming Dynasty	×	×	○	○
Xuanqing Hall	Qing Dynasty(1661)	△	×	×	√
Jiqing Hall	○	○	○	○	○
Shiliu Hall	○	○	×	○	◇
Qiyou Hall	○	○	×	○	◇
Youzhu Hall	○	○	○	○	√
Ruizi Hall	○	○	○	○	◇
Changzhu Hall	○	○	○	○	○
Shizi Hall	○	○	○	○	◇
Zhen Mei Hall	○	○	○	○	◇
Tuányun Tower	First year of Ming long Qing (1567)	△	√	√	√
Wen Chang Cabinet	Northern Song Dynasty (960–1127)	△	√	√	√
Yuquan Temple	Southern Song Dynasty (1127–1279)	△	×	√	√

Notes: √ sure, × negate, ○ No textual criticism, ◇ Site or occupation, △ rebuild.

In recent years, the creation of public space closely related to rural landscape has become more and more innovative. The restoration, reconstruction and abandonment of public space such as Xinye Village ancestral hall, and the restoration and expansion of some branch ancestral halls reflect the people's national consciousness. Xishan ancestral temple (now the total ancestral temple), Ming Dynasty (1531) moved to the north of the Tuányun Tower, Qing Dynasty (1759) reconstruction; Youxu Hall (Outer House), Ming Dynasty (1505–1521), Qing Dynasty (1795–1820) expansion, reconstruction in 1926; Chongzhi Hall, rebuilt in the early Qing Dynasty, is now moving to Sanshitian village; Chongren Hall was relocated at the end of Ming Dynasty and rebuilt in Qing Dynasty (1880); Chunxintang was rebuilt in Qing Dynasty (1795–1820) and 1950; Xuanqing Hall was rebuilt in Qing Dynasty (1880) and in the eighteenth year (1929) of the Republic of China. Tuányun Tower was hit by a typhoon in the 1990s and repaired in 1999. Wenchangge, rebuilt in the Qing dynasty from 1862 to 1874; Yuquan temple, in the Qing dynasty (1821–1850) by the local 18 ethnic groups to rebuild cooperation. In addition, Chongxin Hall, Chongzhi Hall, Chongyi Hall, Yu Qingtang, Qiyou Hall, Youzhu Hall and Zhenmei Hall have no architectural space and no ruins. Of them, Shiliu Hall remains only the ruins of steps and patios. Qiyou Hall was caught in a fire in 1949. Its ruins have been occupied by other ethnic groups; Shizi Hall remains; Chongzhi Hall and its ethnic groups have moved to the nearby Sanshitian Village.

(1) "Competition" for Space Power

The "ancestral temple" is the "sacred space" of "family" in traditional Chinese settlements. Being endowed with cultural significance and place spirit, it is the symbolic space of family organization and authority, and the core "public space" of competition culture. According to the genealogy of the settlements, in "Xinye Village", there are several ancestral temples for worship. Based on ethnic groups, there are 22 ancestral temples, forming a unique "ancestral temple group" (Figure 7). Everyone associates their dwelling place with the ancestral temple as the "center" to gain their status in ethnic history and society. Ancestral temple groups have maintained the public order and security of villages for more than 700 years. The phenomenon of "survival of the fittest" in the "competition" hides the life rule of "public space". The stability and persistence of the "ancestral temple group" can reflect the development, prosperity and decline of a "consanguineous" village [12]. The public space landscape of ancestral temple, which is linked by "blood", can not only meet the function of village public gathering, but also meet the needs of spiritual belief, reflect the collective characteristics of its society, and reconcile the common contradictions and problems of the society [19].

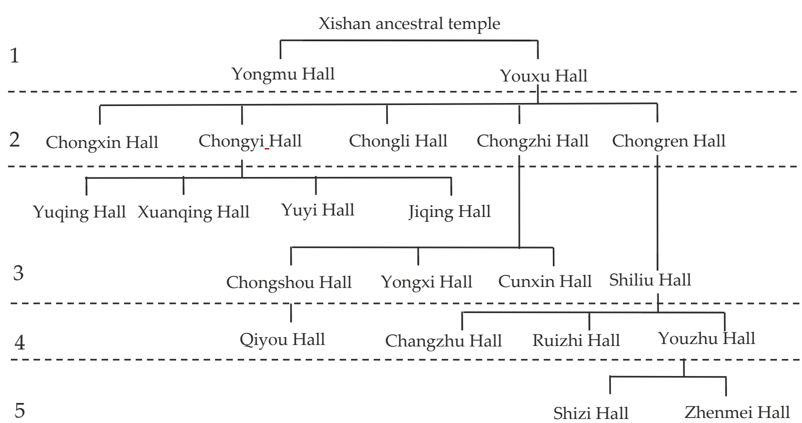

Figure 7. The development and decline of the "Ancestral Temple Group".

Therefore, the public space "ancestral temple group" in Xinye Village has two functions: one is to satisfy the spiritual sustenance of "ancestral belief" space, which serves as a place of worship and festival, and plays the role of connecting the public consciousness of ethnic groups; the other is to meet the needs of daily public life, which is the material space to carry out village gatherings, entertainment and so on—an important place for public activities. With the growth of the village population, they will have the expansion of human settlements, the antagonism of ethnic interests under limited resources, the differentiation of public consciousness, and the establishment of branch ancestral halls by different tribal groups [36]. During the development of ancestral temples in branches, conflicts among ethnic groups have been accumulated in order to compete for living space and living resources, resulting in civil unrest. Challenges faced by ancestral temples in branches have led to a crisis of decline in villages; some ancestral temples of branches and veins disappeared or became dilapidated due to the extinction or weakness of the clansmen, and even were occupied by other ethnic groups. In a word, the public space of "ancestral temple group" in Xinye Village is competing with each other, and the situation of survival of the fittest is formed.

The organization of public spaces should be hierarchical [37], through the spatial simple structure map; we can discuss the problem of spatial level. Among the 22 ancestral temples in Xinye Village, there is a dual spirit of competition centrality and differentiation, as a result of the competition; there are only 11 ancestral temples. In order to occupy better spiritual sites or better spatial resources with Fengshui, "competition" appears between ancestral temples of branches and veins in Xinye Village (Figure 7).

Xinye Village believes in ancestral culture, Confucian culture and geomantic culture. First, it builds the "Xishan ancestral Hall", a public space that embodies the consciousness and spirit of the village. In the first generation, two groups were divided into two groups, which respectively established the Yongmu Hall and Youxu Hall. Later, the Yongmu Hall group declined and the ancestral hall declined; the second generation constructed the public space of ancestral temples with the title of "benevolence, righteousness, propriety, wisdom and faith" based on Confucian core concepts, Among them, Chongxin Hall and Chongli Hall have declined; therefore, the third generation was divided into Yuqing Hall, Xuanqing Hall, Youyi Hall and Jiqing Hall by Chongyi Hall, and Rongshou Hall, Yongxi Hall and Chunxin Hall by Chongzhi Hall, and Shiliu Hall by Chongren Hall. In the fourth generation, there were many declining branches, among which the branch of Chongshou Hall multiplied Qiyou Hall and the branch of Shiliu Hall multiplied Changzhu Hall, Ruizhi Hall and Youzhu Hall; In the fifth generation, Qiyou Hall declined, and Youzhu Hall differentiated into Shizi Hall and Zhenmei Hall. To sum up, the village changes because of natural and human-made competition, group multiplication, differentiation and competition. With the prosperity and decline of populations, "ancestral temple group" between the defensive and the "competition" life and death, some of the "public space" in ancestral halls in the "competition" have either collapsed or expanded: we can see clearly from Figure 7 village public space "ancestral temple group" of the development and evolution of trajectory, namely in the village "ancestral hall" along with the development history of vertical direction, and the corresponding reality still saves on the lateral public space, we can also find Chongren Hall branch off until now.

(2) "Competition" of Cultural Life

Public space and public life have formed a mutually interdependent relationship. A specific public life requires a specific public space structure. Public space is a common and intersecting space with cultural and life characteristics [38]. Christian Norberg-Schulz [37] wrote: "Clusters mostly imply a rule, which may be a geometric, two-dimensional or three-dimensional spatial organization. Chinese "families" have a set of organizational rules and spatial order. Ancestral halls in the public space are divided due to the contradiction between the expansion of ethnic groups and the limited resources. People have developed the introverted character of advocating Confucianism in ideology, which does not emphasize individual emotions and thoughts, but takes ethnic groups as the center. Human beings have a passion for attachment and protection to a particular place, and define their boundaries by occupying space and creating a safe living space. Therefore, territorial nature is a spatial category and a social phenomenon. Territorial nature includes two important factors: boundary and core area. Occupying core territory is the most important way to construct traditional family. The spatial organization of family territory is generated by the power competition of life, and defending territory has become human nature [24].

With the growth of Xinye Village, clan differentiation has emerged since the Ming dynasty. Residents have built living space around each branch temple and formed "cluster" characteristics. The construction of ancestral halls has planning significance for the layout of a cultural landscape [11]. In Xinye Village, unstable public space "ancestral temple groups" play in a competition with each other, just like in a chess competition (Figure 8). White symbolizes the declining or extinct ancestral temple space, black is the existing ancestral temple space, dotted circle is the living space constructed around "ancestral temple groups" in order to shape the spirit of their own ethnic groups. Home, playing chess with each other, is like playing Go to compete for the space of life and culture by means of land and enclosure. The "ancestral halls" of declining ethnic groups are gradually used less frequently, and spiritual emptiness is gradually declining. They are often occupied by powerful ethnic groups, and they are declining or dying out.

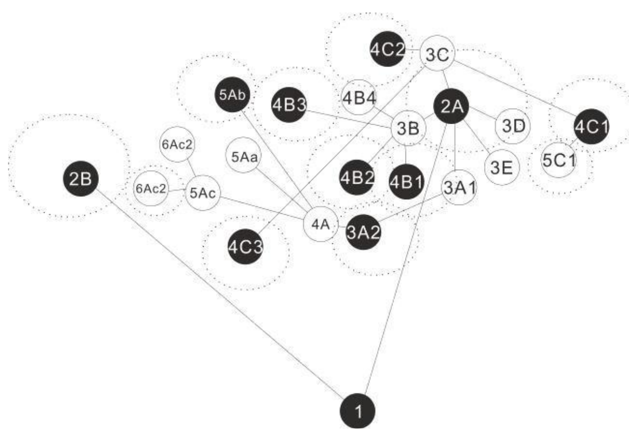

Figure 8. The layout of human living space around the ancestral temple group in public space is presented as a "cluster". Notes: 1. Xishan Temple, 2A. Youxu Hall, 2B. Yongmu Hall, 3A1. Old Site of Chongren Hall, 3A2. Present Site of Chongren Hall, 3B. Chongyi Hall, 3C. Chongzhi Hall, 3D. Chongde Hall, 4A. Shiliu Hall, 4B1. Xuanqing Hall, 4B2. Youyi Hall, 4B3. Jiqing Hall, 4B4.Yu Qing Hall, 4C1. Rongshou Hall, 4C2. Yongxi Hall, 4C3. Cunxin Hall, 5C1. Qiyou Hall, 5Aa. Ruizhi Hall, 5Ab. Changzhu Hall, 5Ac. Youzhu Hall, 6Aca. Shizi Hall, 6Acb. Zhenmei Hall.

(3) "Competition" of Place Spirit

Public space is always perceived and interpreted through the filtering and screening of "cultural value" and "personal belief". Public space is also viewed as a whole. When its structure is decomposed into independent parts and components, the spirit of the public space will be lost [22]. Having a reassuring public space is the basic condition for human survival. People can not only know the world, but also clearly position themselves in all things. That is to say, human beings can produce the dual dependence of spirit and psychology through public space [39]. The ancestral temple, the "public space" carrying traditional Chinese culture, has been gradually abandoned by the current society, but it embodies the "public consciousness", contains the spirit of ethnic groups, and constructs the experience of a lasting "public space". Ancestral temples have also established public and private links, bringing the "distance" between the public and the public closer in human relations. The "ancestral hall group" of Xinye Village carries the culture of the village, educates the residents, standardizes the public behavior and customs of the residents, worshipping ancestors, hosting weddings and funerals, cultural entertainment, maintaining Fengshui and public health, etc., and becomes a public space for public activities such as sacrifice, festivals, entertainment and gatherings, so as to gather the spirit of the ethnic group.

5.2.2. Public Behavior Reinforces Public Landscape Sequence

As Confucianism became the mainstream ideology in ancient China, its classics developed into impregnable and irreplaceable "principles", rendering all etiquettes and regulations reaching further to all walks of life and requiring the architecture closely connected with people's behavior to directly support the positioning and direction of public behavior [12]. There are traditional festivals in Xinye Village to worship ancestors, pray for good weather and enable talents to flourish. As Zhuangzi put it: "Know the nature's order before adjusting regulations; Know the social order before exercising etiquettes" [34].

On the third day of March in Chinese Lunar Calendar, villagers in Xinye Village will hold a parade ceremony. People worship ancestors, along with the Heaven, Earth, Immortal and Buddha. And the procession is decorated with the "Five Colors (green, red, white, yellow and black)" corresponding to "Five Elements (wood, fire, metal, earth and water)". The procession route is designed in line with the "Five Directions (East stands for wood, South for fire, West for metal, and North for water and Center for earth)" of the "Five Elements." The procession is closely related to the public landscape sequence: when the clock strikes 7:30, a god-worshipping procession of over 300 Ye family members starts from halls, walking around the main public landscape and moving on to Yuquan Temple. After the ceremony of heaven-worshipping, earth-worshipping and ancestors-worshipping, the procession will welcome the Immortals worshipped in Yuquan Temple back to the hall of the settlement, and via public worship, express gratitude for heaven and earth and the prosperity of all creatures, as well as reverence for the ancestors' efforts to sustain the family. The resonance among the route, the procession and the public landscape throughout the whole worshipping ceremony not only purifies the settlement space but also enhances the public landscape sequence.

5.2.3. Rebuild the Public Landscape Order in "Competition"

Through case observation, analysis, discussion and research, we can conclude the following order characteristics in the "competition" of public space, including the crisis, stability and sustainability of public space, and make further analysis:

(1) Crisis of Public Space

Since the birth of public space, there has always existed a crisis. Through this study, we found that the connotation and frequency of the construction of public space will directly lead to the "crisis" of public space, which reflects the public nature and vitality. The stronger the public nature of space, the stronger the vitality, the smaller the crisis; the weaker the public nature of space, the shorter the vitality, and the stronger the public nature of space, the greater the crisis. For Xinye Village, the public space based on religious beliefs, cultural beliefs and ancestral beliefs has strong vitality, thus witnessing a smaller crisis. However, the ancestral halls derived from the development process are characterized by the growth of ethnic groups, the lack of resources, and the polarization of clan public space, the fierce "competition" between each other will directly lead to crisis. As a result, the order of the public space landscape has changed.

(2) Stability of Public Space

In the process of public space change, there are stable factors and unstable factors. If a stable public space model is found, it is necessary to distinguish the stability in the public space: The stability factor can measure the self-transparency and sustainability of public space, and the instability factor can reflect the "competition" between public spaces [39]. Religious beliefs, cultural belief and ancestor faith are the factors that stabilized order in Xinye Village, while population growth has generated contradictions and created competition in the public space. The accumulating instability has changed and even reversed the order of the public space.

(3) Sustainability of Public Space

Public space emphasizes that public organizations need to be based on the value of sustainable survival. In the process of cooperation among public groups, they coordinate individual's mind according to common values and concepts, induce the life and ability hidden in the public, and awaken the essence and significance of public awareness. The foundation of sustainability will determine the continuation of focusing on "public interest". The "sustainability" of public space in Xinye Villages mainly manifested in the common consciousness and belief of the village, which maintains the main body and stable public space landscape order.

In short, the frequency of use of "public space" can also directly reflect its stability, sustainability and mutual competition. The traditional "public space" was initially dominated by functions such as gathering, festival and entertainment, but now it has developed into the pursuit of social and leisure and other diverse uses. When the basic units of space are organized together, there will be more abundant orientations than a single part. They can also shape the relationship between internal space and external public space [5]. In Xinye Village, the mass space of human settlement centered on the public space "ancestral temple group" gathers together to form a more complex, meaningful and overall spatial order. This complete organizational law is just like the "proven perceptual organization law" proposed by the Gestalt school: the village as a whole is not a simple sum or addition of ancestral temples, but forms a public space structure and nature that strengthens the whole. Constructing the "new" public space in the competition is not only in the past, but more importantly; it supports the new public life mode by creating public space order. It also contains new relationships between people and people, between people and land, and even between people and society. If these relationships are used for reference by the new urban public space, it not only helps to enhance public recognition, but also promotes the quality of life in public society.

6. Conclusions

As Chinese residential settlement is closely related to such factors as ecological considerations, ideological concepts, public behavior, social organization, economy, production, experience and technology, a settlement takes many factors into consideration when building its public landscape sequence. The public landscape sequence of Xinye Village not only meets material needs, but also merges such factors as history, society, culture and psychology and ideology to console the minds of the settlement residents.

With a complicated spatial structure and connotation, the ancestors of Xinye Village adopted "Five Elements and Nine Divisions" of the traditional Chinese cosmic model to organize the public landscape sequence of the settlement space and adjust the possible relations between all sorts of shapes of public landscape, making each factor coexist in harmony with each other in the space in order to maintain the residential environment of settlement villagers. Such a traditional public landscape sequence showcases the spatial wisdom of traditional ancient Chinese culture system based on public spatial landscape and public behavior mode of the specific universal outlook of the Chinese.

When public space is affected by economy, power and culture, it will produce "competition", which will lead to a change of public landscape. In order to maintain the continuity of public space, it is more important to understand the nature and characteristics of "competition" in "public space" through the use of physiological, psychological and spiritual functions. Then, we can anticipate the planning or creation of public space landscape in the future. It is suggested that public culture and public life can be integrated into the landscape planning and design of the future public space. Through the evaluation of public space competition and our life experiences, we can understand the value of the public space landscape. Public space planning and design can be used to avoid the lack of a sense of locality and disruption of local culture. The study attempts to provide clear evidence for future urban and rural public space planning and design practice to provide a cultural schema reference through which it is possible to create an organic and systematic public space.

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Article

Spatio-Temporal Changes and Dependencies of Land Prices: A Case Study of the City of Olomouc

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Abstract: Land price sustainability issues have been addressed by many authors in the past. Most of these researchers used land prices (from land price maps) as the primary data source in their studies. Only a few papers analysed official land price maps, which are available very rarely. For this reason, we studied the spatial and temporal changes of land prices in the city of Olomouc based in an analysis of official land price maps from 1993 to 2017. We proposed several research hypotheses to confirm some general statements about land price changes. We concluded that some economic indicators had a significant impact on changes in land prices. In the residential and commercial areas and historical centre, land prices are significantly higher than in other monitored aspects (land-use types). We also concluded that no link existed between land-use stability and land price stability. Surprisingly, no long-term stable areas were found in the area of interest. The analysis also confirmed that land price and its change over time varied in different spatial aspects. Unexpectedly, the smallest influence was reflected in the economic aspect. Regarding natural events in recent decades, we observed a significant drop in land prices in the vicinity of watercourses threatened by flooding. These findings can assist in better understanding local development and changes in land price. The results of this study can help in gaining better understanding of economic, social, and environmental aspects of sustainability of land price changes.

Keywords: land price map; land-use development; geographic information system; spatio-temporal changes; sustainability; Olomouc

1. Introduction

1.1. Land Price Sustainability

Land price plays an important role in guiding land resource allocation for urban planning and development, particularly in big cities of fast developing countries where infrastructures and populations change frequently [1]. This is one of the main reasons why land price sustainability issues have been previously addressed by other authors (e.g., [2,3]). The research centres on issues linked to land price volatility [4,5], inflation [3], structure [6], changes [7–9], and factors influencing land price [1,10–12]. An estimation of the effect of environmental factors on the real estate prices caused by environmental change has been analysed in the research of Del Giudice and Massimo [13,14]. Their case study deals with noise pollution influence on residential units. The result of econometric analysis proves that real estate price is reduced by the negative quality of living, here represented by noise pollution. The specific research field deals with predictive models [15], implementation of GIS (Geographic Information System) software [16], and many others [17].

Regarding the city sustainability, price map plays an undeniable role, when information about real estate and its price is essential for fast decision-making. For that reason, price information can be used not only for private purposes but also at a level of policy-making potential. Integration with the concept of smart cities should be considered—sophisticated ICT technologies, which enables communication between the important authorities, are a crucial basis of smart cities. Relevant questions dealing with the smart-cities concept in conjunction with sustainability and planning are discussed by Lytras and Visvizi [18,19].

Researchers in the Czech Republic studied land prices after the Velvet Revolution in 1989. After 40 years of communism, ownership of land was returned in restitution processes to the original owners (or their descendants), and prices started to grow rapidly. Almost all Czech studies have looked at general housing prices issues or land price analysis at the regional or state level (e.g., [20]). Lux and Musil [21–23] studied the housing system and its development during the transition period. Sklenička et al. [24] focused their research on farmland prices; Temelová et al. [25] elaborated on housing estate issues that are associated with segregation. Other researchers examined price bubbles and their determinants in the Czech Republic [26] and compared the housing system to those in other countries [20].

Another area of research investigated land price maps of building parcels. Official land price maps are essential documents that influence and control the real estate market in the big cities of the Czech Republic. They are one of the most critical aspects of a city's economy for entrepreneurs and citizens. Land price map analysis in the Czech Republic has been pursued by only a few authors [27–33]. Dobiášová [27] compared the price maps of selected European Union (EU) countries, Chrudimská [28] and Pászto et al. [32] proposed a new procedure for updating the land price map of Olomouc in the ArcGIS for Desktop software. Emphasis was placed on the technological process, which would automate and improve the efficiency of processing land price maps. Šindelářová [33] and Kovaříková [30] also analysed price maps, describing the changes and practical use of price maps in the Czech Republic while using the price maps of Brno and Olomouc. The land price map in relation to rent was discussed in a PhD thesis [31]. The author investigated the relationship between land rent and price in price maps of the Czech Republic. The author questioned whether it was possible to use this to determine the rental price of similar plots in the same way as with price maps. According to Kubíček [31], with a sufficient amount of quality data it would be possible to set a coefficient for price conversion in the price map to the rental price of the land.

Only a few authors performed a detailed analysis of land price at a local level (municipality) [29,33]. This is surprising, because local studies can explain many connections, relationships, and dependencies that are not visible at a national level. This is due to the fact that only a few cities in the Czech Republic produce land price maps as the primary land price data source. For this reason, we decided to perform an in-depth analysis of land prices in the city of Olomouc, which has produced land price maps since 1993. This issue has not been previously studied and it is currently highly relevant because land prices in Olomouc (100,494 population in 2018) are the third highest in the Czech Republic after Brno (379,527 population in 2018) and Prague (1,294,513 population in 2018) [34,35]. This is mainly explained by the high attractiveness of Olomouc (UNESCO heritage, quiet city, high standard of living), which is, however, in contrast to average regional salaries (third lowest in the Czech Republic) [2].

Based on these findings, our study examined the spatial and temporal changes of land prices in Olomouc by analysing the official land price maps from 1993 to 2017. For this purpose, the following research hypotheses were proposed: (1) Changes of land prices are dependent on macro-economic indicators; (2) The highest increase in land prices can be observed in residential and commercial areas and the historical city centre; (3) Stable areas exist (comparable to stabilized land-use) where land prices do not change over time; and, (4) Land price sustainability is influenced by spatial factors (environmental, economic, and social). To test these hypotheses, we performed spatial (overlay) and regression analysis. To analyse the possible dependencies between economic, social, and demographic indicators, methods of correlation, and regression analysis were used. This approach could help for better understanding of economic, social, and environmental aspects of sustainability of land price changes.

1.2. Land Price Maps in the Czech Republic

Two land price sources can be found in the Czech Republic in the form of official or unofficial land price maps. The official land price map (land price map of building plots) is defined by the relevant legislation ([36,37]) and its acquisition and updating is maintained by the respective municipality. This type of map displays the prices of building plots and it is created according to prices in purchase contracts (managed by the regional cadastral offices) and is modified according to the type of land and its other characteristics.

According to Act No. 151/1997 Coll. [36], the land price map is defined as a graphical representation of land price and building plots in the territory of a municipality with a scale of 1: 5000 or more detailed level. Building parcels on the price map are valued by the actually negotiated prices contained in the purchase contracts (base price), although it is not always possible to value all parcels. In some cases, it is not possible to determine an actual price or the price data is out of date or not comparable to the prices of similar parcels (too high or too low price). Very heterogeneous prices on adjacent parcels may also cause problems. In this case, prices are determined by the prices of comparable parcels in the municipality or a similar municipality (according to the legislation, [37]). A comparable parcel means land that is intended for the same use and is located in a similar location as the parcel being valued. The final price of a building parcel is calculated as a multiple of the base price of the group of land to which it belongs and its total area in square metres. The price of the parcel is then increased by the price of the building(s) standing on the parcel and by the price of green areas. The price map does not include prices of agricultural or forested land or water areas. Information about the parcel is taken from the Land Register of the Czech Republic.

The land price map is updated at the end of each year by adding new prices of land parcels. After the price map is processed, the municipality is obliged to submit a proposal to the Ministry of Finance of the Czech Republic, which subsequently publishes it in the Price Bulletin. Any citizen can see the content of the price map of a given municipality free of charge. The land price map serves as a basis for evaluating issues that are addressed by court experts, banks, or government officials.

Land price maps have been created in the Czech Republic since 1991 for 54 municipalities, but many municipalities have ceased this activity due to fluctuating prices and the need for regular updates. Eight municipalities in the Czech Republic have created more than ten price maps. Most of these were published in Ostrava (18), Prague (21), and Olomouc (21). Currently (3 October 2018), price maps are valid only in seven municipalities in the Czech Republic.

Besides the price maps governed by law, several unofficial price maps (e.g., [38]) are also available and are usually created by real estate agencies who process them very individually. These maps, however, do not show land prices but rather the average prices of apartments and houses or rents. Data sources are most often recorded by real estate agencies from achieved sales or rentals. The validity of these maps is not guaranteed by law and depends only on the quality of processing [33]. Access to these maps often requires payment.

1.3. Land Price Map of the City of Olomouc

The first land price map of Olomouc was created in 1939 because people had foreknowledge of the Second World War. During the 1930s, many Czech people invested their money primarily in real estate, which caused a disproportionate increase in land prices. The government was therefore forced to fix prices at the level current at the time, which was subsequently taken into account in a price map to prevent further price increases. After the Second World War, land price maps were not used, and city development was mainly based on master plans [39,40]. The first modern land price map of Olomouc was created in 1993. The city was divided into zones according to the character and function of individual areas. For these zones, the average purchase price (base price) was used to calculate the actual price of a parcel. For each zone type, the coefficients were defined to multiply the base price. This procedure was based on the relevant legislation and has been preserved to this day, except for 1993, 1995, 1996, 2000, and 2002, when the price map was not updated because of minimal changes. The only significant difference in the pricing methodology was in connection with parcels that had not been valued. These are predominantly areas used for public administration, education, culture, health, security, defence, communications, and other technical equipment that practically do not change ownership and their price cannot be determined regularly.

In total, 21 price maps were created in Olomouc between 1993 and 2017. Since 2006, they have been created digitally (CAD and GIS) and are also published via the web map application that is available at http://apps.hfbiz.cz/apps/olomouc/cm/.

2. Data and Methods

2.1. Used Datasets

As our primary data source, official land price maps of the city of Olomouc in a scale of 1:5000 were used. The maps cover the whole Olomouc area (100,494 population; 103.4 km^2). The city is the regional capital of the Olomouc Region. Land price maps from the period 1993–2005 are available only in analogue format (each map comprises 36–39 map sheets), and it was necessary to digitize them. Because digitization is extremely time-consuming, two representative time periods were selected (1993 and 1999). Data from 1993 represents the first available analogue data set, the year 1999 was selected in the middle of the period between 1993–2006. Land price maps from the period 2006–2017 are available in vector format (dgn), and all of them were used for the analysis.

In order to digitize and georeference analogue land price maps, cadastral maps from the comparable period were used. In order to analyze different land-use types, the master plans of the city of Olomouc from 1999 and 2016 were used. Master plans (land-use types, flood areas, evaluated soil ecological units, urban conservation areas, urban conservation zones), cadastral maps, and land price maps were obtained from the Magistrate of the City of Olomouc (Department of Research and Development).

For the statistical analysis, the following data sources were used: Czech Statistical Office—Statistical Yearbook of the Olomoucký Region [41], Statistics on Income and Living Conditions [42]; Czech National Bank—CNB official discount rates [43].

Details of the variables presented in the Table 1 are as follows: "Land price"—in Olomouc in CZK per square metre, calculated as a median of all prices of all land in Olomouc in certain years in the period 2006–2016; "GDP"—per capita in CZK per year, Olomouc Region [41]; "Income"—total net income per capita in CZK per year in municipalities with a population of 100,000+ [42]; "Unemployment"—number of unemployed people in thousands, Olomouc Region [41]; "Discount"—average discount rate per year, Czech Republic [43]; "Population"—number of inhabitants, district of Olomouc [41]; "Started flats"—number of started flats, district of Olomouc [41]; "Finished flats—number of finished flats, district of Olomouc [41]; "Econ. subjects"—registered economic entities (31 December), district of Olomouc [41]; "Year"—the period 2006–2016.

Table 1. Descriptive Statistics—Correlation and Regression Analyses.

Variables	Max	Min	Average	Median
Land price	1500	600	1121.8	1170
GDP	346,788.5	232,639.2	291,319.2	296,889.1
Income	219,580.6	161,811.629	195,917.1	196,452.4
Unemployment	28.2	11.5	22.3	23.5
Discount	2.39	0.05	0.64	0.25
Inhabitants	233,992	228,956	232,062.1	232,226
Started flats	1209	379	700	663
Finished flats	1156	534	783	733
Econ. subjects	140,735	130,427	136,051	136,229
Time	2016	2006	2011	2011

2.2. Data Processing

As mentioned above, land price maps were available in vector and analogue (printed) format. Data in digital format (dgn files) from 2006–2016 (11 layers) were imported into the spatial geodatabase in GIS. Analogue land price maps (maps from 1993 and 1999) were georeferenced (each map comprised 36–39 map sheets) and digitized. Historical cadastral maps from suitable years were used for georeferencing. The output polygons of land price maps were checked and repaired by using topology rules in ArcGIS for Desktop, and the final layers were imported into the spatial geodatabase of all land price maps.

Comparing the absolute values of land prices over the 15-year period was not appropriate. In such a timeframe, the impact of inflation must also be taken into account to make the prices between the years comparable. Inflation is a general rise in the price level in the economy—the value of the same amount of goods in the time interval changes, mostly upwards. This change in price level needs to be included in any analysis and the original absolute value of land prices over the reference period must be adjusted [44]. Inflation is monitored through several indexes, such as the consumer price index or the product price index. The CZSO monitors these in the Czech Republic. The calculated values of the average annual index were used to adjust land prices to a comparable level. The year 2016 was chosen as the reference year, and all other years across all dates were recalculated to produce a time series of comparable values.

2.3. Data Analysis

2.3.1. Spatial Analysis

Several basic statistical characteristics were calculated from the available data: mean, median, and mode. For the reasons given above, the same quantity of priced parcels was not available for each time interval. The number of valued parcels in the years had decreased from 44% to 28%. Medium-value indicators have served as a general tool for assessing land price changes over the past 15 years.

For spatial analysis of the changes of the land price map in Olomouc, the data were modified with overlay operations to be able to monitor the changes of land price at each location. Only three years were selected for spatial analyses: 1993, 2006, and 2016. These years have approximately the same time interval. Adding additional years would increase the number of unvalued parcels obtained by overlay operations. Using a GIS tool, a new layer was created to aggregate changes in the periods 1993–2006 and 2006–2016. This processing tool performs the geometric union of all input layers. The result contains information from all inputs, which allowsfor the changes in every part of the original area of interest to be analysed. Since not all parcels in the input data were valued, it was necessary to remove those areas where price for one of the years was absent. A total of 5020 new areas with an area of 4109 ha were created, of which 1999 ha (48.7%) were valued in all three years. In these areas, land prices were analysed to identify stable/changing sites. These were subsequently classified into synthetic classes describing the changes of land prices in years.

2.3.2. Regression Analysis

For the purposes of analysing possible dependencies between economic, social, and demographic indicators, methods of correlation and regression analysis were used. Since suitable data are not available for all years in the period 1993–2016 and both statistical methods are based on a regular time period, we used the data for the period 2006–2016.

Correlation analysis serves as a means for observing possible relationships between certain variables, mainly if a statistically significant positive or negative relationship exists. A Pearson correlation coefficient was therefore used.

The second step required a more complex model to be created in order to include all possible variables at once and to detect any variable(s) within the model, which could be important in increasing the land price in the selected region. Based on this key idea and the results that were obtained from the correlation analysis, different regression models were tested. For the purposes of our analysis, three regression models MOD1, MOD2, and MOD3 are presented. Certain models differ in parts of independent variables, while the dependent variable is the same in all tested models. MOD3 represents the most suitable model, MOD1 and MOD2 represent other selected models for the purposes of comparing and evaluating certain possibilities that include possible independent variables. MOD1 is based on indicators connected mainly with households and their behaviour, MOD2 represents the shorter version of MOD1, based on only statistically significant variables and MOD3 represents the model with no multicollinearity problems, no autocorrelation, and high statistical significance of selected variables. Detailed characteristics of regression models are as follows.

MOD1

$$Y = \beta0 + \beta1X1 + \beta2X2 + \beta3X3 + \beta4X4 + \beta5X5 + \beta6X6 + \beta7X7 + \beta8X8 + u \tag{1}$$

where $\beta0 \ldots \beta8$ represent regression coefficients that can show the influence of independent variables on a dependent variable. Dependent variable Y is represented by land price in Olomouc in CZK per square metre, calculated as a median of all prices of all land in Olomouc in certain years of the period 2006–2016. Variable u represents a dummy variable. MOD1 is based on the following independent variables:

- $X1$—GDP per capita per year, Olomouc Region (GDP);
- $X2$—total net income per capita in CZK per year, municipalities with a population of 100,000+ (Inc);
- $X3$—number of unemployed people in thousands, Olomouc Region (Unem);
- $X4$—average discount rate per year, Czech Republic (Disc);
- $X5$—population/number of inhabitants, district of Olomouc (Inhab);
- $X6$—number of started flats, district of Olomouc (Flatst);
- $X7$—number of finished flats, district of Olomouc (Flatfi); and,
- $X8$—time/years 2006–2016 (Time).

MOD2

$$Y = \beta0 + \beta1X1 + \beta2X2 + \beta3X3 + \beta4X4 + \beta5X5 + u \tag{2}$$

where $\beta0 \ldots \beta5$ represent regression coefficients that can show the influence of independent variables on a dependent variable. Dependent variable Y is represented by land price in Olomouc in CZK per square metre, calculated as a median of all prices of all land in Olomouc in certain years of the period 2006–2016. Variable u represents a dummy variable. MOD2 is based on the following independent variables:

- $X1$—GDP per capita per year, Olomouc Region (GDP);
- $X2$—number of unemployed people in thousands, Olomouc Region (Unem);
- $X3$—population/number of inhabitants, district of Olomouc (Inhab);
- $X4$—number of started flats, district of Olomouc (Flatst); and,
- $X5$—number of finished flats, district of Olomouc (Flatfi).

MOD3

$$Y = \beta0 + \beta1X1 + \beta2X2 + u \tag{3}$$

where $\beta0. \ldots \beta2$ represent regression coefficients that can show the influence of independent variables on a dependent variable. Dependent variable Y is represented by land price in Olomouc in CZK per square metre, calculated as a median of all prices of all land in Olomouc in certain years of the period 2006–2016. Variable u represents a dummy variable. MOD3 is based on the following independent variables:

- *X*1—population/number of inhabitants, district of Olomouc (Inhab); and,
- *X*2—number of finished flats, district of Olomouc (Flatfi).

3. Temporal Dependencies and Changes in Land Prices

3.1. Temporal Changes

The first analytical step was evaluating the temporal changes of the price map in Olomouc. Several basic statistical characteristics were calculated: the arithmetic mean, median, and mode. For the reasons given in the chapter on data, the same quantity of priced parcels was unfortunately not available for each time interval. The number of parcels had decreased over the monitored period from 44 to 28%. These indicators of central tendency have served as a general tool for assessing price changes over the past 15 years. The median was used as the main measurement of changes, which is not, as opposed to the mean, so affected by extreme values.

Two significant periods can be observed in the changes of prices. The first is in the period 1993–2006, when land prices fell slightly. In this post-revolutionary period, economic growth was not yet strong and people were not affluent, and there was therefore no leading demand for land. This claim is based only on three values, but the tendency is evident. The effect of adjusting price for inflation is significant: excluding inflation, prices are shown as slightly higher, whereas according to price levels from today's point of view (2016), we see a slight decline. For comparison, see Figure 1. The most expensive land in the city centre was around CZK 9000 (1993), and in the following years, it dropped significantly (CZK 4600 in 1996). Until 2006, the median price was almost unchanged (around CZK 600), mainly because of the overall saturation of the real estate market that was caused by extensive construction of apartment buildings in the 1990s. Another event that affected land prices was the flood of 1997. This revealed the propensity of some urban areas to flooding, which may have contributed to price stability/decline.

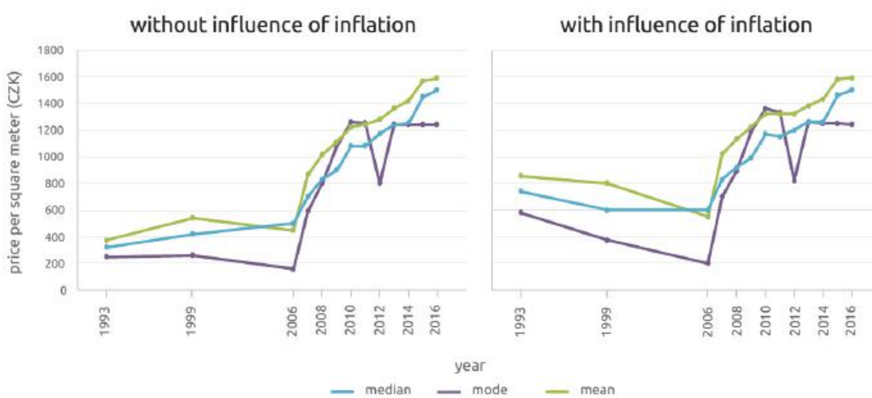

Figure 1. Land price changes in Olomouc. The differences between the original and recalculated values (mean, median and mode) can be observed. The most significant differences are evident in the oldest records (1993 and 1999), where inflation was the most influential.

The year 2006 was a breakthrough in the second phase, in which a much more dynamic change of prices is observed, especially growth. Except for the period 2010–2011, when the median price dropped slightly, the value of land has increased since 2006. The reason is the re-awakening of demand for housing in the form of both dwellings and family houses. The most significant leap in the maximum price of land was in 2007, when the highest price increased from CZK 5900 to CZK 10,850. Stagnating prices in the period 2010–2011 can be attributed to the impact of the 2008 global financial crisis (visible in the Czech Republic after a two year delay).

3.2. Temporal Dependencies

Regarding the evaluation of temporal dependencies between economic, social, and demographic indicators, it is worth starting with a correlation analysis (Table 2). The results of the correlation analysis show possible relationships between certain variables, in our case, between "Land price", "GDP", "Income of households", "Unemployment rate", "Discount rate", "Inhabitants", "Started flats", "Finished flats", "Registered Economic Subjects", and "Time".

Table 2. Correlation Analysis.

	Price	GDP	Inc	Unem	Disc	Inhab	Flatst	Flatfi	EconS	Time
Price	1									
GDP	0.9601	1								
Inc	0.975	0.958	1							
Unem	−0.366	−0.519	−0.353	1						
Disc	−0.763	−0.671	−0.744	−0.141	1					
Inhab	0.979	0.954	0.981	−0.408	−0.702	1				
Flatst	−0.434	−0.325	−0.407	−0.470	0.831	−0.346	1			
Flatfi	−0.261	−0.286	−0.169	−0.004	0.343	−0.084	0.308	1		
Econs	0.923	0.9321	0.932	−0.417	−0.659	0.906	−0.394	−0.291	1	
Time	0.967	0.9776	0.955	−0.371	−0.785	0.941	−0.462	−0.350	0.903	1

In the key variable "Land price", we observe a statistically significant positive correlation between Price and GDP, Income, Inhabitants, and Time. By contrast, a statistically significant negative correlation can be seen between Price and Discount rate. The possible relationship between Price and Unemployment rate, Flats started and Flats finished is rather negative, but not statistically significant.

In the second step, we created and tested more complex regression models, working with all of the variables used in the correlation analysis. Based on the results of the correlation analysis, three regression models MOD1, MOD2, and MOD3, were created. Detailed characteristics of these regression models are described in Chapter 2. The Durbin-Watson test was used for the purposes of eliminating autocorrelation. The variance inflation factor (VIF) was used for detecting possible multicollinearity within the models.

All of the models work with the same dependent variable Y, which is represented by land price in Olomouc in CZK per square meter, calculated as a median of all prices of all land in Olomouc in certain years in the period 2006–2016. The key results of all regression models are shown in Table 3.

Table 3. Regression Analysis.

	MOD1		MOD2		MOD3	
	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.
X1—GDP	0.08410	−0.00619	0.01251	−0.00326	x	x
X2—Inc	0.33726	0.00248	x	x	x	x
X3—Unem	0.08191	−9.3093	0.02902	−6.20463	x	x
X4—Disc	0.19618	43.78856	x	x	x	x
X5—Inhab	0.01031	0.241803	0.00000	0.23893	0.00000	0.18100
X6—Flatst	0.06849	−0.17491	0.01204	−0.10439	x	x
X7—Flatfi	0.01634	−0.36197	0.00010	−0.33761	0.00050	−0.25159
X8—Time	0.31664	19.51697	x	x		
Constant	0.08927	−92,337.5	0.00000	−52,896.8	0.00000	-40,684.9
Observ.	11		11		11	
R2	0.99967		0.99885		0.99571	
Signif	0.00261		0.00000		0.00000	
DW	2.33		2.15		1.78	

The key question, also suggested at the beginning of our research as one of the hypotheses in our research, is whether land price is influenced by the changes of macroeconomic indicators. Focusing on regression models MOD1, MOD2, and MOD3, we can see that the answer is neither yes nor no. Generally, some of macroeconomic indicators are statistically significant in the selected models, namely GDP and unemployment. However, other economic indicators such as net income, average discount rate and number of registered economic entities are not statistically significant.

Looking at the models in more detail, MOD1 represents in general a statistically significant model, the Durbin-Watson test simultaneously confirming no autocorrelation. Not all of the included variables are statistically significant, though. Moreover, VIF coefficients are extremely high and show multicollinearity between the variables (Table 4). Therefore, we excluded some of the non-significant variables and created the shorter yet statistically significant model MOD2.

Table 4. Overview of Variance Inflation Factors.

	MOD1	MOD2	MOD3
	VIF	**VIF**	**VIF**
*X*1—GDP	183.30	48.19	x
*X*2—Inc	51.99	x	x
*X*3—Unem	8.19	5.35	x
*X*4—Disc	15.94	x	x
*X*5—Inhab	53.25	33.57	1.00
*X*6—Flatst	7.69	3.21	x
*X*7—Flatfi	3.43	2.89	1.00
*X*8—Time	101.75	x	x

Model MOD2 also contains no autocorrelation. Regarding the significance of certain variables, we can distinguish 0.01 and 0.05 as two levels of significance. Regarding the 0.01 significance level, we can say that the number of inhabitants influences land price in Olomouc rather positively and the number of finished flats rather negatively. Other coefficients represent variables with 0.05 significance level, and their influence within the model is rather negative (GDP, unemployment, number of started flats). Focusing on multicollinearity issues, the VIF coefficients of GDP and the number of inhabitants are high. The multicollinearity problem can occur in connection with the number of observations and number of variables. Therefore, we excluded selected variables and created the shorter, statistically significant, model MOD3.

When compared to MOD1 and MOD2, MOD3 is based on only two independent variables, to diminish multicollinearity problem. MOD3 is statistically significant and the Durbin-Watson test proves no autocorrelation. The selected variables correspond with variables with the 0.01 significance level in MOD2. Similarly, as in MOD2, we can say that the number of inhabitants influences land price in Olomouc rather positively and the number of finished flats slightly negatively.

4. Spatial Relationships and Changes in Land Prices

The first objective was to identify areas where prices did not change significantly over time or where price changes might have been occurring. For this analysis, the data were modified as described in Chapter 2.3. First, the absolute price difference between two years was calculated, which was then converted to a relative value for better mutual comparison. The values were adjusted to logic: 0%—the price did not change; 100%—the price increased by 100%, (i.e., twice the original value), etc. Stable areas were defined as areas where the price changed by a maximum of 5%. Both absolute values and temporal changes were visualized (Figures 2 and 3) and the basic spatial distribution of prices and changes was evaluated.

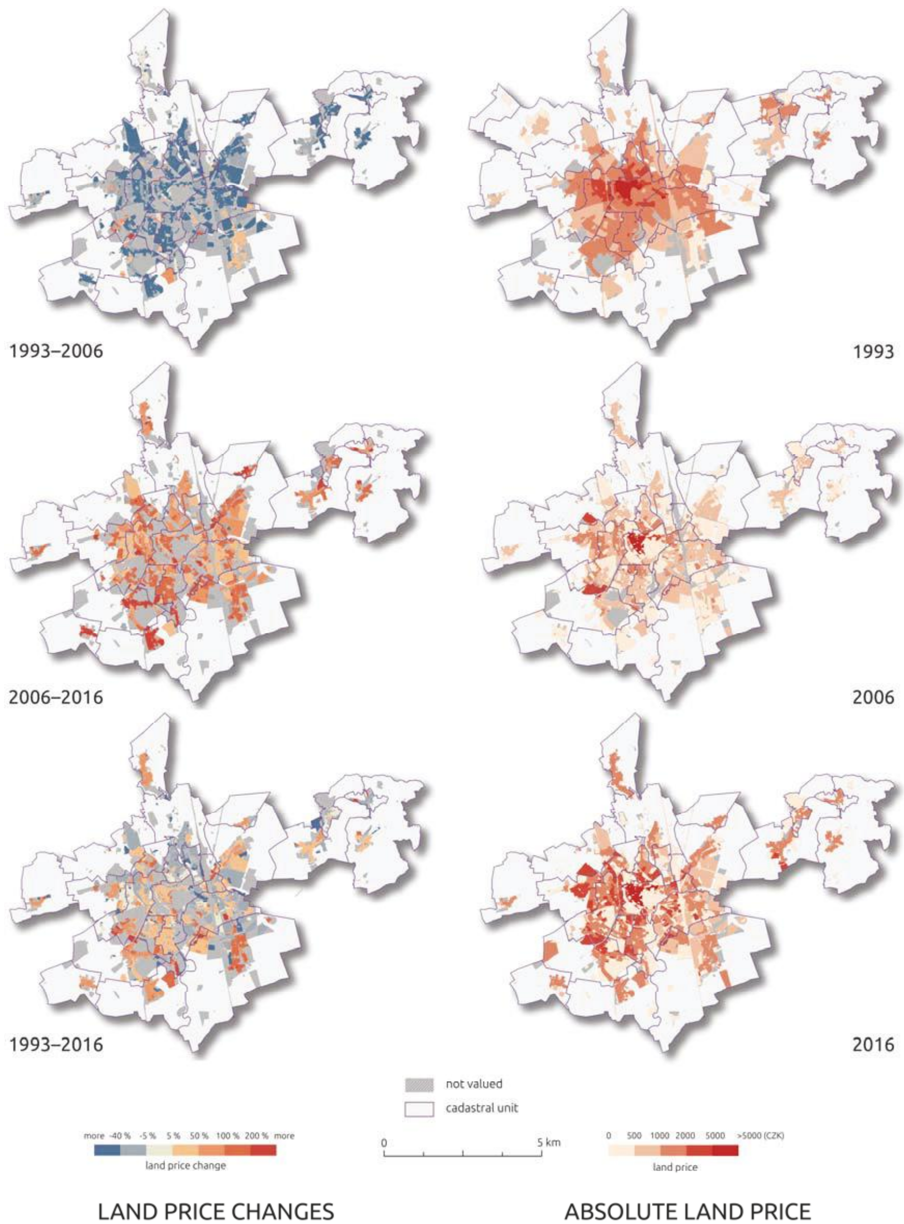

Figure 2. Land price changes in Olomouc.

In the first part of the monitored period (1993–2006), the overall decline in prices in most parts of the city, even in the historical centre, which was the most expensive area (the absolute value of the land is still, however, in the highest category above CZK 5000), was observed. In this period, the value grew only in the south-eastern part Holice, where areas of individual housing dominate. A significant area of long-term growth is also located in the south of Nemilany, where a retail/industrial complex has gradually been established. The highest land prices were in the historical city centre. In the following period (2006–2016), prices increased across the city. Relevant growth was seen in the city districts Slavonín and Řepčín (the southern and north-western parts of the city), which both had new shopping centres that were established in 2002 and 2005. In part of the city centre, prices were strengthened, for example, by the completion of the Šantovka shopping centre, which increased the attractiveness of this locality. Another increase is also found in the Nedvězí and Nemilany cadastres. Here, areas of personal housing dominate, and the rise in prices is related to an overall trend of suburbanization when areas in the suburbs started being attractive for living and several new residential areas of individual housing were created.

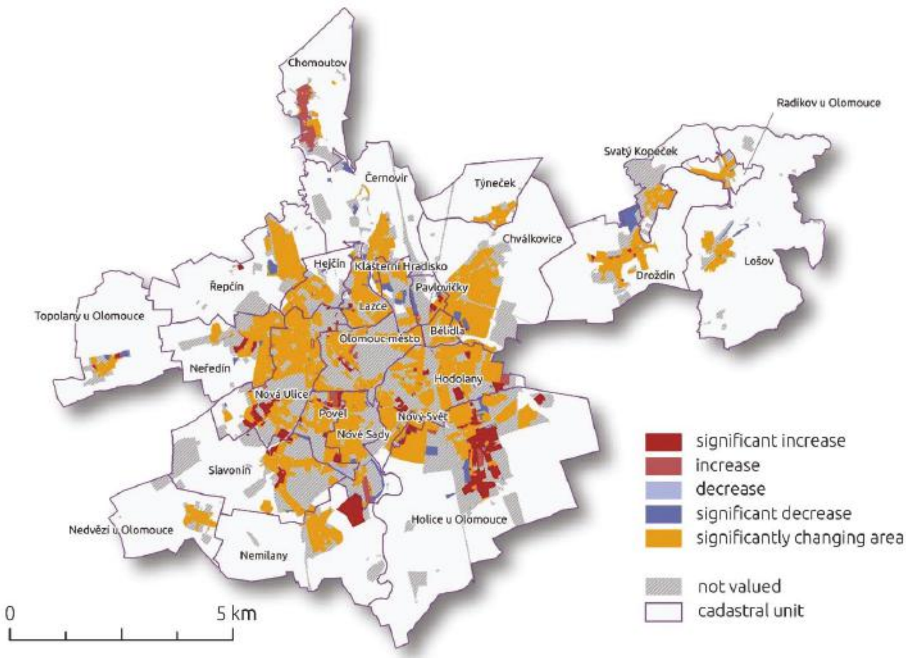

Figure 3. Land price changes in Olomouc.

Regarding the absolute price of parcels, spatial distribution changed over time. In 1993, it was possible to see a pattern of increasing prices towards the centre, the highest prices being in the historical centre of the town. In the peripheral areas, most of the parcels were in the two cheapest price categories, i.e., up to CZK 1000 (except for the eastern parts Svatý Kopeček, Lošov, and Radíkov). In 2006, the price of most parcels fell significantly, while the highest prices were maintained in the historical centre and in two areas on the outskirts—the new shopping centres (Olomouc City in Řepčín and Centrum Haná in Slavonín/Nová Ulice). By 2016, expensive land again remained in the historical centre, but the value of more parcels in the outer parts of the city was also increasing. By contrast, many areas in the inner part of the town had fallen to the lowest price category. From a temporal point of view, the permanent preservation of high prices in the historical centre is seen, other areas have changed over time, and peripheral areas have become more attractive.

However, the overall change in land price does not indicate the dynamics of the changes in the period analysed or the trend of price behaviour. For this reason, a typology of areas was designed concerning price changes. We determined whether a decrease or growth occurred in the time interval and whether this change was above the significance limit (i.e., greater than + 5%). The typology is summarized in Table 5.

Table 5. Typology of Land Price Changes.

1993–2006	2006–2016	Changes Category	Area Ratio
+	+	significant increase	9.2%
/ or +	+ or /	increase	3.7%
/	/	stable area	0%
/ or −	− or /	decrease	0.5%
-	-	significant decrease	5.2%
+ or −	+ or −	significantly changing area	81.4%

where: + means a significant price increase (more than 5%); − means a significant price decrease (more than 5%); / means no significant change (less than 5%).

This analysis shows that the temporal evaluation dominates areas where the price has changed significantly in both directions and no clear trend can be observed. This behaviour follows the overall drop in prices in the initial period and their subsequent growth in the second half of the monitored period, as described in Chapter 3.1. No long-term stable areas were found in the area of interest (Figure 3), with a 5% tolerance of change. Different tolerance limits were tested: with 15% tolerance, only 1.3% is stable; with 20% tolerance, 4.5% is stable; and, with 30% tolerance, 6% is stable. Even with higher tolerances for change, an insignificant number of areas is categorized as stable in terms of price. This is surprising, because several stabilized areas exist, as defined by Burian [40,45], from the master plans of the city of Olomouc. Probably, there is no correlation between stability of land-use and stability of land prices. Long-term rising price parcels are located mainly in the suburbs; their largest representation is in the residential south-eastern part of the city.

Since the changing patterns of parcel price dominate the typology, we concluded that partial temporal changes and trends are not significantly decisive for overall spatial assessment. Therefore, relative price changes in the period 1993–2016 followed by absolute price in 2016 were used to assess overall sustainability in three individual aspects (environmental, social, and economic). These were defined as a key part of evaluating sustainability changes. In each aspect, we identified several topics for assessing price changes in a spatial context. All topics and their values are presented in the Figures 3–5 and subchapters.

Figure 4. Land price changes related to economic, environmental, and social aspects.

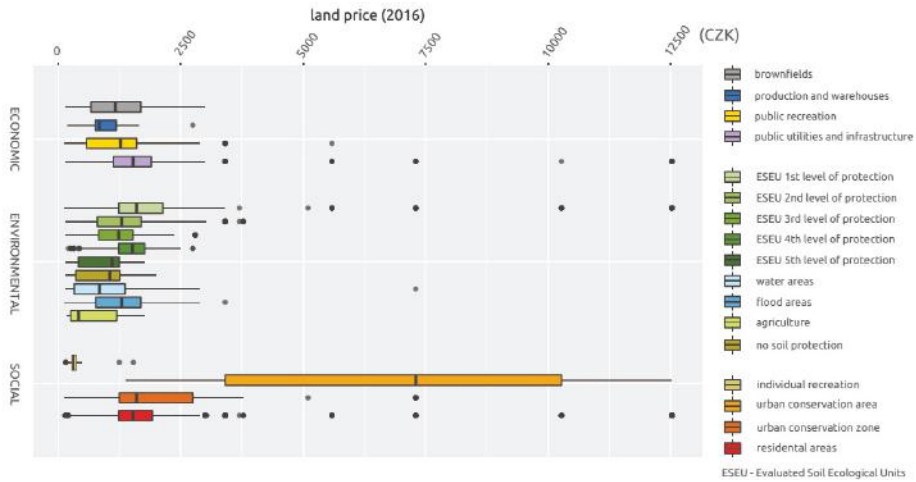

Figure 5. Land prices related to economic, environmental, and social aspects.

4.1. Economic Aspects

From an economic point of view, land prices were analysed in categories defined by the Olomouc master plan as brownfields, production and warehouses, public recreation, and public utilities and infrastructure (Figures 4–6). The aim was to elaborate on the relationships between land-use type and land price and to find out whether any land-use category was more significant for the real estate market than others. Surprisingly, prices did not change as dramatically as in other aspects. For brownfields, we observed even a slight overall decline in prices, as these locations are probably not interesting to investors, perhaps because of the higher costs for reconstruction and the elimination of environmental burdens. From a spatial point of view, these categories do not have any spatial pattern, except for production and warehouses located mainly in the eastern part of the city near rail transport. Generally, it is possible to say that the four selected economic spatial aspects are the most stable in terms of price changes and they did not record any dramatic changes in the monitored period. Also, regarding absolute price (2016), the price of most land in economic land-use categories did not exceed CZK 2500.

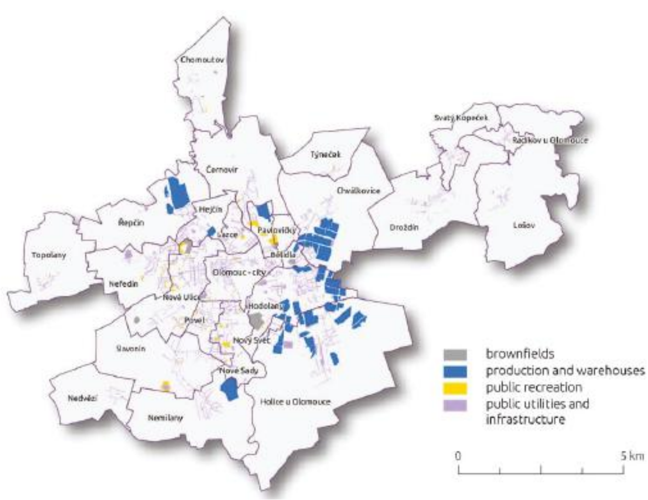

Figure 6. Spatial distribution of economic aspects.

4.2. Environmental Aspects

From an environmental point of view (Figures 4, 5 and 7), the significant impact of soil protection level (ESEU—Evaluated Soil Ecological Unit) on the changes of its price is evident. The highest increase is in the price of land in the first and third protection levels, which covers the majority of the area of priced parcels. The zone of these soils passes through the city from north to south and occupies more than 50% of parcels. However, a noticeable stagnation/decrease can be seen for the fifth level of soil protection and soils without any ecological protection. These areas are in the eastern outskirts of the city (Droždín, Lošov, Svatý Kopeček, and Radíkov). In this part of the city, the slope of the terrain changes significantly and increases the degree of afforestation. Top quality soils (the first four degrees of protection) went up considerably in price over the years. Their absolute price is also higher than for the remaining levels (fifth level and land without protection). An interesting category is land related to watercourses—parcels in the flood zone of 20-year water and areas classified as 'water areas' (which are the closest parcels to watercourses) were selected. These categories (as one of the few) declined in price. This is probably due to the floods in 1997 (100-year floods), which had a significant impact on the city. Disastrous floods affected one-third of the city, 50 people died, and more than 26,000 inhabitants were evacuated from the area [46]. The propensity of these locations to flooding was therefore reflected in the price of land. The most significant decline occurred in the northern part of the city in the Černovír, Klášterní Hradisko, and Lazce cadastral units. The flood area mostly comprises areas of individual housing. Least important for the analysis is the agricultural area category, which covers only a few parcels of the monitored area. Similarly, the water area category includes only a limited number of parcels, but flood areas complement it.

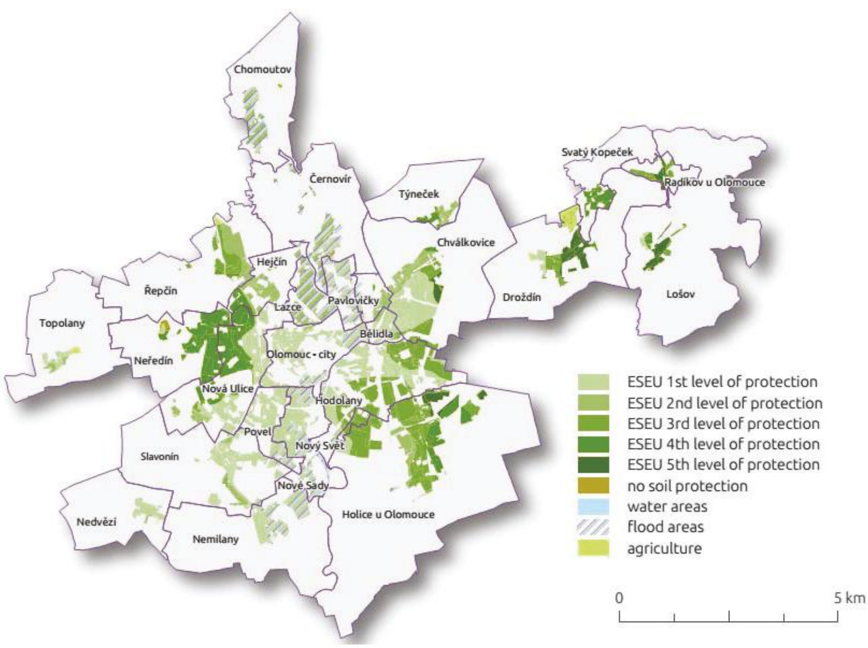

Figure 7. Spatial distribution of environmental aspects.

4.3. Social Aspects

The social aspect (Figures 4, 5 and 8) is the most interesting to analyse regarding land price. The most significant changes and overall price increases were expected in residential areas. For this assessment, residential areas, individual recreational areas, and parcels located in the urban conservation zone and area (historical centre of the city) were selected. Individual recreational areas, most of them being gardening and cottage areas, showed a strong drop in price. These areas have minor representation and they are located mainly in the city suburbs. Currently, interest in these gardening activities is low, engaging mainly seniors, and overall demand is declining. This is evident in the price trend, which has the most significant drop in all the monitored categories. Also, the absolute value of these parcels is the lowest. Progressing conversely, prices in residential areas and protected areas changed. The current demand for personal housing in Olomouc is very high and the price of these parcels is continually increasing. Several locations are experiencing intensive construction of new units designed for individual housing. Generally, residential areas are relatively equally distributed across the city. In the studied period, this category experienced a significant price increase across the city, even more extensively than in the urban conservation zone. Except for the city centre itself, price has grown significantly in peripheral parts of the city (the south-eastern cadastre of Holice and southwestern Slavonín, Nové Sady, and part of Nová Ulice). Concerning absolute price, however, conservation areas still lead. A specific category is the historical centre, which is protected as an urban conservation area. Here, a strong price increase is observed, and regarding absolute price, it is unequivocally the highest. The variation of prices here is also great; however, even 50% of all parcels in this category surpass all other assessed aspects.

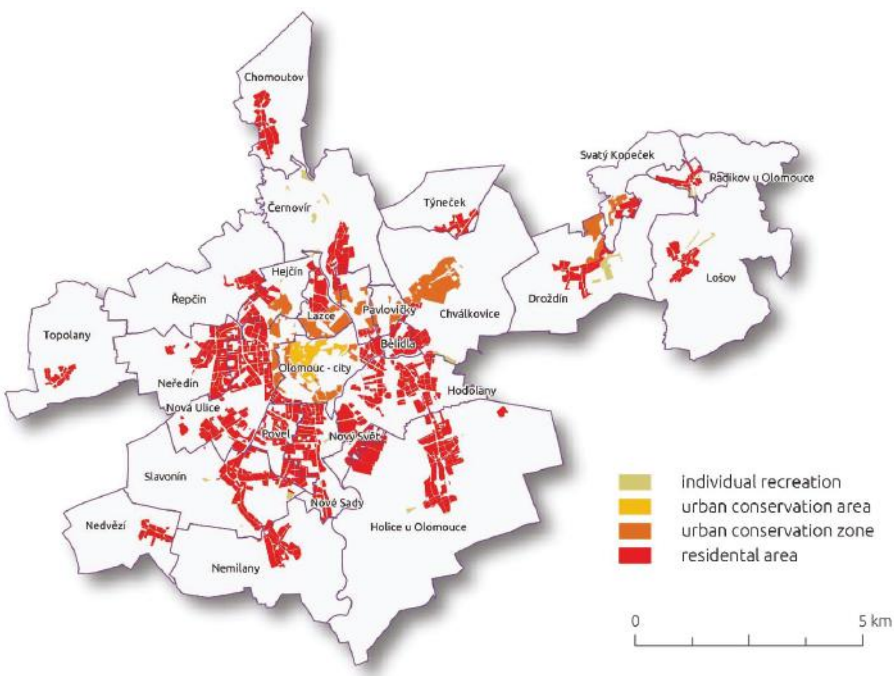

Figure 8. Spatial distribution of social aspects.

The overall assessment points to the most significant impact of social and environmental spatial aspects: a rise in prices occurred in these categories. Categories with a decrease in price are minimal—these are primarily risk areas near watercourses that are prone to flooding. The growth of land prices for high-quality land is also significant. This might be because the Olomouc Region is characterized by soil of the highest quality in the Czech Republic. Parcels with lower soil quality were built on in the past and the city can now only be developed on parcels with higher soil protection levels. These classes compare to those of personal housing, which has seen increased interest in recent years and lead construction activities to being focused on this type of housing. The analysis confirmed the expectation that the most lucrative parcels are located in the city's historical core. This is demonstrated both in the absolute price of land and its change over the monitored period.

5. Discussion

Regarding the influence of the changes of macroeconomic indicators on land price, the results of the regression analysis show that the most significant indicators for land price increase/decrease in time are the indicators "number of inhabitants" and "number of finished flats". Other indicators with a significant impact can be "GDP", "unemployment", and "number of started flats". It partially corresponds to the results of Yang [12], where the influence of immigrant population, GDP, and investment in residential buildings were observed. However, the influence of "net income per capita" is not significant for land price changes in Olomouc as compared to results that were obtained by Mou [10] in his analysis, which also includes the influence of average wages of employees on land price in selected cities.

It is important to emphasize that the results presented in this study are based on a detailed data set for one city: Olomouc. However, the studies mentioned above examine a selected group of cities, and their results show that the significance, direction, and magnitude of the relationships between selected factors can vary across cities [10]. For example, the impact of macroeconomic indicator GDP varied from relatively strong positive to strong negative impacts on residential land price in different cities in China, as observed by Yang [12].

Based on an analysis of master plans, Burian [40] explored the changes in several stable areas in Olomouc (450 ha of agricultural land; 352 ha of housing areas; and, 128 ha of city parks and public services areas). We assumed that these stable areas would have been linked to stable land prices. Surprisingly, no long-term stable areas were found in the area of interest, with a 5% (or higher) tolerance of change. There is a link, however, between price increase and some changes in the land-use type in the master plan. This study shows that long-term rising parcel prices are seen mainly in the suburbs, with their largest representation being in the residential south-eastern part of the city. Most are located in areas marked by Burian [40] as the most variable localities. Two of them are represented by commercial activities (Globus shopping centre in the Řepčín cadastre and Šantovka shopping centre in the city's centre).

In relation to the spatial analysis of the impact of different aspects, some valued parcels overlap and a parcel may comprise several aspects (for example, parcels in the historical centre are included in both residential area and urban conservation area categories). As evaluation was performed from different points of view, this phenomenon cannot be avoided. This means that the differences in price changes in individual categories are not so significant, however, the analysis offers a more complex evaluation.

The overall assessment of total prices and their changes over the three time intervals revealed some patterns in price map behaviour. The most conspicuous is the city's historical centre: here, we can see the highest long-term land prices, even in the period of decrease in prices. As we move away from the city centre, prices gradually decreased. In the second interval of the monitored period, the original spatial pattern disappeared as the value of peripheral parts of the city increased because of personal housing construction. The temporal changes described in Chapter 3.1 are also reflected in the spatial visualization. An overall decline in prices in most parts of the city, even in the most expensive historical centre, was observed. Between 1993 and 2016, there was primarily an increase of price; the decrease is particularly evident in some parts of the city, being affected mainly by the environmental aspect of flood areas.

6. Conclusions

Land price sustainability issues have been analysed by other authors previously. Based on the literature review, we discovered that only a few researchers had focused on an analysis of official land price maps, which are available very rarely. These maps are very significant documents that influence and control the real estate market in the larger cities of the Czech Republic. For this reason, we decided to perform an in-depth analysis of land prices of the city of Olomouc. Official land price maps from 1993 to 2016 were used as the primary data source for temporal and spatial relationships and changes in land prices in Olomouc. Spatial changes were analysed from three aspects of sustainability: economic, environmental, and social. We proposed several research hypotheses to confirm some general statements about land price changes.

The first research hypotheses concerned the link between changes in land prices and changes in macroeconomic indicators. The results of the regression analysis and consequent changes of certain variables for the observed period suggests the answer to this question is partially affirmative. Some macroeconomic indicators had significant impact on the changes in land prices in Olomouc in the period 2006–2016, but not in the case of all of the observed macroeconomic indicators. We can conclude that the changes of land prices are influenced by a mixture of economic, demographic, and social indicators. It is also important to highlight that the analysis is based on land prices in CZK per square meter in Olomouc, calculated as a median of all prices of all land in Olomouc only. In case of using different prices for different localities, the results can be more precise.

In the residential and commercial areas and historical centre, land prices are significantly higher than in other monitored aspects. Overall price is dominated by the city's historical core. From the point of view of changes during the monitored period, part of the hypothesis can be rejected: no significant growth in the commercial categories (represented here by the economic aspect) was revealed. The price increase in three selected factors was quite low. Brownfields even showed a decrease in price. The hypothesis concerning residential areas and the historical centre is valid: price changes were the highest in the three monitored categories. Absolute price in residential areas, especially those located in the historical centre, have been highest in the long term.

We assumed that there would be stable areas with no land price change that were comparable to stabilized land-use. Based on our analysis, we conclude that no connection exists between land-use stability and land price stability. Surprisingly, no long-term stable areas were found in the area of interest. Parcels with changes in land-use type are located mostly in areas with a significant land price increase (commercial areas).

The analysis confirmed that land price and its change over time varied in different spatial aspects. Surprisingly, the smallest influence was reflected in the economic aspect. However, price was significantly affected by land quality and its location within or outside the protected urban conservation area, as discussed above. Regarding natural events in recent decades, we observed a significant drop in land prices in the vicinity of watercourses that are threatened by flooding.

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Geographical Assessment of Low-Carbon Transportation Modes: A Case Study from a Commuter University

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Abstract: This case study examines the geographic variation in students' low-carbon transportation (LCT) modes to a commuter university campus. Three major goals are accomplished from this research: (1) identifying commuting zones for the bicycling, walking, and transit mode choice for UNCG students; (2) understanding whether the real vs. perception of space can be predictive to mode choice; and (3) understanding the relative importance of demographic, psychological, and logistic factors on students' mode choice, using a suite of variables developed in multiple fields. Our analyses support the assertion that various physical, demographic, and psychological dimensions influence LCT mode choice. While the presence of sidewalks is conducive to walking, the distance, either perceived or actual, within 1.61 km from UNCG is the most important factor for walking mode share. The bicycling commute is not associated with either the distance or presence of bicycle lanes, while transit ridership most likely increases if students live >8 km from the UNCG campus with the nearest bus stop within 1 km from home. Given the limited bicycle lanes in Greensboro, students who commute to campus by bicycle are resilient to unfavorable bicycle conditions by sharing the road with cars and adjusting their travel routes. Our findings also concur with previous studies showing that bicycle commuters are disproportionately represented by self-identified whites while bus riders are disproportionately comprised of self-identified non-whites. Our analyses support Greensboro's current planning and policy emphasis on low-carbon travel behaviors via equitable and safe transit-oriented multi-modal infrastructures, and suggest that UNCG should utilize its influence to advocate and further facilitate these ongoing efforts.

Keywords: low-carbon transportation; walk; bike; transit; built-environment; perceptions; UNCG; Greensboro; North Carolina

1. Introduction

This case study intends to understand spatial variation of students' low-carbon transport (LCT) modes to a commuter university. The LCT such as walking, bicycling, and transit had always been popular in the university and college campuses around the United States despite the domination of automobile-oriented transportation since post-World War II [1]. The LCT has been, however, receiving renewed attention in higher education campuses since the beginning of 21st century [2–4] as a mechanism to reverse CO_2 emissions from auto-dominated commuting [5–7]. Automobile transportation dependents on fossil fuels is the primary sources of CO_2 emissions and is growing at faster rate than any other energy sector in the United States [8] mainly due to the unlimited desire for personal mobility [9]. As part of the reversion process, a descent investment in LCT infrastructures has been ongoing not only in American college and university campuses, but almost in every urban areas of the United States [5,10–13].

Understanding university students' commuting behaviors is steadily growing as well [14,15]. University communities that are built by incorporating LCT infrastructures, housing affordability and mixed land-uses promotes travel benefits including lower automotive drivers [16] and higher LCT users [7,14,17]. These studies, however, warned that the successful implementation of low-carbon transport transition requires the careful consideration of the specific contextual factors such as socio-cultural features of the examined campus and the corresponding urban built-environment and transport network [18,19]. Given the fact that the passenger transport must needs to be decarbonized sooner than later to reverse greenhouse gas emissions (GHG) [20] from university campuses, further research is warranted for a deeper understanding of students' commuting behaviors.

There is, yet, a lack of research in examining students' low-carbon mode choice in a commuter university campus [21], especially by using knowledge learned from different disciplines [22]. Commuter universities are different in many aspects, such as they may have a diverse range of student population, including traditional (recent high school graduates to age 24) and non-traditional (25 years or older), holding full-time or part-time jobs, and or may even raise a family. Each of the demographic groups has preferred transportation modes resulting in complex travel patterns. These students are also part of the transportation system and urban structure that may have inadequate infrastructure for using alternative modes (e.g., [23]). Students in commuter campuses tend to have lower share of bicycle and walking commuters to campus than universities located in college towns [14]. Hence, our case study intends to contribute in the literature by combining a suite of variables relating to students' commute collected at University of North Carolina at Greensboro (UNCG) campus. The campus adopted a sustainability policy and Climate Action Plan to achieve zero net GHG emission goal by AD 2050, part of the American college and university campuses (ACUPCC) sustainable initiative [24,25]. The results of this research can be directly beneficial to strengthen policy and implementation of strategies aiming at promoting low-carbon transportation behavior at this university or any similar kind of places even after an individual owns a car.

2. Conceptual Framework

The research related to LCT has focused on two main issues: (1) barriers that prevent students from utilizing LCT as a commuting option; and (2) policies and improvements of organizations that can be used to mitigate these barriers.

2.1. Barriers Preventing People from LCT

2.1.1. Physical Environments and Practical Issues

A better infrastructure for walking and bicycling is associated with increase in such transportation modes [26,27]. Many university campuses in the United States are trying to expand infrastructures for LCT, yet they are not completely adequate for walking and bicycling to campus [14,17]. Cities where universities are located lack in such infrastructures [23,27] and, hence, impeding connectivity in the walking and bicycling networks [4,28]. Higher pedestrian and cyclist fatality rates in the U.S. remain serious concerns for mode switching from car to LCT [12]. Crashes taking place on campus peripheries tend to be more serious [29]. That said, there is also argument that students can select neighborhoods with built-environment conducive to biking and walking if they prefer such transportation modes [14]. Other studies suggest that typical decision of individual mode choice is based on other relating activities for the entire day [30]. For instance, a student may decide to drive to campus if she/he is carrying stuff that are heavy or going to another destinations (e.g., work, child care) not served by other transportation [14].

2.1.2. Distance, Time, and Space: Real vs. Perceived

The distance from living place to university is the primary factor influencing on walking and bicycling to campus (e.g., [15,17,31,32]), but the optimum distance for such transportation mode choices for university students are less understood. Shannon et al. [31] confirmed based on an Australian university campus that the proportion of students utilizing bicycling and walking for trips within one-kilometer of campus were twice that of students living more than one-kilometer from campus. Walking drastically declined beyond one kilometer from the campus and few students bicycled beyond eight-kilometer from campus. Based on two urban universities in Spain, Chillon et al. [32] determined the distance thresholds for walking and bicycling: 2.6 km and 5.1 km, respectively. In contrast, Zhou [14] did not find any correlation between commute distance and students' biking in University of California–Los Angeles, USA. Distance between home and the transit stop, usually less than a kilometer is also associated with transit use [33]. Individual's time constraints is another significant barrier for students' choice of LCT to campus [4], regardless of distance.

Recent research on general adults suggests a mismatch between measured (actual) and self-reported (perceived) distance to activities [34]. Relatively little research of this sort has been conducted among university students. Research examining the role of perceptions in travel behavior found that not only actual distance, but also people's perceived distance has an impact on walking and bicycling [35,36]. Use of bicycle as commute mode increases if people think they live 'near enough' [37,38]. Similarly, perception of car as a necessity to save travel time results in the increased car use [38–40]. That said approximately two-thirds of the population in Amsterdam, The Netherlands would consider riding public transport if the perception of travel time for public transportation was accurate [41]. The amount of 'near enough' or 'too far' in distance varies significantly and the perceived distance seems to be a stronger deterrent in the adoption of bicycle transportation than the actual distance [42,43]. Clearly, resistance to travel by walking or bicycle increases disproportionately with distance and time—either perceived or actual—due to the physical effort these modes require.

Individuals' perception of distance and lack of time not only affect LCT travel behavior, the perceptions on the safety in their neighborhoods can be also a deciding factor for potential alternative mode shares [23,44]. Traffic patterns, themselves, can affect the perception of an area and mode choices [45]. Local areas congested by traffic and excessive parking create a more negative perception of the neighborhood among residents as either walkable or bicycleable [28]. Perceptions are difficult to quantify accurately, but there is a direct connection between how an area is perceived and residents' willingness to engage in walking and bicycling [12,38]. Individuals are more likely to perceive the area as bikeable if there are high numbers of cycle commuters in an area [17,46].

2.2. Policies and Interventions to Mitigate LCT Barriers

Significant policies such as high-density built-environment around and within commuter shade areas [47] of a campus with well-connected and wide sidewalks and bicycle environments have been discussed [7,45]. To some extent these policies are implemented, yet there is limited success in changing university students' mode choice, particularly in increasing bicycling commute [4]. Some studies (e.g., [37]) suggest that monetary incentives, not availability of facilities, is more significant in encouraging bicycling. For instance, Zhou [14] found that specific services such as affordable housing and proximity to a bus line are incentives for students' alternative mode choices. Since availability and affordability of parking spaces encourages car use, strategies for reducing parking spaces are discussed, including raising parking prices to a point when affordability can be an issue for students [15,48]. This program is criticized for being ineffective to higher income students and the possible long-term impact on students' enrollment, especially in commuter campuses [40].

Significant interventions approaches are also discussed [12,17] such as free transit systems in changing students' automotive travel habits. Students at the University of Giessen in Germany were provided prepaid bus tickets as an intervention method to alter students' habitual travel for a longitudinal analysis [49]. This study found that prepaid bus tickets increased positive perception about transit and, hence, concluded that habitual car users may switch to alternative modes by implementing appropriate interventions. However, others argue that earlier travel habits continue if circumstances do not change substantially [50] and, therefore, removing barriers is more effective than promoting the benefits of modal change from automobiles [14,31].

2.3. Sociodemographics, Psychological, and Environmental Perceptions

Socio-economic characteristics, such as age, race, gender, income, home and car ownerships also have an impact on university students' commute mode choice [7,51] and their magnitude can be larger than urban built-environment characteristics [40]. Studies, however, reports that today's university students are less likely to own a car and more likely have positive attitudes towards using alternative LCT modes [16,52–54]. Gender makes a large difference in cycle commuters, as female university students more likely to avoid this mode [7,15]. Additional transportation research conducted by social psychologists shown that car use habits, perceived mobility needs, and pro-environmental behaviors affect university students' mode choice [45,49]. LCT commuting is often determined by an individuals' desire to receive health and environmental benefits from such modes, especially for longer distance travel [55], and this choice is independent of car ownership [31,56].

2.4. Summary

While previous research from various disciplines made significant contributions in understanding the complexity of low-carbon transportation modes choice, there is a lack of integrative approaches for understanding this topic [57]. At the same time it is essential to examine this topic from a spatial context such as built-environments and sociodemographic characteristics of corresponding campus for the successful transition of low-carbon transport. The conceptual framework of this case-study is, thus, based on variables identified in various disciplines and local context (Figure 1).

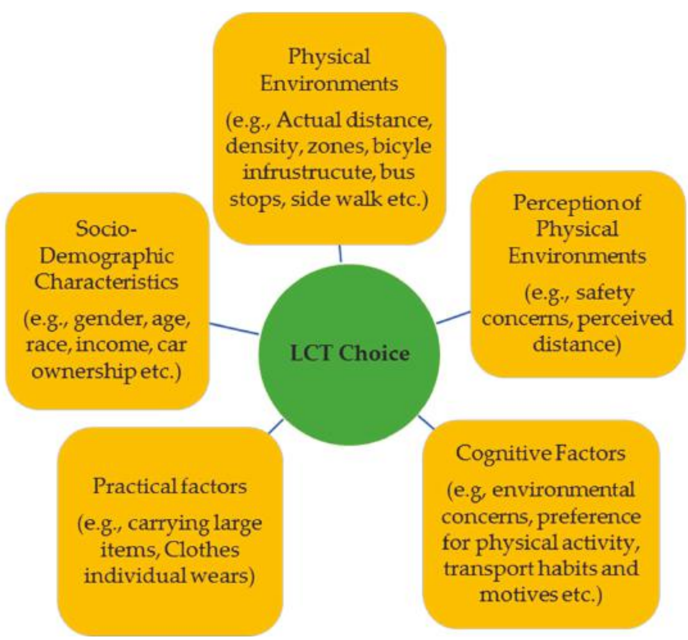

Figure 1. Theoretical framework of mode choice.

3. Study Site, Data, and Methodology

3.1. Study Site

The UNCG, the third largest campus of the UNC system, has mandated to be carbon neutral by AD 2050 [24] and is selected for our study site. It is an urban campus located approximately one mile SW of downtown Greensboro, NC (Figure 2) and is known as largest commuter campus (215-acre campus) in the Piedmont Triad Area. During the academic year 2016–2017, the campus has more than 19,922 students and 2500 faculty and staff [58]. The undergraduate students represent a diverse group of populations; over 40% of students are from underserved populations, and many are first-generation students and hold full-time or part-time jobs.

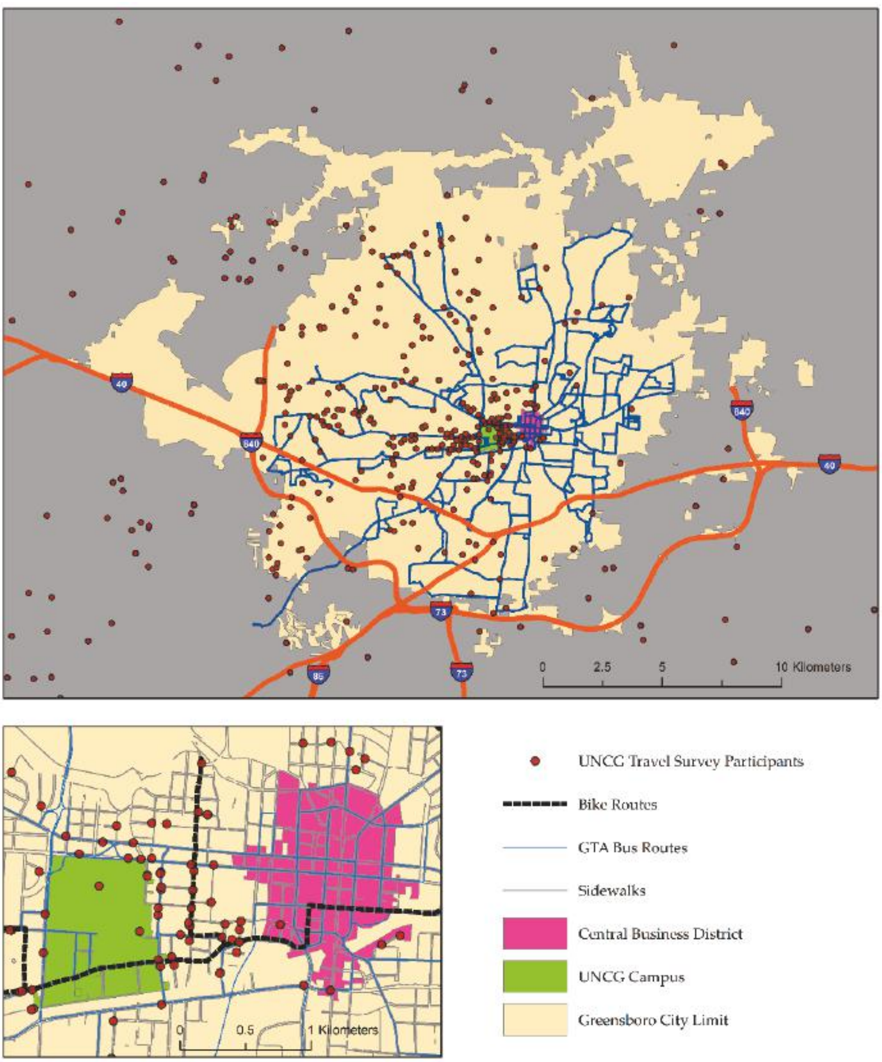

Figure 2. City of Greensboro, NC with participating students' residential locations.

The campus has been recognized a as one of the best bike-friendly university campuses in the United States [59]. These recognitions confirm that the campus is well-connected with bicycle and walking networks, as well as with the local public transit system, the Greensboro Transit Authority (GTA) (Figure 2). A number of alternative transportation modes, such as LimeBike bicycle-sharing program carpooling, car-sharing, emergency ride-home programs, zip car rental program, and priority parking for low-emissions vehicles are available. Greensboro, where the university is located, is a fast-growing city that is anticipating its future transportation needs with a transit-oriented (TOD) multi-modal transportation network to promote transit, bicycling, and walking as alternative modes of transportation for the residents [60]. Despite having an active bicycle advocacy group in Greensboro, it has a limited bicycle network [61], sidewalks, and transit service.

3.2. Data and Procedures

A web-based survey was designed to collect data for this case study. The human-subject approval for this survey was obtained from the UNCG office of the Institutional Review Board (IRB). Undergraduate students were targeted to collect data since this group commutes more than graduate students. Survey participants were invited through emails, which were collected from the University Registrar's Office. Participation in the survey was voluntary. The students were asked to provide their current residential address or the names of the nearest intersecting street to respect a certain level of privacy. They were also asked to provide their age, race/ethnicity, income including their parents' income, employment status, car ownership or access to car, mode of transportation to campus, and housing information (rental or student ownership). Additionally, a series of questions were asked regarding individual perceptions and attitudes on transit facilities, bicycling, and walking to campus, and environmental beliefs using a five-point Likert scale.

A total of 2274 students participated in the survey, but not everyone answered all the questions. Records with missing values are excluded wherever it is appropriate for the analysis. Digital representation of the Guilford County street network, bus routes and stops, sidewalks, and bicycle routes were obtained by contacting the city of Greensboro GIS department. A bike accident location shape file was collected from the Greensboro Department of Transportation (GDOT) [62]. Survey participants who provided their home addresses are geocoded to capture the spatial/geographic features of each student's location. A total of 700 (about 98% of sample size who provided their addresses) addresses were geocoded correctly. Of 700 samples, 570 addresses are within the city of Greensboro, the home of the UNCG (Figure 2). The variables that represent the spatial characteristics or physical built-environment at students' home locations are interpolated at a raster grid (with 100 m $\times$ 100 m cells). These variables are: population density, length of sidewalk and bicycle lane, and network distance from students' home locations to bus stops and to campus. The calculated values are then assigned to each student record. For the purpose of this research, the city limits constrict the study site to designate the probable extent of transit, bicycle, and walking transportation. The public transportation, such as GTA or Heat bus, do not provide services outside the city limits. Similarly, there are no designated bicycle routes outside Greensboro, nor a single sidewalk outside Greensboro connected to the campus.

The city of Greensboro was then divided into five transportation zones based on factors such as network distance, access to bus routes, and bus stops (Figure 3). Zone 1 represents less than 1.61 km or 1 m from UNCG, zone 2 represents more than 1.62 km to less than 3.33 km from UNCG, zone 3 represents 3.34 km to less than 8.0 km distance from UNCG + less than 1 km from the nearest bus stop, Zone 4 represents distance more than 8 km from UNCG + less than 1 km from the nearest bus stop, and zone 5 represents distances more than 8 km from UNCG + more than 1 km from the nearest bus stop. Student populations are then aggregated by these five zones and all these calculations are performed in ArcGIS 10.00 Network Analyst (ESRI, Redlands, CA, USA).

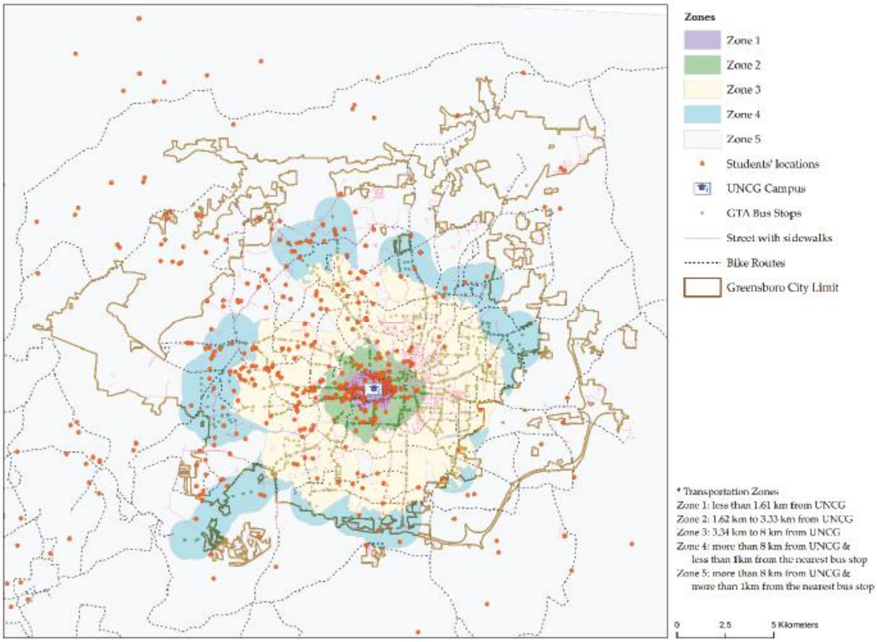

Figure 3. UNCG network zones with survey participants' home locations.

Additionally, Walk Score and Bike Score at each student's location were collected from the website https://www.walkscore.com/ to capture additional walkable and bikeable potentials at students' home locations. A number of studies used Walk Score and Bike Scores for studying the relationship between walkability and walking [63] and bikeability and bicycling behavior in urban areas [64]. The Walk Score website also offers transit score as measurement of transit accessibility at a location, but Transit score data for Greensboro area is not available for each student's location. Therefore, we did not include transit score in our analysis. Both Walk and bike Scores range from 0 to 100, where 0 means no walkability and bikeability; whereas, 100 means highest possible walkability and bikeability an area can have. Accessibility and street connectivity from an origin to number of destinations or amenities (e.g., public transport, restaurants, shopping, parks/green spaces, and schools) are taken into consideration for calculating both walk and bike scores. The Walk Score index is calculated based on the connectivity and distance to destinations. The maximum points are allocated in an address if destinations are within a 5-min of walk or within 0.25 m and no points are allocated if destinations are outside 30-min walk. Similarly, in addition to street connectivity to destinations, bike infrastructures such as bike lanes, trails, hills/topography, and the number of bike commuters are taken into consideration for calculating Bike Score. Variables that are selected for the analysis are presented in Table 1.

Table 1. Selected variables for analysis.

Socio-Demographic Characteristics
Age
Race: White = 1; 0 = All Other
Gender: Female = 1; Male = 0
Fulltime: Fulltime = 1; Part-time = 0
Total income
Car ownership: Yes = 1; No = 0
Home ownership: Own = 1; Rent = 0
Physical Characteristics at Students' Home Locations
Walk score
Bike score
Distance from campus
NetZone1 = 1; All other = 0
NetZone2 = 1; All other = 0
NetZone3 = 1; All other = 0
NetZone4 = 1; All other = 0
NetZone5 = 1; All other = 0
PercievedZone1 = 1; All other = 0
PercievedZone2 = 1; All other = 0
PercievedZone3 = 1; All other = 0
PercievedZone4 = 1; All other = 0
Length of sidewalk; Sidewalk ratio
Length of bike lane; Bike lane ratio
Population density
Bus stop distance from home
Number of bike accidents; Number of pedestrian accidents
Psychological Variables: Habits, Beliefs, Attitudes, and Perceptions
Convenience to UNCG is the primary reason for home location: Yes = 1; No = 0
Affordability is the primary reason for home location; Yes = 1; No = 0
Like to be physically Active: Yes = 1; No = 0
Bike for transportation: Yes = 1; No = 0
Walk for transportation: Yes = 1; No = 0
Saving time is the most important reason for driving to campus: Yes = 1; No = 0
Obstruction for walking/bicycling 1: Too many things to carry = 1; All Other = 0
Obstruction for walking/bicycling 2: Too many cars on the street = 1; All Other = 0
Obstruction for walking/bicycling 3: Unsafe street crossing = 1; All other = 0
Obstruction for walking/bicycling 4: Traffic is too fast = 1; All other = 0
Obstruction for walking/bicycling 5: No bike path = 1; All other = 0
Obstruction for walking/bicycling 6: No side walk or bad condition = 1; All other = 0
Obstruction for walking/bicycling 7: Too busy to walk = 1; All other = 0
Obstruction for walking/bicycling 8: Not enough light on street at night = 1; All other = 0
Consider myself an environmentalist: Yes = 1; No = 0
Willing to move close to campus for reducing GHG emission: Yes = 1; No = 0
Willing to move close to campus for reducing travel time and cost: Yes = 1; No = 0

4. Results

4.1. Socio-Demographic Characteristics of Participating Students

A total of 570 survey participants, who live within the study area (see Figure 3), are majority full-time, traditional—age below 25 years old, female, and non-Hispanic white students (Table 2), which are good representations of UNCG student populations. While many respondents live on or near campus, the geographic distribution of students' residential location is dispersed: 23.9% of students are living in zone 1 (less than 1.61 km or 1 m from UNCG campus), another 13% lived in zone 2 (more than 1.62 to less than 3.33 km from the UNCG campus). Therefore, only about 37% student live within less than 3.33 km distance from the campus (Figure 3 and Table 2). Another 23.5% live in zone 3, which range distance between 3.34 km to 8.0 km from the campus. Students (39.6%) who live beyond 8.0 km distance from the campus (zones 4 and 5), only 12.8% has access to a bus stop less than 1 km distance from their home.

Table 2. Survey participants' basic demographic, location, and transport characteristics.

Basic Characteristics of Students		Respondents (*n*)	Percent Valid Respondents	Total Valid Sample (N)	Missing
Student status	Full-Time	476	90.5	526 (92.3%)	44 (7.7%)
	Part-Time	50	9.5		
Age	Traditional Students ($\leq$25 years old)	336	62.7	536 (94%)	34 (6.0%)
	Non-traditional ($\geq$25 years old)	200	37.3		
Gender	Male	150	28.1	534 (93.7%)	36 (6.3%)
	Female	384	71.9		
Race/ethnicity	White	363	68.1	534 (93.7%)	36 (6.3%)
	Black/African American	72	13.5		
	Asian	36	6.7		
	Hispanic	12	2.2		
	Multicultural	23	4.3		
	Native Am, Pacific Island & other	28	5.2		
Students' income	<25 K	363	70.1	515 (90.4)	55 (9.6%)
	>25 K	152	29.5		
Parents' income	<50 K	107	57.5	186 (32.7%)	384 (67.3%)
	>50 K	79	42.5		
Owned car/s	Yes	446	78.2	570 (100%)	
	No	124	21.8		
Live within zone (network distance from campus)	1 ($\leq$1.61 km)	136	23.9	570 (100%)	
	2 (>1.61 km, $\geq$3.22 km)	74	13.0		
	3 (>3.22 km, $\leq$8 km + <1 km from bus stops)	134	23.5		
	4 (>8.1 km + <1 km from bus stops)	72	12.6		
	5 (>8.1 km + more than 1 km from bus stops)	154	27.0		
Dominant travel mode to campus	Walk	96	19.4	495 (86.8%)	75 (13.2%)
	Bike	27	5.5		
	Drive Alone	316	63.8		
	Carpool	27	5.5		
	Transit and Other	29	5.9		

It is not a surprising that the majority of students (78.2%) reported owning at least one car—a statistic that represents American car culture well. Of 515 students who reported their own income, 70% of them have less than $25,000 annual income. Only 32% student body reported their parents' income and, of them, 58% student body came from households whose parents make less than $50,000, which is well representative of socio-demographic characteristics of UNCG students' body. Of 87% students reported their dominant/primary mode of transportation to campus, 19.4% walked, while 5.5% biked to campus regularly. Another 5.9% students used transit and other form of transit predominantly. Approximately 64% identified their predominant transportation mode as single-passenger vehicle while 5.5% reported carpooling (Table 2).

4.2. Distance and Modal Splits

Figure 4 shows the proportion of modal split by network zones. Modal split differences by zones are statistically significant with a chi-square value of 224 and $p \leq 0.001$. Walking is the dominant transportation mode in Zone 1 (1.61 km or 1 m from campus) (Figure 5), about 60% of all modes, while car driving makes about 25% of all modal choices in this zone. The walking mode share drastically declines in zone 2 (Figure 5)—only 22% of commuters in this zone walk to campus, while driving alone makes up more than 50% of the modal share in this zone. The walking mode share continues to decline in zone 3 and becomes non-existent in zone 4, the proportion of the walking mode share slightly increased in zone 5, which is surprising to us. Bicycling comprises about 10% of the modal share both in zones 1 and 2 (Figures 4 and 5), but its share continues to decline in zones 3 and 4, and then slightly increases in zone 5.

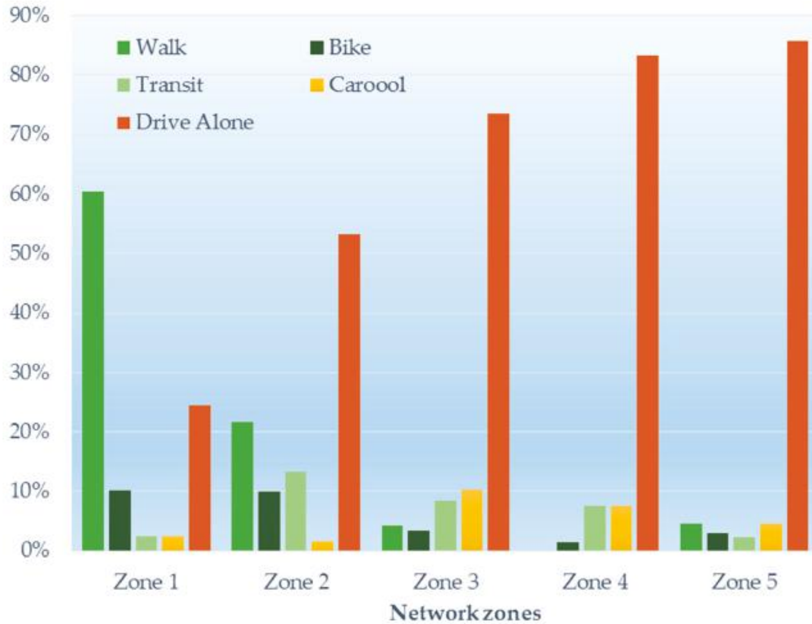

Figure 4. Proportion of modal splits by transportation network zones.

While the proportion of the transit mode share is low in zone 1, the largest modal share by transit is found in zone 2, about 12% of all modes. It slightly goes down in zones 3 and 4, and then drastically goes down in zone 5 (Figures 4 and 6). Many places in zone 5 have limited transit access to students within a kilometer from bus stops (Figure 6). A small percentage of the modal share by carpool (about 2–5%) is found in all zones, but carpools do not seem to take-off slightly until zone 3, which makes up about 10% of the modal share in this zone and the highest of all zones. Given the American car culture, it is not surprising that cars steadily make up the dominant mode share, somewhere between 75% and 85%, for zones 3, 4, and 5 (Figure 4).

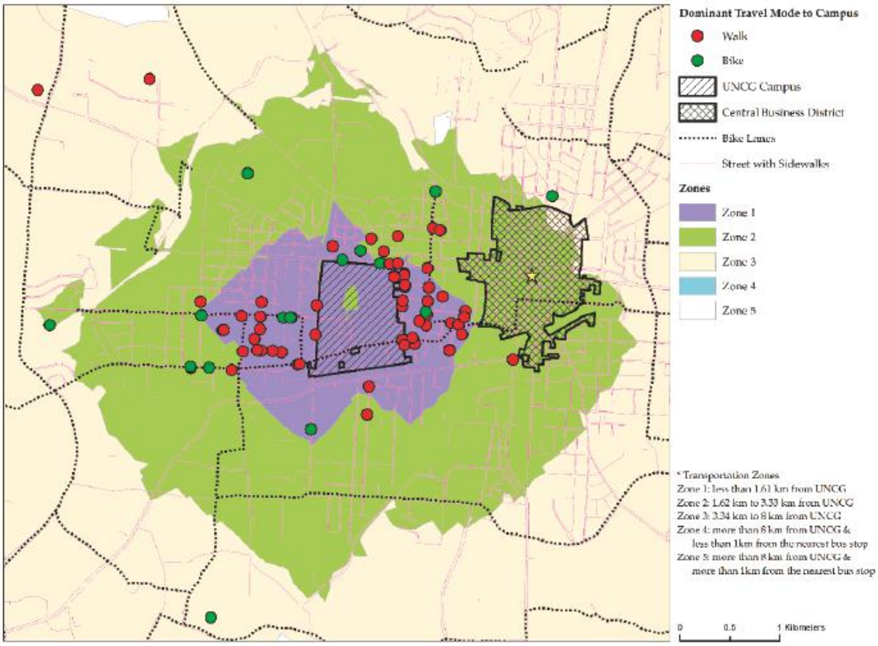

Figure 5. Walking and bicycling to UNCG by transportation network zones.

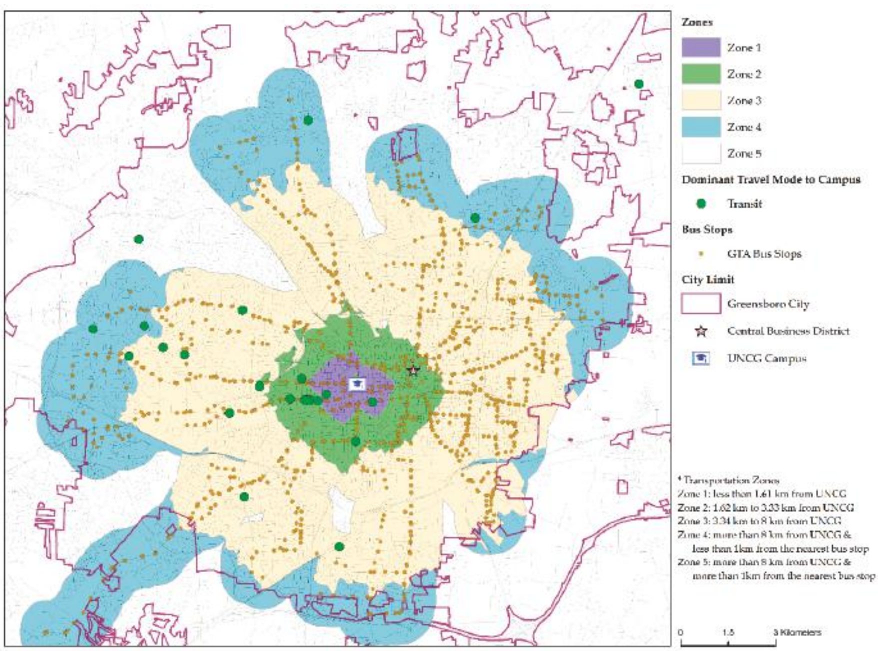

Figure 6. Geographic locations of transit riders with bus stops.

4.3. Modal Choice by Actual vs. Perceived Distance

Figure 7 shows proportion of each mode choice based on individuals' actual distance (AD) vs. perceptive distance (PD) to identify whether perceptive distance makes any difference on mode choice. The AD is calculated using the network distance and PD is measured based on students' selected answers in a survey questionnaire on how far from campus they live. All the differences in the mode of transportation and zones are statistically significant with a chi-square value of 210 and $p = 0.001$ (results are not shown in table). Of all regular walking commuters (19.4% students), 75% live within AD zone 1 and only 14% live within AD zone 2 (Figure 7), which are consistent with what Shannon et al. [31] have found among Australian university students. The perceptive distance (PD) seems to have different outcomes on walkers. The proportion of walking commuter is higher if students thought they lived within 1.61 km, or 1 mile, from campus compared to the actual distance, 92.7% vs. 75%, respectively. In contrast, none identified themselves as walking commuters if students thought they lived beyond 8 km, or 5 miles, from campus, whereas 6.3% of the walking commuters, in fact, lived at this distance in zones 4 and 5 (Figure 7).

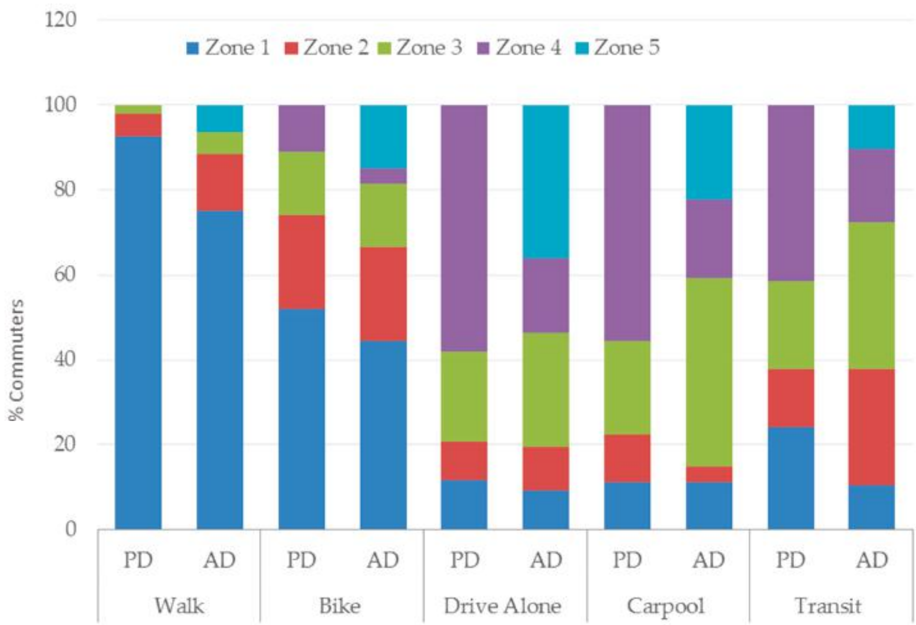

Figure 7. Mode choice by actual distance (RD) vs. perceived distance (PD).

Of the small percentage of survey participants who use bicycles as the primary mode of transportation to campus (5.5%), 44% live within AD zone 1, followed by 22% in AD zone 2, and then it gradually declines in AD zone 3 (15%) and slightly rises again in AD zone 5 (19%) (Figure 7). In contrast, self-identified bike commuters are substantially higher (about 8% more) if students thought they lived in PD zone 1. Similarly, fewer students identified themselves as bicycle commuters (11% vs. 19%) if they perceived that they lived beyond 8 km (PD zone 4) from the UNCG campus (AD zones 4 and 5). While a majority of walking and bicycle commuters lived within AD zones 1 and 2, within 3.3 km from UNCG campus, 98% of all walkers and 74% of all bicycle riders perceived that they lived within 3.3 km from campus. In reality, 89% of all walkers and 66% bicycle riders actually lived within these zones (Figure 7).

Of all transit users (about 6%), the proportion of transit riders (about 10%) is lowest in AD zone 1, but it rises in AD zones 2 and 3. The largest percentage of transit users (35%) are found in AD zone 3 (Figures 6 and 7). Transit users continue to decline in AD zones 4 and 5, 17% and 10%, respectively. In contrast, transit commuters are substantially higher if students thought they lived beyond 8 km (PD zone 4) from campus than the real distance, 41% vs. 27%, respectively. Similarly, of all carpool commuters (5.5%), a majority (44.4%) of all carpoolers live in the AD zone 3 (Figure 7), but only 22% carpoolers thought they lived in this zone. While only 41% carpoolers lived in AD zones 4 and 5, which is 8 km from the campus, 53% of carpoolers thought they lived beyond this distance. Similarly, the proportion of driving alone is substantially higher if students thought they lived beyond 8 km from campus. Clearly, there are mismatches in modal shares between perceptive and objective distances as the perception of closeness in distance increases the motivation of using walk and bike modes. The perception of higher distance increases the car, carpool, and transit uses to the UNCG campus.

4.4. Barriers for LCT

In order to assess the major perceived (or real) barriers on the pedestrian and bicycling networks for those students who were not walking or bicycling to campus, the survey included such questions. The participants are allowed to choose more than one reason. A total of 353 participants responded to this question and the results are shown in Figure 8. The most cited reasoning for not walking or biking to campus is "I have too many things to carry", followed by "too busy to walk". The first answer is consistent with the logistic concept as resistance to travel by walking or bicycling increases disproportionately if there are too many things to carry due to insufficiency of those modes or the inconvenience that they create. The later selection is consistent with the "law of constant travel time" which demonstrates that commuters always try to minimize travel time and will change modes in order to save time (e.g., [65]). Individual's perceptions about their environment are the second largest reasoning for discouragement of low-carbon mode choices, such as concern about the speed and the number of cars on the street, the lack of sidewalks, concern about the safety of intersections/street crossings, and not enough lights at night.

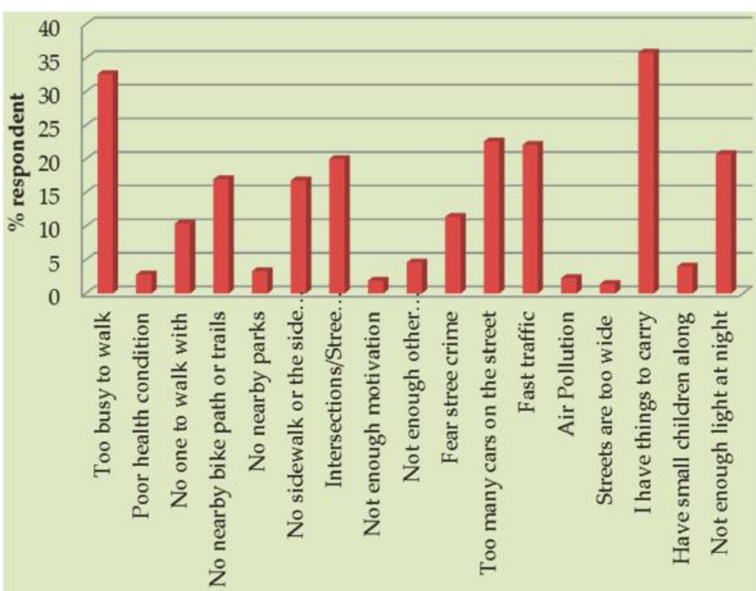

Figure 8. Reasons for not walking or bicycling to campus.

The following question was also posed to non-LCT commuters: "What would motivate you to ride a bike?" Few responded to this question, and of those the majority respondents said that living closer to campus would be a major factor in their transportation choice. Others listed either separate bike paths from the street as a component, or bike paths along the street. Only one person expressed that he/she would never switch modes. Survey participants were also asked the reasons for not using transit. Very few students participated in this question, but most of them viewed transit as unreliable and unsafe. While one student stated, "[the] bus is not dependable to get me to class on the hour or on the half hour", another stated "public transportation is bad and I am busy and can't wait for [the] bus. PART bus does not run late enough for evening classes". Concern over the safety of the transit service is mostly associated with students for nightly classes. "I work late nights on campus and I didn't feel safe waiting around for public transportation to pick me up" and "I drive to my night class because I do not like to walk back to my apartment in the dark, not enough street lights and it doesn't feel as safe as it does in the day time" are examples of students' responses. Clearly, our data supports that reliability in transit service would motivate students to use transit more. Since 40% of those surveyed responded live at least 8 km from campus (see Table 2), it is safe to say that the majority of students would be more than willing to use LCT if they find it safe and practical (e.g., run on time) for their use.

4.5. Predictive Modeling

A binary logistic regression model is estimated for each mode of LCT: walking, bicycling and transit. Binary logistic regression is well suited for this analysis since this research is interested in identifying risk factors by odd ratios (OR) for each travel, yes vs. no, while controlling for all other explanatory variables in the logistic model. Public transit is included in LCT under the assumption that the user will have to walk or bicycle at both ends of the journey to reach the public transport "nodes" or stops [31]. At the same time transit produces significantly lower CO_2 emissions than cars [66]. While carpooling represents more energy savings than solo-driving, both models are important for understanding the barriers of LCT and, hence, carpooling and solo-auto commuter models are also estimated. The forward conditional method for logistic regression is performed using IBM SPSS 25 developed by SPSS Inc. located in Chicago, IL, United States. The best models with statistically significant explanatory variables (at $\alpha \leq 0.05$) for each commute mode is shown in Table 3. While perceived zones have more explanatory power than real network distance (results are not shown in this paper), we used real distance for logistic purpose since locational variables, such as distance from the bus stops, sidewalk length and ratio, and bicycle length and ratio variables are associated with real distance, not with perceived distance.

Table 3. Binary logistic regression model for walking, bicycling, and transit commuters (Yes/No).

Variables	Walk Model (n = 96)			Bicycle Model (n = 27)			Transit Model (n = 23)		
	B	**SE**	**OR**	**B**	**SE**	**OR**	**B**	**SE**	**OR**
Socio-Demography									
Race: White = 1; 0 = All Other				1.941	0.812	6.965 *	−1.358	0.473	0.257 *
Own a car = 1; No = 0				−1.621	0.623	0.198 **	−2.041	0.512	0.130 **
Spatial features or built-environment at students' home locations									
NetZone1 = 1; All other = 0	2.139	0.438	8.491 **						
NetZone3 = 1; All other = 0							1.208	0.578	3.347 *
Sidewalk ratio	0.010	0.003	1.010 *						
Bus stop distance from home	0.109	0.056	1.116 *						
Psychological Variables: Habits, beliefs, attitudes, and perceptions									
Convenience to UNCG is the primary reason for home location = 1; No = 0	1.171	0.396	3.224 *						
I like to be physically active = 1; No = 0				1.565	0.775	4.783 *			
I Walk for transportation = 1; No = 0	1.846	0.395	6.333 **						
Saving time is the most important reason for driving to campus = 1; No = 0				−1.459	0.542	0.233 **	−1.299	0.485	0.273 **
Obstruction for walking/bicycling 1: Too many things to carry = 1; All Other = 0	−2.066	0.576	0.127 **	−2.411	1.043	0.090 *			
Obstruction for walking/bicycling 3: Unsafe street crossing = 1; All other = 0	−2.496	1.142	0.082 *						
Nagelkerke R Square value		0.688			0.318			0.217	

** Significant at $p \leq 0.01$; * Significant at $p \leq 0.05$.

4.5.1. Walk

The walk model is correctly able to predict a 69% variation of walk commutes to UNCG (Table 3). The odds ratio of NetZone1 vs. all other zones are 8.491, meaning that the odds of walking commuters increases by 749% with each percent increase of additional students in zone 1, which is within 1.61 km form the UNCG campus,. An increase in sidewalk ratio at students' home location increases the odds of walking to campus, too. The most importantly, the odds of walking increase 633% if students are habitual walkers for their transportation needs. Similarly, the odds of walking increase by 322% if neighborhoods are self-selected by the students for convenient access to the campus. Interestingly, a higher distance from a bus stop to the home location increases the odds of walking to campus. In contrast, the odds of walking to the campus decrease if students have too many things to carry and if they perceived street crossing was unsafe. Similarly, student's car ownership decreases the odds of using such mode.

4.5.2. Bicycle

The bicycle model explains a 32% variation in bicycle mode choice, which is lower than the walk model (Table 3). This may be due to the small bicycle riders' sample (n = 27) in the data. White and more physically active students are more likely to engage in bicycling to campus. For example, an individual who self-identified as white is seven times more likely to bike to campus, while student's car ownership decreases the odds of using such mode 81%. The odds of bicycle commute increase almost five times if students like to be physically active, while the odds of bicycling decrease 77% if a student perceives a car would be faster to commute to UNCG than riding a bicycle. It is no surprise that the odds of bicycling also decreases 91% if an individual has many things to carry.

4.5.3. Transit

The transit model is correctly able to predict a 22% variation of transit commutes to UNCG (Table 3). Given the fewer transit riders in the sample (n = 23) (Figure 6), such low predictability of the model is not unusual. Individuals living in zone 4, which is >8 km from UNCG + <1 km from the nearest bus stop, are 3.35 times more likely to ride transit to campus than students living in any other zones. In contrast, the odds of riding transit decrease 73% if anyone chose their transport mode based on the perception that car would be faster. Similarly, car ownership decreases the likelihood of transit commuting. Self-identified white individuals are also less likely to ride transit than any other racial/ethnic groups.

4.5.4. Carpool

The carpool model explains a 12% variation in mode choice, which may be due to the lower (n = 27) sample size (Table 4). Individuals living in zone 3, which is between >3.2 km and $\leq$8 km from the UNCG + <1 km from the nearest bus stop, and zone 4, distance >8 km from UNCG + <1 km from the nearest bus stop, have greater odds (4 and 3.37 times, respectively) to carpool than living in any other zones. While a higher distance from the bus stop increases the odds of carpooling, car ownership decreases the odds of carpooling.

Table 4. Binary logistic regression model for carpool and solo-auto driver (Yes/No).

Variables	Carpool (n = 27)			Solo-Auto Driver (n = 316)		
	B	**SE**	**OR**	**B**	**SE**	**OR**
Socio-Demography						
Car ownership: Yes = 1; No = 0	−1.468	0.533	0.257 **	2.721	0.571	15.199 **
Spatial Features or Built-Environment at Students' Home Locations						
NetZone1 = 1; All other = 0				−1.320	0.353	0.267 **
NetZone3 = 1; All other = 0	1.785	0.543	4.094 **			
NetZone4 = 1; All other = 0	1.218	0.603	3.379 *			
NetZone5 = 1; All other = 0				1.101	0.540	3.006 *
Bus stop distance from home	0.141	0.047	1.152 **			
Psychological Variables: Habits, Beliefs, Attitudes, and Perceptions						
Convenience to UNCG is the primary reason for home location: Yes = 1; No = 0				−0.905	0.336	0.404 **
Walk for transportation: Yes = 1; No = 0				−1.110	0.311	0.329 **
Saving time is the most important reason for driving to campus: Yes = 1; No = 0				1.148	0.306	3.151 **
Obstruction for walking/bicycling 1: Too many things to carry = 1; All Other = 0				1.388	0.328	4.006 **
Nagelkerke R Square value		0.123			0.583	

** Significant at $p \leq 0.001$; * Significant at $p \leq 0.05$.

4.5.5. Solo-Driver

The solo automobile commuters' model is correctly able to predict a 58% variation of mode choice to UNCG. The two most influential variables that increase the odds of the solo-auto mode choice are car ownership and individuals having many things to carry (15 and four times, respectively). Similarly, individuals living in zone 5, at a distance >8 km from UNCG + >1 km from the nearest bus stop, and those who perceive car as a faster mode choice are three times more likely to be solo-driver. In contrast, individuals living in zone 1, want to live close to campus, and walking for transportation decrease the odds of solo-driving.

5. Discussion and Conclusions

This case study examines geographic variation of students' low-carbon transportation (LCT) choice to a commuter campus by integrating a suite of variables developed in multiple disciplines. The LCT mode shares are impacted by various physical, demographic, and psychological dimensions. First, while physical environments are the most important factors for walk and transit commute, bicycle commute is not dependent on such factors. Distance (1.61 km from campus) either perceived or real is the most important factor for walk commuter, while transit ridership is most likely increases if students live >8 from UNCG campus with nearest bus stop within 1 km from home. Sidewalk ratio, as well as the increase in distance from bus stops, increase the odds for walking. The later factors suggest that students rather walk to campus if distance between home and bus stops are more than 1 km. In contrast, bike score or bike lanes do not have significant impact on bicycle commuters, nor the distance from the campus. This is consistent with Zhou's [14] finding suggesting no correlation between commute distance and students' biking to UC–Los Angeles. Given the limited bicycle lanes in Greensboro, this is no surprising. Students who commute to campus by bicycle are resilient to unfavorable bicycle condition by sharing the road with car and adjusting their travel routes [56,67]. Solo-auto driver most likely increases 15 times in commuter zone 5, where no bus service is available and the area is outside 8 km from campus, while less likely decreases in zone 1. Clearly, the relationship between the built-environment and solo-driving and built-environment and walking have opposite effects.

Second, while socio-demography has no significant impact on walk mode choice, bicycle commuting is heavily impacted by such factors. Self-identified white students are 200% more likely to ride a bike and 75% less likely to take transit to campus. Car ownership has a negative impact on both bicycle and transit mode shares, but not for the walking mode choice since walking is heavily dependent on the 1.61 km distance threshold. While race does not make any difference on solo driving commuters, car ownership increases the greatest likelihood of such commuters that include carpooling. Our findings are in line with past studies that identified cycle commuters are more likely white middle class [68], and bus riders are low-income non-whites in the USA [54,69].

Third, psychological factors, such as perceptions, motives, habits, beliefs and attitudes have a significant impact on LCT. While we could not include perceptive zones in our models for logistic purposes, our cross-tabulation analysis and walking model (not presented in the Results section) with perceived zones show that students walk greater distances if they perceive that they live within 1.61 km from campus. Our research finds that not only the actual distance, but also people's perceived distance has an impact on walking and bicycling [36,38,42]. While safety concerns about street crossing decrease the odds of walkers, there is no significant impact on such a perception of space for bicyclers. Habit is an important factor for mode choice. For example, having a walking habit increases the likelihood of walking. Students who are habitual walkers for meeting transportation needs are more likely commute to campus by walking. In contrast, the decision to cycle every day is affected by the direct benefit factor [55]. For example, our findings suggest that bicycle commuters are motivated heavily by their willingness to remain physically active or the joy of riding it [56]. The odds of both bicycle and transit commuters decrease if individuals have to carry many things and the perception about a car as a necessity for faster mobility needs increase.

Fourth, while this research does not compare transportation modal shares between university towns vs. commuter urban universities, underrepresentation of cycle and transit commuters in the study sample might be an indication of lower share of bicycle and transit commuters at UNCG. Additionally, given the distance from campus is the most important factor for the share of LCT mode, which is consistent with earlier mode-choice research, it is not unlikely that a commuter university like UNCG will have a lower level of LCT. Most importantly, this research supports that perceived space and faster mobility necessity are more influential than actual distance and mobility needs [31,39,70]. Similarly, this research supports the self-selection hypothesis, which demonstrates that students can locate closer to campus if they prefer to LCT mode.

Fifth, given that the majority of our participants are female, and the small sample size for bicycle and transit users, our models have some limitations in this study. Some important variables did not enter in the models due to their insignificant relationships with LCT, but we think this is because of the small sample size. Therefore, they are worthy of discussion. For example, unlike past studies (e.g., [15,71]), our analysis did not give an indication that being female, or more bicycle and pedestrian accidents are associated with lower level of LCT mode shares. A higher population density seems to make slightly positive differences in the walk mode, but shows negative association with the bicycle mode. These variables should be considered seriously for further study with larger sample sizes because of their direction of relationships in our analysis. Similarly, pro-environmental behaviors seem to slightly positively affect the LCT mode. Further, this research did not collect data for students' year at college (e.g., sophomore, freshman, senior. etc.). We think the length of time students have been in college affects their familiarity with the area, as well as the degree to which they have been exposed to diverse social, political, and environmental ideals, which may impact the mode choice. Our research also did not have data about the time of students' classes, or destinations after classes. These variables should be considered seriously for further study.

Finally, although this analysis has limitations, the results presented here have important implications for commuter campuses, like UNCG or non-student communities. While energy-saving technologies, such as electric or hybrid cars, can play an important role in transitioning to low-carbon transport, it may not be realistic to expect to address the challenge of CO_2 emissions rapidly enough with this technology [72]. Alternative-fuel vehicles (AFVs) are already established in the market, but refueling infrastructure for these types of vehicles is still in its initial stage in most places and has limited consumer acceptance [73]. Even though a new AAA survey finds 20% of Americans thinks their next vehicle will be an electric car, most Americans cannot afford a new car [74]. While zero emission car development technology may be environmentally beneficial, at the same time it may contradict transport equity due to the issue of affordability [75]. We also acknowledge that it is not realistic to change travel behavior rapidly to reduce car usage in the United States, but college campuses have populations that are acceptable to the idea of LCT. Therefore, commuter universities can greatly increase the use of LCT on their campuses and in their surrounding communities. Investment in LCT will not will decrease the CO_2 emissions, it will also decrease the socio-spatial inequalities associated with automobile and increase public health benefits, such as a reduction in mortality and morbidity [76].

There are many opportunities for commuter universities to build communities for low-carbon travel behaviors. For example, universities can partner with cities to build affordable housing with mixed-land uses targeting students within 2 km of campus to make zero car use zone. Improving the bicycle network and public transit with zero emission buses with integrated land use and close proximity to bus stops can reduce many negative externalities of automobile mobility for individuals living beyond 2 m from campus [77]. Our findings strongly support Greensboro's current initiative "Mobility Greensboro 2040" and "Vision Zero" planning and policy initiatives for enhancing equitable and safe transit-oriented multi-modal infrastructures [60]. There is considerable agreement in the literature and our findings reiterate cities that build with a mixed-land use, transit accessible, well-connected street network with good sidewalks encourage higher levels of LCT mode shares for the entire populations. Therefore, the "Vision Zero" program will not only enhance the LCT mode for the UNCG students, it also can encourage non-student populations to utilize LCT modes. Universities often play a major role in expanding the quality of the local economy and cultures, hence, we suggest that UNCG should utilize its influence to advocate and further facilitate these ongoing efforts by partnering with local transportation and planning stakeholders.

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Performance Analysis of a Polling-Based Access Control Combining with the Sleeping Schema in V2I VANETs for Smart Cities

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Abstract: In vehicular ad hoc networks (VANETs), one of the important challenges is the lack of precise mathematical modeling taking into account the passive vacation triggered by the zero-arrival state of nodes. Therefore, a polling-based access control is proposed in this paper using a sleeping schema to meet the challenge of quality of service (QoS) and energy-efficient transport in VANET environments for smart cities. Based on IEEE 802.11p, it was developed in an attempt to improve the energy efficiency of the hybrid coordination function of controlled channel access (HCCA) through a self-managing sleeping mechanism for both the roadside unit (RSU) and on-board units (OBUs) or sensor nodes according to the traffic load in vehicle -to-infrastructure (V2I) scenarios. Additionally, a Markov chain was developed for analyzing the proposed mechanism, and the exact mathematical model is provided with regard to the passive vacation. Then, the performance characteristics—including the mean cyclic period, delay, and queue length—were accurately obtained. In addition, the closed-form expression of the quantitative relationship among sleeping time, performance characteristics, and service parameters was obtained, which can easily evaluate the energy efficiency. It was proven that theoretical calculations were completely consistent with simulation results. The simulation results demonstrate that the suggested method had much lower energy consumption than the standard strategy at the expense of rarely access delay.

Keywords: smart cities; ICTS; energy efficiency; polling control; probability generating function; vehicular Ad-hoc networks (VANETs); vehicle-to-infrastructure (V2I)

1. Introduction

As a key symbol of smart cities, intelligent and connected transportation systems (ICTSs) are growing rapidly, and so vehicular ad hoc networks (VANETs) have attracted a great deal of attention in the research community because of their contributions to road safety, traveling support, traffic efficiency, user-oriented service, etc. [1,2]. Urgent information, traffic-related information, and entertainment information are exchanged either between on-board units (OBUs) in vehicle-to-vehicle (V2V) scenarios or between OBUs (or sensor nodes) and infrastructure in vehicle-to-infrastructure (V2I) environments. Furthermore, data collected on the road can be forwarded to any other data centers through vehicle-to-everything (V2X) communications [3].

Connectivity and security are major concerns in V2V communications, as all the communication parameters rely on neighboring participants, such as wireless technologies and relative speed that play an important role in communication performance [4]. In V2I, roadside units (RSUs) are usually located apart from each other along the sideways to provide safety service and traffic management in urban or highway environments. Unlike the high-throughput and broad bandwidth requirements in user-oriented applications, safety services and traffic management messages are exchanged between vehicles and the roadside, which emphasizes the need for low access delay and transmission delays to provide the highest possible level of safety. Gristiano M. Silva et al. investigated the limitations and challenges associated with such infrastructure-based vehicular communications [5]. In the IEEE 802.11p standard, the hybrid coordination function of controlled channel access (HCCA) uses a collision-free polling scheme to provide the bounded delays for real-time applications. However, this may lead to resource overshooting, especially for low-load scenarios.

The passive vacation arising from the zero-arrival state often occurs when system load is not heavy, in which nodes can be allowed to sleep. Moreover, the sleeping schema is very useful in achieving a green environment because it helps to reduce unnecessary energy consumption and channel resources occupation, even if the nodes can be easily charged. In [6], a periodical sleeping and awakening mechanism on stations (STAs) was used in the Power Save (PS) model in order to save energy at the cost of data transmission during the sleep state. Transmission Opportunity Power Save Mode (TXOP PSM) can greatly improve the energy efficiency of STAs in highly dense networks and with heavy traffic conditions. In fact, traffic oscillation properties are significant in both temporal and spatial domains. Therefore, frequent transmission and idle listening from the RSUs cause much power to be lost. Unfortunately, most of the proposals in the power-saving do not take the RSUs into account.

On the other hand, although many sleeping-based power-saving mechanisms were studied, most of them were based only on computer simulations or energy consumption models [7,8], or only the maximum achievable energy efficiency was analyzed. However, the passive vacation or sleeping state resulting from the zero-arrival state of nodes is rarely considered during system modeling, which has led to a decrease in accuracy [9]. This situation requires a theoretical model that can easily assess the quantitative relationship among system performance, sleeping factor, and network control parameters.

Accordingly, considering the passive vacation, a k-limited $(k = 1)$ polling-based access control protocol with the sleeping technique named Polling Control with Sleeping (PC-S) media access control (MAC) is proposed in this paper for V2I VANETs. A self-managing sleeping mechanism is used for both RSUs and OBUs (or nodes) to improve the energy efficiency of HCCA according to the traffic load. For those OBUs or sensor nodes with transmission requirements, RSU notifies and updates the reserved service slots, respectively depending on their registered sequence. As a result, the nodes can turn off the radio transceivers to save energy and just wake up on their service slots. When none of the nodes request to transmit data and wake up after a sleeping period, the RSUs also turn to sleep or can maintain a low-power waiting state to deal with critical messages.

In addition, the relationship between system performance characteristics and sleeping period will be examined in this study. The mathematical model of PC-S will be adjusted using the embedded Markov chain theory and the probability generating function. It should be noted that for the first time, the precise expressions of the first-order and high-order performance characteristics with the sleeping factor (e.g., the mean cyclic period, the queue length at polling epoch, the mean waiting time, and the queue length) are obtained in this study. As will be shown, the calculation deviation was reduced from more than 9% to almost zero compared to the standard strategy.

The rest of the paper is organized as follows: Section 2 provides an overview of VANETs in ICTS and related work. The proposed model is presented in Section 3. Section 4 contains a detailed analysis of the generating functions and the relationship between sleeping period and network performance.

Numerical examples are also presented in Section 5 that provide insight into performance behavior and energy consumption. Finally, Section 6 concludes the paper.

2. Related Work

In VANET communication, several media access control (MAC) protocols are designed that can be cataloged as contention-based, contention-free-based, and hybrids of the previous two. In recent years, some advances have been made in the field of MAC for VANETs based on IEEE 802.11p (802.11p for short) [10]. Enhanced distributed coordination access (EDCA) at 802.11p is sufficiently flexible to deal with high mobility and frequent topological changes. However, it is completely decentralized, and random access features include deficiencies in strict timing and reliability, which makes it unfeasible in safety-critical applications. To overcome these problems, several MAC protocols based on time division multiple address (TDMA) are presented [10,11]. An overview of TDMA-based MAC protocols for VANETs is given in [2]. In 802.11p, the hybrid coordination function (HCF) of controlled channel access (HCCA) mechanism employs a polling scheme because of its ability to guarantee high QoS, which is essential for emergency information and some traffic related information delivery in vehicular environments. In current 802.11p HCCA, as with the point coordination function (PCF) in IEEE 802.11 for wireless local area networks (WLANs), if an OBU does not have any packet for transmitting, it will either send a null frame, or will send nothing back to the RSU. Idle polling will lead to resource dissipation and overshooting, and further it is a waste of energy. To enhance the channel utilization, a dynamic polling method has been proposed in [12], in which the central HCF coordinator assigned the TXOP dynamically by gathering requirements from the OBUs, even there was an improvement in throughput and delay. However, the complexity of HC scheduling was increased from O(n) to O(n2). In [13], a token passing approach on top of a random access MAC protocol is proposed to prevent channel contention and improve the reliability of the safety message transmissions. Although these protocols have improved the delay performance or beacon delivery ratio in VANETs, most of the analyses were done by simulation. Therefore, the lack of accurate and scalable models to achieve the quantitative relationship between quality of service (QoS) and network parameters is still felt.

According to the performance analysis, the superframe is employed in [14] to cut down the number of polling frames and improve the performance of a highly loaded system, but the idle energy consumption is ignored. In [15], the M/G/1 vacation model is introduced to analyze the latency feature of IEEE 802.11 PCF. However, the authors only considered the regular periodical vacation of the server. It did not matter if the nodes were idle or not, which could increase the delay when the nodes were not idle. In [16], the queue length distribution in the K-limited polling service is discussed using an iterative approximation, regardless of the sleep state. In [7], the GreenPoll MAC protocol combining the TXOP PSM with reservation and implicit polling is proposed to save power, but the node must take some energy to detect its transmission slots by overhearing the channel before it exchanges data with the access point (AP). Moreover, only the computation model for energy consumption analysis is presented, ignoring the system model.

To reduce energy consumption, some researchers have proposed some sleep strategies in the literature to minimize the effect of the sleeping mechanisms on system performances [17–28]. In [17,18], a sleeping/awakening mechanism with loose synchronization was proposed to extend the lifetime of the nodes by reserving long-length-frame sending, but the delay also increased. In [19], a method of slots reservation is used to save energy and improve system throughput in a burst traffic scenario by dividing the service time into periodic requests and sending-out slots. In order to reduce the delay, both the energy consumption and the packets are considered in [23] for updating the vacation period dynamically. In [25], a dispatching control scheduler to build an architectural health monitoring sensor network was suggested to save energy and reduce the end-to-end delay by deploying the father link based on the children links' occupying on the routing tree. In [26], the scheduling lists of neighbors are collected to reduce consumption. In another study [27], a self-adapted sleep scheme is proposed to follow the changing traffic dynamics. In [28], the periodic polling system of the limited service is analyzed theoretically, but the zero-arrival state and the following sleep state is neglected in the mathematical model. In [29], the sleep state is combined into the mathematic model for the first time, and the expression of the mean cyclic period, first-order performance characteristic is obtained. However, the mathematical expressions of the high-order performance characteristics have not yet been obtained, let alone the relationship between performance and sleep period.

Therefore, to the best of our knowledge, none of the previous works have analyzed the performance characteristics theoretically using the sleep state in a mathematical model that simultaneously considers the energy efficiency. Therefore, in this paper, the PC-S, which is a 1-limited polling-based access control protocol with sleeping technique, is proposed for V2I VANETs. A sleeping technique (as will be described in Section 3.3) is applied to both OBUs and RSU. In addition, the mathematical model of PC-S is set so that the quantitative relationship between system performance and network control parameters can be easily evaluated.

3. Mechanism of PC-S

In this section, the access control mechanism of PC-S is described, including application vehicular environment, service mechanism, and sleeping technique.

3.1. Network Environment

Here, a mobile vehicular environment will be considered where the OBUs or nodes in the cluster have three different types:

- Applicant Node (AN): An OBU or a sensor node that has applied to join the cluster;
- Cluster Member (CM): An OBU or a sensor node that has been joined to the cluster and has been added to the polling list table;
- Dissociative Node (DN): An OBU or a sensor node that has left the current cluster, but has not yet joined the other.

In Figure 1, an example of the proposed polling-based structure is presented. OBUs and other environmental sensor nodes in the coverage of the RSU form a cluster by a distance-based clustering algorithm, in which the RSU acts as a cluster header. Under the mechanism of PC-S, OBUs and sensor nodes can enter a sleep state and wake up at the time slot allocated by the RSU for sending its uplink messages. Furthermore, in some of spare cases, if none of the nodes in the cluster have data to transmit, the RSU will also go to sleep until the next round of transmission. Active RSUs in neighborhood work under different SCHs to prevent frequency interference.

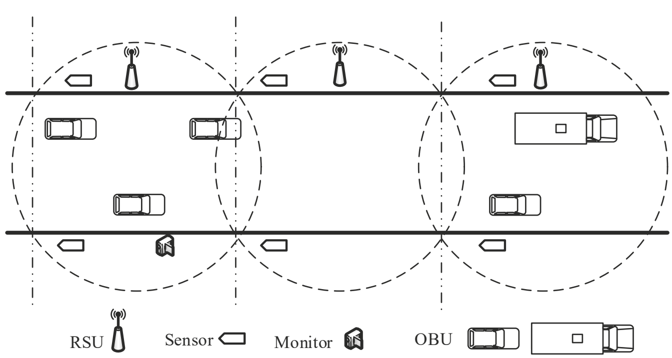


Figure 1. Application scenarios under the Polling Control with Sleeping media access control (PC-S MAC) protocol. OBU: on-board unit; RSU: roadside unit.

3.2. 1-Limited Polling Access Mechanism

An HCCA superframe consists of a contention-free period (CFP) and a contention period (CP). For safety services and traffic management with a highly real-time requirement, data packets are delivered by a polling scheme in CFP with a high-level QoS guarantee. The user-oriented service data packets transmission and cluster update are executed at the CP phase.

During the CFP, the RSU broadcasts a beacon with cluster ID, user ID, and NAV time at the beginning of the CFP. It can also deliver downlink data packets after the beacon.

An immigrating OBU or a node with a transmission requirement (i.e., AN) will send an application to join the cluster after receiving the CFP_END (CE) frame. The RSU will assign a user ID for each AN, and broadcast in the beacon. Then, ANs turn into CMs after receiving their user ID and will be polled in a round robin fashion during the CFP, as shown in Figure 2. CMs will hold their user ID until leaving the current cluster. If a CM moves outside the coverage of the cluster head and still has transmission requirement, it will apply to join another cluster and be treated as an AN. Otherwise, it will be a DN.

All CMs receive the beacon to update the network allocation vectors (NAVs). On the PC-S MAC network, OBUs and nodes can deliver either one uplink data or null data with constant packet length when receiving a polling frame from the RSU. CMs inform the RSU of their buffer states in the ACK frame during visit periods. In the successive CFP, the RSU will not poll the CM that has declared its idle state.

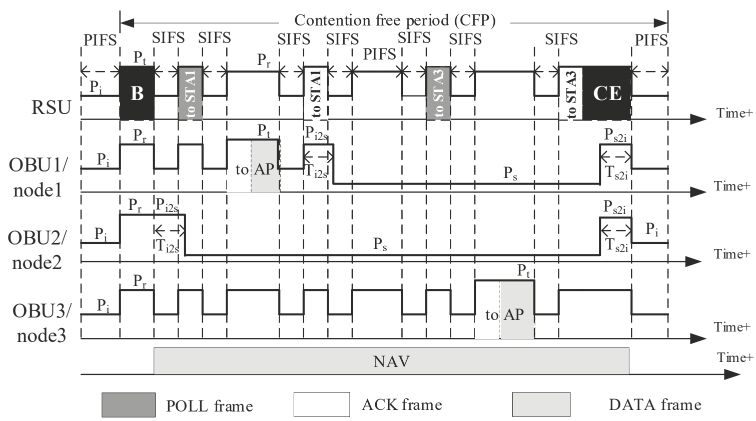


Figure 2. PC-S MAC: Active OBU1/node1 and OBU3/node3 transmit safety and traffic data packets to the RSU in order, while OBU2/node2 in idle state turns into sleep after receiving the beacon and downlink data from the RSU. CE: CFP_END ; STA: station; PIFS: point interframe space; SIFS: short interframe space.

3.3. Sleeping Technique

In the 802.11p standard, an OBU must respond within a short interframe space (SIFS) period once it receives a polling frame from the Hybrid Coordinator (HC) in the CFP duration. When the OBU or sensor node does not have any queued packet to send, it will send back a null frame, which is a waste of channel resources and energy consumption. Obviously, continuous interception and polling from the RSU in a completely empty network would be a serious energy waste. On the other hand, idle listening and null frame transmission from OBUs or sensor nodes would take up a large amount of channel resources.

In PC-S, the sleeping technique is used for both OBUs and the RSU. An OBU or a node will soon be in sleep state upon completion of the transmission and will announce its state to the RSU in the

ACK. The RSU will not poll the sleeping OBU until new arrivals awaken it. As shown in Figure 3, the state transition is as follows:

- For an RSU, it broadcasts a beacon frequently as long as there is at least one active OBU/node in the coverage area.
- A vehicle/sensor node in the coverage starts as an AN, and then it becomes a CM when it has communication requirement and is added to the polling list by an RSU.
- A CM waits for the polling from an RSU, and becomes a DN it is once beyond the communication coverage or finishes all the data transmission.
- A CM will turn into sleep state as it has finished the entire data transmission, and will wake up when it has new requirements.

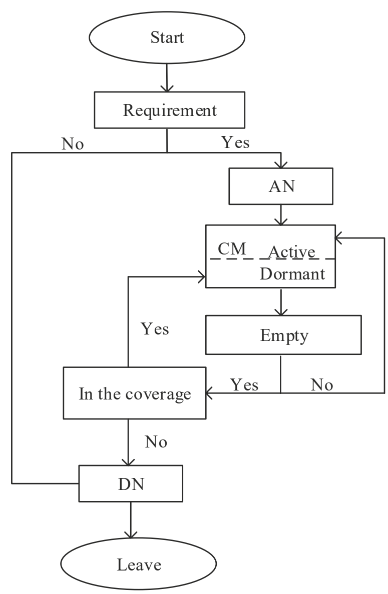


Figure 3. State transition diagram of the PC-S MAC. AN: Applicant Node; CM: Cluster Member; DN: Dissociative Node.

When the RSU's polling list is empty (i.e., no active OBUs or nodes in the cluster), the RSU can choose to set a timer and go to sleep after sending a beacon frame, or it can remain in an active state to respond immediately.

4. Mathematical Model of PC-S and Performance Evaluation

In this section, the mathematical model of PC-S is obtained and the explicit expressions of the system performance characteristics are derived.

4.1. Outline

Most of the existing works in the literature have analyzed the performance of the HCCA-based medium access mechanism using simulations. To model the relationship among system parameters such as the sleeping period, traffic load, and the QoS, we expand the classical discrete-time 1-limited polling model to analyze the performance of PC-S. The service model can be described as follows:

In a cycle of service, an AP (i.e., an RSU) serves the node (i.e., sensor nodes and OBUs) in its polling list table one by one with a 1-limited service strategy in a subnet. The AP authorizes the channel to the polled node in turn. If the current node does not have any requests for data transmission or no response, the AP will poll the next node because it thinks the current node is sleeping or outside the subnet. When all nodes are idle, the AP will set a timer and will go to sleep after sending a beacon frame, and it will reset the polling service when the timer expires.

4.2. Mathematical Model of PC-S

Assume the PC-S system as a discrete time (timeline is divided into time slots) polling system that contains $N(N \geq 2)$ infinite-buffer nodes $Q_1, Q_2, \ldots, Q_N$. Active nodes will access the AP in FIFO order and transmit the data packets with 1-limited service discipline. The node keeps active when accessing to the AP and then turns to sleep if it is idle or served by the AP. If a node does not respond to the polling of the AP, the AP will skip it in the current polling round and remove it from the polling list, which can save the unnecessary switch-over time wasted on those idle nodes so as to improve the QoS of the AP when serving other nodes in need.

4.2.1. System Work Conditions

Suppose the system work conditions are as follows:

- Data packets arriving at Q_i $(i = 1, 2, \ldots, N)$ can be regarded as an independent statistical process in accordance with the Poisson distribution. The generating function of the arrival process in node i is $A_i(z_i)$ with the variance of $\sigma^2_{\lambda_i} = A''_i(1) + \lambda_i - \lambda_i^2$ and the arrive rate of $\lambda_i = A'_i(1)$, so the total arrive rate is $\Sigma_{i=0}^{N}\lambda_i$.
- Data packets in node i $(i = 1, 2, \ldots, N)$ receive individual services. The service time of a packet on each node is independent of each other. Their generating function is $B_i(z_i)$, with the variance of $\sigma^2_{\beta_i} = B''_i(1) + \beta_i - \beta_i^2$ and the mean value $\beta_i = B'_i(1)$. Therefore, the load offered by Q_i is $\rho_i = \lambda_i\beta_i$ and the system load ρ is equal to $\Sigma_{i=0}^{N}\rho_i$.
- The switch-over time of the AP from node i $(i = 1, 2, \ldots, N)$ to its logical neighbor is independent. The generating is $R_i(z_i)$, with the variance of $\sigma^2_{\gamma_i} = R''_i(1) + \gamma_i - \gamma_i^2$ and the mean value $\gamma_i = R'_i(1)$.
- The sleeping time of the AP is independent. Its generating function is $S(z_i)$, with the variance of $\sigma^2_{\zeta_i} = S''(1) + \zeta_i - \zeta_i^2$ and the mean value $\zeta = S'(1)$.

Moreover, suppose the random variables as follows:

- $v_i(n)$ denotes the service time of the AP for Q_i $(i = 1, 2, ..., N)$;
- $u_i(n)$ denotes the switch-over time of the AP from Q_i $(i = 1, 2, ..., N)$ to $Q_i + 1$;
- $\mu_i(n)$ denotes the packets arriving at Q_j $(j = 1, 2, ..., N)$ in $u_i(n)$;
- $\eta_i(n)$ denotes the packets arriving at Q_j $(j = 1, 2, ..., N)$ in $v_i(n)$.

Let $\xi_i(n)$ denote as the number of data packets present at Q_i $(i = 1, 2, ..., N)$ at t_n when Q_i begins to access the AP, the system status is described as $\{\xi_1(n), \cdots, \xi_i(n), \cdots, \xi_N(n)\}$, and changes to Q_i after the AP has served Q_i and turns to poll Q_{i+1} at t_{n+1}.

Under the necessary and sufficient conditions for the stability ($\Sigma_{i=0}^{N}\lambda_i(\beta_i + \gamma_i) < 1$), the probability distribution is defined as

$$\lim_{n\to\infty} P[\xi_i(n) = x_i; i = 1, ..., N] = \pi_i(x_1, ..., x_N).$$

4.2.2. N-Dimensional Generation Function of PC-S

Let $G_i(z_1, ..., z_N)$ represent the N-dimensional distributions of $\xi_i(n)$. Then, the generation function is

$$G_i(z_1, z_2, \cdots, z_i, \cdots, z_N) = \sum_{x_1=0}^{\infty}\sum_{x_2=0}^{\infty}\cdots\sum_{x_i=0}^{\infty}\cdots\sum_{x_N=0}^{\infty}\pi_i(x_1, \cdots, x_i, \cdots x_N)z_1^{x_1}z_2^{x_2}\cdots z_i^{x_i}\cdots z_N^{x_N} \quad i = 1, ..., N. \tag{1}$$

When the AP just finishes the service for Q_i and starts the polling on Q_{i+1} at t_{n+1}, the expressions are

$$\begin{cases} \xi_k(n+1) = \xi_k(n) + \mu_k(u_i) + \eta_k(v_i), & k \neq i \\ \xi_i(n+1) = [\xi_i(n) - 1]^+ + \mu_i(u_i) + \zeta_i(v_i), & \end{cases}$$

where

$$[\xi_i(n) - 1]^+ = \begin{cases} 0, & \xi_(n) \leq 1 \\ \xi_i(n) - 1, & \xi_(n) > 1. \end{cases}$$

Then, we can obtain:

$$\begin{aligned} & G_{i+1}(z_1, z_2, ..., z_i, ..., z_N) = \lim_{n\to\infty} E[\prod_{k=1}^{N} z_k^{\xi_k(n+1)}] \\ & = R_i[\prod_{k=1}^{N} A_k(z_k)]\{\frac{1}{z_i} B_i[\prod_{k=1}^{N} A_k(z_k)][G_i(z_1, ..., z_N) - G_i(z_1, ..., z_N)|_{z_i=0}] \\ & + G_i(z_1, ..., z_N)|_{z_i=0}\} + S[A_i(z_i)]G_i(0, ..., 0) \\ & \qquad i = 1, ..., N. \end{aligned} \tag{2}$$

4.3. Performance Analysis of PC-S

In this section, explicit expressions are obtained for the system performance parameters. Initially, an expression for the mean cyclic period of PC-S is obtained. These results ultimately lead to the first and second moments of the PC-S, and obtain the expression for the joint queue length at the polling epoch at Qi, further deriving the mean waiting time of packets and mean queue length on the timeline.

4.3.1. Mean Cyclic Period

Calculate the generating functions and their derivation at the point $\mathbf{z} = l$, where $\mathbf{z}$ is the abbreviation of the $(1 \times N)$ vector of $(z_1, z_2, ..., z_i, ..., z_N)$, and $\mathbf{1}$ is the $(1 \times N)$ vector with 1, $\mathbf{0}$ is the $(1 \times N)$ vector with 0. Define the first derivative of $G_i(\mathbf{z})$ at $\mathbf{z}$ = l as

$$g_i(j) = \lim_{z_1,\cdots,z_i,\cdots,z_N \to 1} \frac{\partial G_i(\mathbf{z})}{\partial z_j}, \qquad g_{i0}(j) = \lim_{z_1,\cdots,z_i,\cdots,z_N \to 1} \frac{\partial G_i(\mathbf{z})|_{z_i=0}}{\partial z_j},$$

where $g_i(j)$ is the length of Q_j at the polling epoch when the AP serves the Q_i, and $g_{i0}(j)$ is the length of Q_j at the polling epoch when the AP is polling the Q_i which is empty.

Define θ as the mean cyclic period that the average time the AP takes to serve all the demanding nodes for a round. Thus, the mean cyclic of PC-S is formulated as (detailed derivation process described in Appendix A):

$$\theta_{PC-S} = \frac{N\gamma + \zeta G(\mathbf{0})}{1 - N\beta\lambda} \tag{3}$$

where G($\mathbf{0}$) represents the system state, where all the nodes have no data in a polling round. That is, the system is currently idle.

4.3.2. Joint Queue Length at the Polling Epoch

Define the second derivative of $G_i(\mathbf{z})$ at $\mathbf{z} = l$ as

$$g_i(j, l) = \lim_{z_1,\cdots,z_i,\cdots,z_N \to 1} \frac{\partial^2 G_i(\mathbf{z})}{\partial z_j \partial z_l}, \qquad g_{i0}(j, l) = \lim_{z_1,\cdots,z_i,\cdots,z_N \to 1} \frac{\partial^2 G_i(\mathbf{z})|_{z_i=0}}{\partial z_j \partial z_l}.$$

Calculate $\Sigma_{i=1}^{N} g_{i+1}(j,l)$ and $\Sigma_{i=1}^{N} g_{i+1}(j,j)$ (Equations (A4)–(A8) in Appendix A), the first derivation of $G_i(\mathbf{z})$ is given by:

$$g_i(i)_{PC-S} = \frac{N}{2[1-N\lambda(\beta+\gamma)]}\{2[\lambda\gamma+\frac{\zeta\lambda}{N}G(\mathbf{0})](1-\lambda\gamma)+[\gamma+\zeta\lambda\beta G(\mathbf{0})]\frac{\lambda^2(N-1)(\lambda\beta-\gamma)}{1-N\lambda\beta}$$
$$+\lambda^2R''(1)+[1+\frac{\lambda\beta}{1-N\lambda\beta}+\frac{1-(N-1)\lambda\beta}{N\gamma(1-N\lambda\beta)}\zeta G(\mathbf{0})]\gamma A''(1)+\frac{N\gamma+\zeta G(\mathbf{0})}{1-N\lambda\beta}\lambda^3B''(1)$$
$$+\frac{1-(N-1)\lambda\beta}{N}\lambda^2G(\mathbf{0})S''(1)\} \tag{4}$$

4.3.3. Mean Waiting Time and Mean Queue Length on the Timeline

Define $E[W]$ as the average waiting time for packets, which represents the time from the epoch when a packet arrives at the node to the time it is served. According to the related research in [28], the mean waiting time of packets in PC-S is given by:

$$E[W_{PC-S}] = \frac{R''(1)}{2\gamma}+\frac{1}{2[1-N\lambda(\beta+\gamma)]}[(N-1)\gamma+(N-1)\lambda\beta+2N\lambda\beta\gamma+(N\lambda\gamma+\lambda\beta)\frac{A''(1)}{\lambda^2}$$
$$+N\lambda B''(1)+N\lambda R''(1)]+\frac{(1-\lambda\beta)G(\mathbf{0})}{2[N\gamma+\zeta G(\mathbf{0})][1-N\lambda(\gamma+\beta)]}\{[1-(N-1)\lambda\beta]S''(1)$$
$$-\frac{R''(1)}{\gamma}\zeta-(N-1)(\lambda\beta-\gamma)\zeta\} \tag{5}$$

According to Little's law, the mean queue length on the timeline can be obtained as follows:

$$E[L_{PC-S}] = \lambda E[W_{PC-S}] \tag{6}$$

4.4. Performance Analysis of IEEE 802.11p

Using the same derivation method, the 802.11p performance parameters can be calculated as [28]:

$$\theta_P = \frac{N\gamma}{1-N\lambda\beta} \tag{7}$$

$$g_i(i)_P = \frac{N}{2[1-N\lambda(\beta+\gamma)]}[2\lambda\gamma(1-\lambda\gamma)+\lambda^2R''(1)+\frac{(N-1)(\lambda\beta-\gamma)\lambda^2\gamma}{1-N\lambda\beta}$$
$$+(1+\frac{\lambda\beta}{1-N\lambda\beta})\gamma A''(1)+\frac{N\gamma\lambda^3B''(1)}{1-N\lambda\beta}] \tag{8}$$

$$E[W_P] = \frac{R''(1)}{2\gamma}+\frac{1}{2[1-N\lambda(\beta+\gamma)]}[(N-1)\gamma+(N-1)\lambda\beta+2N\lambda\beta\gamma$$
$$+(N\lambda\gamma+\lambda\beta)\frac{A''(1)}{\lambda^2}+N\lambda B''(1)+N\lambda R''(1)] \tag{9}$$

and

$$E[L_P] = \lambda E[W_P].$$

However, the passive vacation caused by the zero-arrival state of all the nodes was neglected in [28], which treats the influence of passive vacation on system performance as zero, and inevitably yields precision error.

Unfortunately, the research done in [7] also did not provide the mathematical model that its service mechanism is similar with 802.11p when $\zeta = 1$, in which the AP moves forward a slot and keeps the active state (it is equivalent to that sleeping factor is 1 slot) when no nodes have data to transmit.

4.5. Analysis of Sleeping Time

In this section, the energy efficiency of PC-S is compared to 802.11p. To be fair, a subnet composed of an AP (or RSU) and N associated nodes (or OBUs) in the coverage of the AP are considered.

As expected, idle nodes will consume extra energy because of overhearing. Therefore, as the idle node sleeps longer, more energy is saved. Thus, analyzing the nodes' sleeping time can verify the energy efficiency, which can avoid the different power consumption of radio chips from producers.

Under the premise of a stable state (i.e., $N\lambda(\beta+\gamma)<1$), let $E[T_S]$ and $E[T_{Slp}]$ denote the average service time and average sleep time in a polling period, respectively. Let $E[T_{Idl\_AP}]$ denote the AP's average idle time when all nodes have no data transmission requests. Let $E[T_{AT}]$ denote the time that a sleepy node will take to access the AP's polling list if it is awakened by the new arrival, and $E[T_{IBS}]$ denote the idle time that a joined node will take to acquire its transmission order.

4.5.1. Sleeping Time Analysis for PC-S

In PC-S, each node with no packet to transmit will keep sleeping state and switch to the active state only if new packets arrive or at its own service time. This means that a node with data to transmit will return to the active state at its service slots allocated by the RSU in the latest ACK, and then go to sleep after $\gamma+\beta$ slots in a cyclic period, during which those nodes without transmitting data are sleeping. The RSU can also go to sleep during the remaining time if there is no transmission.

Therefore, under ideal conditions, each node in the PC-S system will go to sleep in the interval time between two service cycles if it does not have data after the latest data transmission. Thus, the average sleep time of a node in one polling round can be approximately calculated as

$$E[T_{Slp\_PC-S}] = \frac{1}{2}(2\theta_{PC-S} - E[T_{AT\_PC-S}] - E[T_{S\_PC-S}] - E[T_{IBS\_PC-S}]) \tag{10}$$

where

$$\begin{aligned}
E[T_{AT_PC-S}] &= [\theta_{PC-S} - (\gamma+\beta)][1-G_i^{(0)}] = \lambda\theta_{PC-S}[\theta_{PC-S} - (\gamma+\beta)], \\
E[T_{S_PC-S}] &= (\gamma+\beta)[1-G_i^{(0)}] + (\gamma+\beta)[1-G_i^{(0)}]^2 = \lambda\theta_{PC-S}(\gamma+\beta)(1+\lambda\theta_{PC-S}), \\
E[T_{IBS_PC-S}] &= [\theta_{PC-S} - (\gamma+\beta)][1-G_i^{(0)}]^2 = \lambda^2\theta_{PC-S}^2[\theta_{PC-S} - (\gamma+\beta)].
\end{aligned}$$

$E[T_{S\_PC-S}]$ is the service time of a node in two cycles, and $E[T_{IBS_PC-S}]$ is the idle time that a joined node in PC-S will take to acknowledge its transmission order from the RSU if it has some new packets by chance. Otherwise, it will remain in a sleeping state.

Moreover, the average sleeping time and idle time of an AP are calculated as

$$E[T_{Slp\_AP\_PC-S}] = \zeta G(\mathbf{0}) \tag{11}$$

$$E[T_{Idl\_AP\_PC-S}] = N\gamma G(\mathbf{0}) \tag{12}$$

4.5.2. Sleeping Time Analysis for IEEE 802.11p

Nodes in 802.11p will keep active for $\gamma+\beta$ time to exchange data with an RSU if it has data to transmit, and in other cases, it will maintain overhearing or low-power state. So, $E[T_{Slp\_P}] = 0$, $E[T_{Slp\_P\_AP}] = 0$, and $E[T_{Idl\_AP\_P}] = N\gamma G(\mathbf{0})$. Thus, the expression of average idle time of the node can be written as

$$E[T_{Idl\_P}] = \theta_P - E[T_{AT\_P}] - E[T_{S\_P}] \tag{13}$$

where

$$\begin{aligned}
E[T_{AT_P}] &= [\theta_P - (\gamma+\beta)][1-G_i^{(0)}] = \lambda\theta_P[\theta_P - (\gamma+\beta)], \\
E[T_{S_P}] &= (\gamma+\beta)[1-G_i^{(0)}] = \lambda\theta_P(\gamma+\beta).
\end{aligned}$$

$E[T_{AT\_P}]$ means the average idle time of the node in 802.11p, and $E[T_{AT\_P}]$ means the time that an idle node will take to access the AP's polling list when some new packets arrive.

5. Experiments and Discussion

In order to complete the study of the PC-S model in V2I VANETs, it was essential to validate the theoretical analysis of the presented model before comparing the performance characteristics with 802.11p (e.g., mean cyclic period, queue length at the polling epoch, mean waiting time, mean queue length, average sleeping time, and energy efficiency).

Assume that the channel is in ideal condition and channel error correction is managed by an error detection mechanism that is running on the physical layer, and the 1 slot is 25 µs and the nodes are symmetric. Furthermore, the service time slots of all packets are exponentially distributed with mean β, and the arrival processes are the Poisson process with rate λ, Meanwhile, the switch-over time is exponentially distributed with mean γ, and the sleeping time slots are exponentially distributed with mean ζ. The slots of a node which will take to switch from sleep state to active state is T_{sw}, and the power consumption in different states is denoted by P_t, P_r, P_i, P_{s2i}, P_s, and P_{t2s}, respectively. The relative parameter values are listed in Table 1.

Table 1. Test bed.

Parameters	Values	Parameters	Values
N (nodes)	10, 20, 30	P_t (slots)	1.65
λ (packets/slot)	0.0005–0.005	P_r (W)	1.4
β (slots)	9	P_i (W)	1.15
γ (slots)	1, 3	P_{s2i} (W)	1.725
ζ (slots)	5, 10, 20	P_s,P_{s2i} (W)	0.0045
T_{SW} (slots)	2.5		

Monte Carlo simulations were carried out to evaluate the performance of the proposed polling scheme, 802.11p (i.e., mean cyclic period, queue length at the polling epoch $g_i(i)$, mean waiting time $E[W]$, mean queue length $E[L]$, and average sleeping time $E[T_{Slp}]$).

5.1. Performance Comparisons

In this section, a set of experiments are presented to validate the mathematical model and the expressions of performance characteristics between 802.11p and PC-S.

5.1.1. Theoretical Analysis Verification

In Tables 2–5, the calculation error related to the theoretical results and simulation results of θ and $g_i(i)$ in different scenarios are compared, respectively. When the load increased, the theoretical value of PC-S and 802.11p were closer to their own simulation value, which proves the correctness of theoretical analysis. However, for the reference 802.11p model, the error of theoretical expressions [28] exceeded 9% in comparison with simulation results when the load was light. This result shows the effectiveness of the two analysis methods. However, the proposed model is more suitable for realistic scenarios in which the zero-arrival state happens frequently. This means that the zero-arrival state or the following sleep state should be taken into account while modeling, especially when the system load is not heavy.

Table 2. Comparison of theoretical results and simulation results of θ between 802.11p and PC-S when $N = 10$, $\beta = 9$ slots, $\gamma = 1$ slots, and $\zeta = 10$ slots.

λ	Theoretical Value of θ of 802.11p (slots)	Simulation Value of θ of 802.11p (slots)	Calculation Error of 802.11p (%)	Theoretical Value of θ of PC-S (slots)	Simulation Value of θ of PC-S (slots)	Calculation Error of PC-S (%)
0.0005	10.4673	11.4571	9.46%	19.9612	19.9606	0.003%
0.001	10.9901	11.9695	8.91%	20.0396	20.0390	0.003%
0.0015	11.5607	12.5284	8.37%	20.2180	20.2178	0.001%
0.002	12.1924	13.1486	7.84%	20.4993	20.4995	0.001%
0.0025	12.9092	13.8517	7.30%	20.8769	20.8759	0.0048%
0.003	13.6969	14.6163	6.71%	21.3569	21.3580	0.0052%
0.0035	14.5889	15.5004	6.25%	21.9546	21.9549	0.0014%
0.004	15.6338	16.5255	5.70%	22.6778	22.6783	0.0022%
0.0045	16.8092	17.6803	5.18%	23.5740	23.5747	0.003%

Table 3. Comparison of theoretical results and simulation results of $g_i(i)$ between 802.11p and PC-S when $N = 10$, $\beta = 9$ slots, $\gamma = 1$ slots, and $\zeta = 10$ slots.

λ	Theoretical Value of $g_i(i)$ of 802.11p (slots)	Simulation Value of $g_i(i)$ of 802.11p (slots)	Calculation Error of 802.11p (%)	Theoretical Value of $g_i(i)$ of PC-S (slots)	Simulation Value of $g_i(i)$ of PC-S (slots)	Calculation Error of PC-S (%)
0.0005	0.0052	0.0057	9.62%	0.0101	0.0100	0.0996%
0.001	0.0111	0.0121	9.01%	0.0202	0.0202	0.00%
0.0015	0.0175	0.0190	8.57%	0.0309	0.0309	0.00%
0.002	0.0247	0.0267	8.1%	0.0419	0.0420	0.2381%
0.0025	0.0330	0.0354	7.27%	0.0537	0.0538	0.1859%
0.003	0.0422	0.0451	6.87%	0.0664	0.0665	0.1504%
0.0035	0.0528	0.0561	6.25%	0.0802	0.0804	0.2488%
0.004	0.0654	0.0692	5.81%	0.0954	0.0958	0.4175%
0.0045	0.0800	0.0843	5.38%	0.1131	0.1136	0.4401%

Table 4. Comparison of theoretical results and simulation results of θ between 802.11p and PC-S when $N = 10$, $\beta = 9$ slots, $\gamma = 3$ slots, and $\zeta = 5$ slots.

λ	Theoretical Value of θ of 802.11p (slots)	Simulation Value of θ of 802.11p (slots)	Calculation Error of 802.11p (%)	Theoretical Value of θ of PC-S (slots)	Simulation Value of θ of PC-S (slots)	Calculation Error of PC-S (%)
0.0005	31.4166	32.3084	2.84%	35.7996	35.7997	0.0003%
0.001	32.9638	33.7543	2.4%	36.8028	36.8011	0.0046%
0.0015	34.6677	35.3628	2.01%	37.5338	37.5350	0.0032%
0.002	36.5814	37.1816	1.64%	39.4578	39.4594	0.0041%
0.0025	38.7007	39.2164	1.33%	41.1584	41.1567	0.0041%
0.003	41.0908	41.5214	1.05%	43.1318	43.1331	0.003%
0.0035	43.7841	44.1409	0.81%	45.4987	45.4977	0.0022%
0.004	46.8882	47.1738	0.61%	48.1946	48.1939	0.0015%
0.0045	50.3973	50.6187	0.44%	51.4549	51.4572	0.0045%

Table 5. Comparison of theoretical results and simulation results of $g_i(i)$ between 802.11p and PC-S when $N = 10$, $\beta = 9$ slots, $\gamma = 3$ slots, and $\zeta = 5$ slots.

λ	Theoretical Value of $g_i(i)$ of 802.11p (slots)	Simulation Value of $g_i(i)$ of 802.11p (slots)	Calculation Error of 802.11p (%)	Theoretical Value of $g_i(i)$ of PC-S (slots)	Simulation Value of $g_i(i)$ of PC-S (slots)	Calculation Error of PC-S (%)
0.0005	0.0159	0.0163	2.52%	0.0181	0.0181	0.00%
0.001	0.0335	0.0343	2.39%	0.0375	0.0375	0.00%
0.0015	0.0534	0.0545	2.06%	0.0586	0.0586	0.00%
0.002	0.0762	0.0775	1.71%	0.0825	0.0826	0.1212%
0.0025	0.1023	0.1037	1.37%	0.1093	0.1093	0.00%
0.003	0.1328	0.1342	1.05%	0.1397	0.1397	0.00%
0.0035	0.1688	0.1702	0.83%	0.1761	0.1762	0.0568%
0.004	0.2124	0.2140	0.75%	0.2184	0.2185	0.0458%
0.0045	0.2652	0.2664	0.45%	0.2715	0.2714	0.0368%

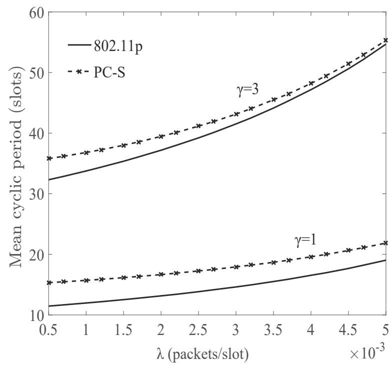
The error of 802.11p mainly results from ignoring the zero-arrival state of its mathematical model. Although the nodes in 802.11p will not turn to sleep state when they have no packets to send, they are actually idle and this fact was ignored while modeling [28]. As far as we know, the existing analysis models are not combined with zero-arrival state or sleep state, and the proposed model is excepted. However, nodes are often idle because of an absence of packets, especially when system load is light. Therefore, to design the networking environment and performance testing, the zero-arrival state, the triggered sleeping state, or rather the passive vacation should be considered.

5.1.2. Comparisons of Performance Variation

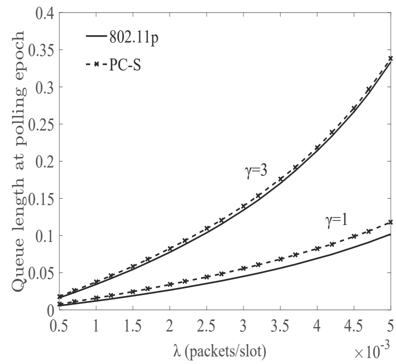
In Figure 4, the variation of θ, $g_i(i)$, $E[W]$, and $E[L]$ are compared, respectively. It became obvious with the increased traffic load, which clearly showed that the performance of the two systems was degraded and also tended to agree with each other when the load was heavy. Additionally, as shown in Figure 4, the increased switch-over time could result in worse performance, which indicates an unsuitable wireless channel or some distance among the AP and nodes. However, under the stability conditions, $E[W_{PC-S}]$ was only 1 or 2 slots longer than that of 802.11p when ζ was 5 slots, which means that the QoS could be guaranteed in the PC-S system even if nodes and AP implemented a sleeping strategy when there was no request from the nodes. The reasons are follows:

1. AP polls the prior neighbor of the current node according to the polling list, but this neighbor is idle just then. When this case happens, the service moment of the current node will be put off.
2. If the AP chooses to turn to sleep while all nodes are sleeping or become DNs, as a result it will not wake up unless the sleeping time ends, even though there are some nodes awakened by the new arrival of packets. However, this is rare in cases of increased load.

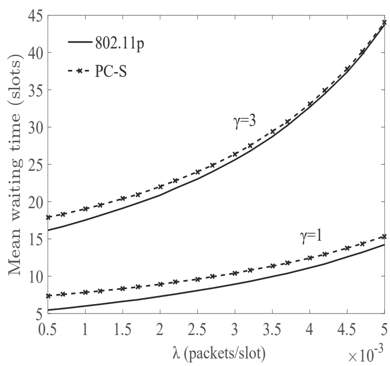
Of course, the AP can also choose to keep being active to immediately respond to the critical messages, which will not affect the performance of those sleeping nodes without data.



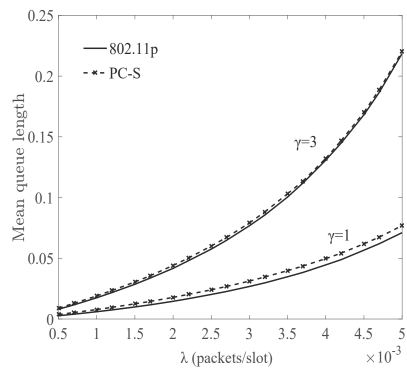
(**a**) Comparison of mean cyclic period



(**b**) Comparison of length at polling epoch



(**c**) Comparison of mean waiting time



(**d**) Comparison of mean queue length

Figure 4. Comparisons of performance parameters in different λ and γ when $N = 10$, $\zeta = 5$.

5.2. The Influence of Sleeping Mechanism on the System Performance

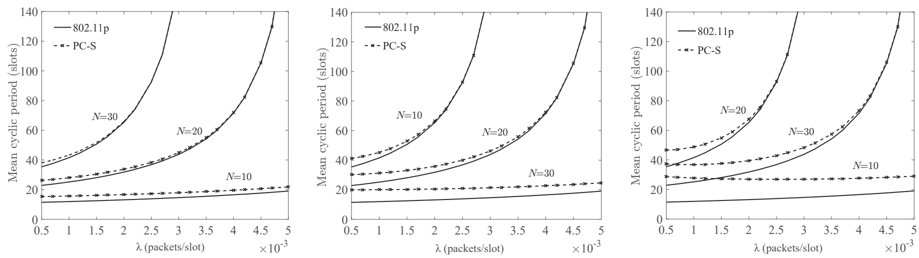
Figures 5–8 show the change trends of system performance through increasing the nodes under different sleeping factors, arrival rate, and switching-over time. Under the system stability condition, increased load led to worsening of the performance of the two systems. While in case of PC-S system, the influence of the sleeping factor on the system performance was more than that of traffic load when the normalized throughput (i.e., traffic load $\rho = N\lambda\beta$) was under 0.3. However, when the load increased, it was considered as a key factor.

Additionally, as shown in Figures 5–8, in the case of short sleeping time, the sleeping mechanism had a slight influence on the performance degradation in different node scale environments. However, a sleeping factor larger than $\beta + \gamma$ resulted in larger undesirable effects, especially when the throughput ρ was under 0.3.

In Figure 9, the performance variations affected by both γ and θ are compared, and it shows that:

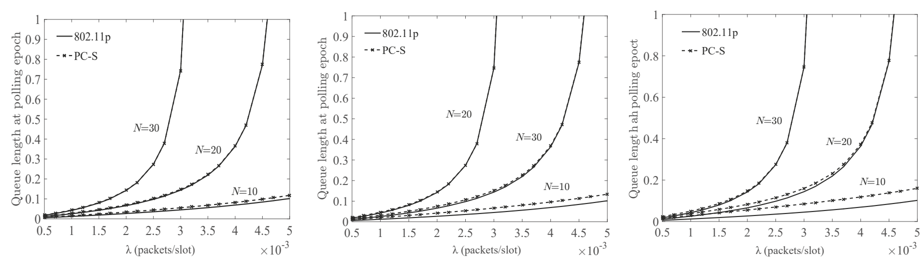
1. Under the same service condition, PC-S performed worse than 802.11p. This is because when the traffic load was light, the bigger θ, the worse the performance. However, when load was heavy, the performances under different sleeping factors gradually tended towards those of 802.11p. This is because with increasing load, the probability that all terminals were idle was reduced. Therefore, regardless of the magnitude of the sleeping factor, the probability of the AP passively sleeping was dramatically reduced and the effect of the sleeping mechanism was reduced as well, and ultimately, almost reached zero.

2. The effect of γ on performance was much greater than the sleeping factor. As shown in Figure 9, even when θ was as large as 20 slots, the PC-S performance with $\gamma = 1$ slot was still much better than that of non-sleeping 802.11p with $\gamma = 3$ slots. Therefore, in system design, more attention should be paid to the distance or barriers between terminals and the AP.



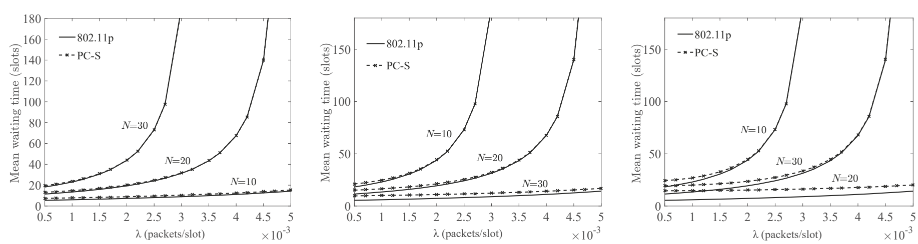
(**a**) Variation of θ when $\zeta = 5$ (**b**) Variation of θ when $\zeta = 10$ (**c**) Variation of θ when $\zeta = 20$

Figure 5. Comparisons of variation of mean cyclic period in different λ, ζ, and N when $\gamma = 1$.



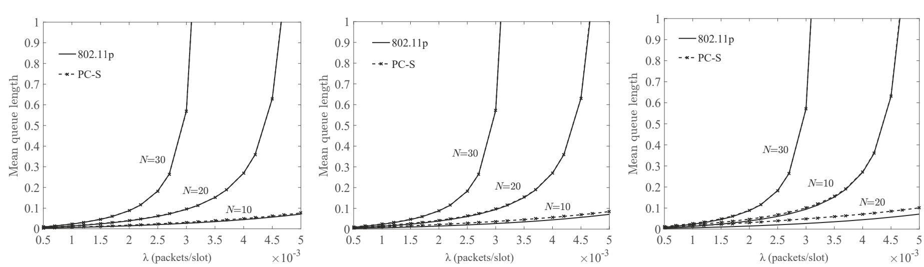
(**a**) Variation of $g_i(i)$ when $\zeta = 5$ (**b**) Variation of $g_i(i)$ when $\zeta = 10$ (**c**) Variation of $g_i(i)$ when $\zeta = 20$

Figure 6. Comparisons of variation of $g_i(i)$ in different λ, ζ, and N when $\gamma = 1$.



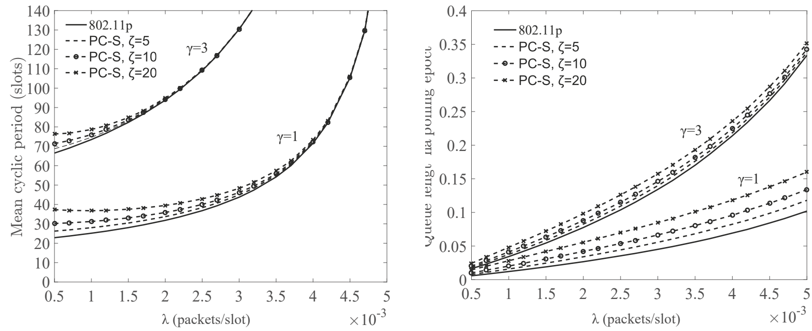
(**a**) Variation of $E[W]$ when $\zeta = 5$ (**b**) Variation of $E[W]$ when $\zeta = 10$ (**c**) Variation of $E[W]$ when $\zeta = 20$

Figure 7. Comparisons of variation of $E[W]$ in different λ, ζ, and N when $\gamma = 1$.

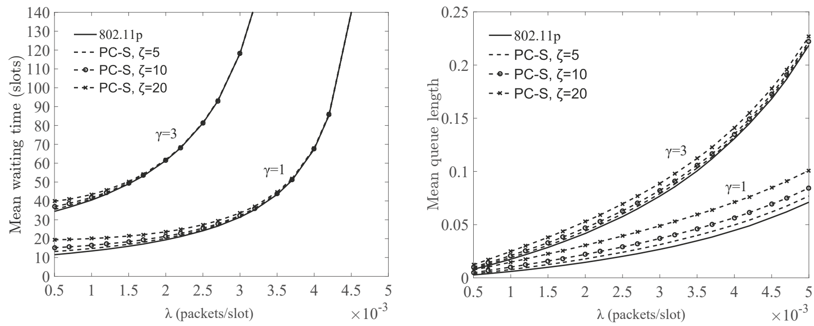


(**a**) Variation of $E[L]$ when $\zeta = 5$ (**b**) Variation of $E[L]$ when $\zeta = 10$ (**c**) Variation of $E[L]$ when $\zeta = 20$

Figure 8. Comparisons of variation of $E[L]$ in different λ, ζ, and N when $\gamma = 1$.



(**a**) Variation of θ in different λ, γ, ζ when $N = 20$ (**b**) Variation of $g_i(i)$ in different λ, γ, ζ when $N = 10$



(**c**) Variation of $E[W]$ in different λ, γ, ζ when $N = 20$ (**d**) Variation of $E[L]$ in different λ, γ, ζ when $N = 10$

Figure 9. Performance parameters variation comparisons in different λ, γ, ζ and N.

5.3. Energy Efficiency Comparisons

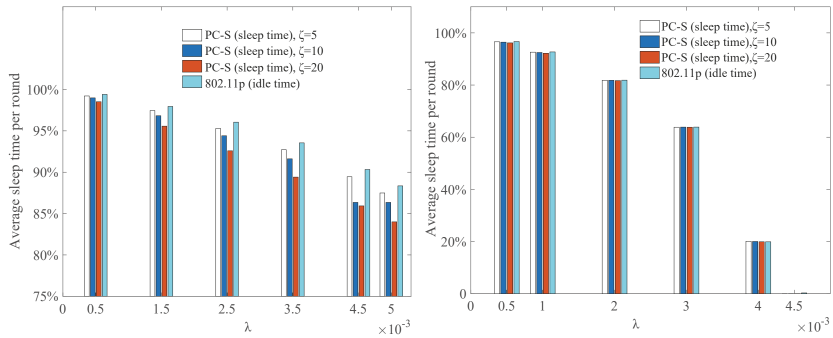
In this section, experiments are presented to compare the average sleeping time and energy efficiency, respectively.

5.3.1. The Comparison of Average Node Sleeping Time

The energy consumption in sleeping mode is so low that is ignored. Hence, the energy consumption by a node's sleeping time can also be evaluated, because under the same condition, the energy consumption of data exchange in these two systems is uniform. Obviously, the longer the idle nodes sleep, the greater the energy efficiency.

In Figure 10, the average sleep time of a node in PC-S under different λ and θ versus the idle time of node in 802.11p is compared.

As shown in Figure 10, the average sleep time of a node in PC-S and the idle time of a node in 802.11p both declined with increasing load. However, when the load was not very heavy, the idle nodes in 802.11p took more than 90% of the time to overhear during the vacation without data transmission. The nodes in PC-S can turn the radio transceivers to sleep in order to reduce the energy consumption. As can be seen in Figure 10b, with increasing γ and N, even if the load almost reached the extreme working condition, the sleep rate for PC-S was still about 20%.



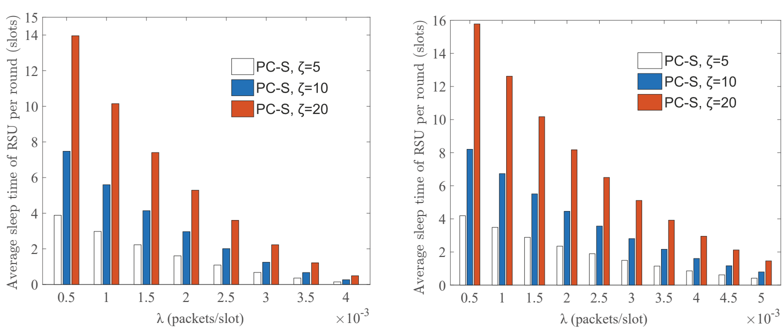
(**a**) Sleeping time ratio when $N = 10, \gamma = 1$ (**b**) Sleeping time ratio when $N = 20, \gamma = 3$

Figure 10. Comparisons of node sleeping time in different λ, γ, ζ, and N.

5.3.2. The Comparison of Average RSU Sleeping Time

The average sleeping time of RSUs under the different arrival rates and sleeping factors when all the nodes were in sleeping mode is shown in Figure 11. For 802.11p, its RSU is always activated, even if the system is idle, so the sleep time is 0 and not shown on the figure.

In Figure 11, it is observed that with increasing sleeping factor under the same conditions, the sleeping time of the RSU became longer but it was shorter than ζ. This is because there were always a few nodes requesting data transmission, and so as long as the traffic load is not zero, the RSU must keep active. Furthermore, increases in the arrival rate and the network scale led to decreases in the RSU's sleeping time, and finally it dropped down to 0. Especially, when the throughput was more than 0.3 (i.e., when the system became busy), the RSU's sleeping time reduced rapidly—even less than 2 slots. Therefore, the RSU can choose to close its sleeping option in order to respond to the nodes quickly. However, this does not mean those idle nodes would remain active, and they can still choose sleeping mode.



(**a**) Sleeping time of RSU when $N = 20, \gamma = 1$ (**b**) Sleeping time of RSU when $N = 10, \gamma = 3$

Figure 11. Comparisons of sleeping time of RSU in different λ, ζ and N.

5.3.3. Energy Efficiency Analysis

Unlike 802.11p, when the node in PC-S is idle, it can turn to sleep. So, the saved energy in its sleeping time can be calculated to measure the energy efficiency. If the energy efficiency is denoted by η, the following equation can be obtained:

$$\eta_{PC-S} = \frac{E[T_{Slp\_PC-S}]P_i - (E[T_{Slp\_PC-S}] - T_{WS})P_s - T_{SW}P_{s2i}}{E[T_{S\_PC-S}]P_t + E[T_{Slp\_PC-S}]P_i + (E[T_{AT\_PC-S}] + E[T_{IBS\_PC-S}])P_r} \quad (14)$$

where $E[T_{S\_PC-S}]P_t$ is the energy consumption when a node sends its data, $T_{SW}P_{s2i}$ is the energy consumption when a node awakens from sleeping state, $E[T_{Slp\_PC-S}]P_i$ is the energy consumption if it keeps idle state during the sleep time, and $(E[T_{AT\_PC-S}] + E[T_{IBS\_PC-S}])P_r$ is the energy consumption of overhearing when it accesses a subnet.

However, the nodes of 802.11p always remain in idle state, even if they have no transmission request. So, the following equation can be obtained:

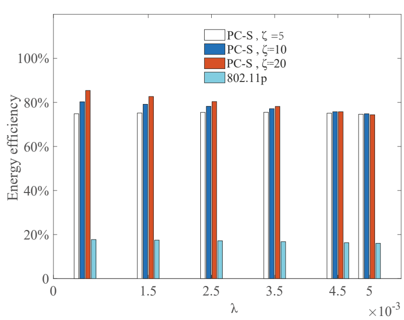
$$\eta_P = \frac{E[T_{Idl\_P}]P_r - E[T_{Idl\_P}]P_i}{E[T_{S\_P}]P_t + E[T_{Idl\_P}]P_r + (E[T_{AT\_P}] + E[T_{IBS\_P}])P_r} \tag{15}$$

where $E[T_{S\_P}]P_t$ is the energy consumption when a node of 802.11p sends its data, $E[T_{Idl\_P}]P_i$ is the energy consumption during its idle state, $E[T_{Idl\_P}]P_r$ is the energy consumption if it keeps overhearing during $E[T_{Idl\_P}]$, and $(E[T_{AT\_P}] + E[T_{IBS\_P}])P_r$ is the energy consumption of overhearing when it accesses a subnet.

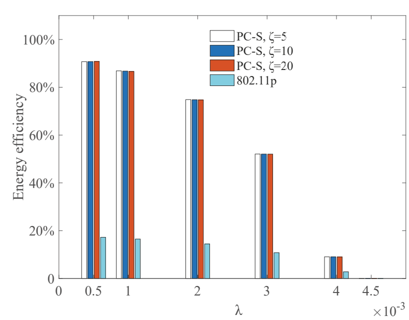
In Figure 12, the energy efficiency of a node under different arrival rates and sleeping factors is compared. The variations of energy efficiency when system load was not very high ($N = 10, \gamma = 1$) is given in Figure 12a. The variations when load was relatively high ($N = 20, \gamma = 3$) are given in Figure 12b. Thanks to employing the sleeping mechanism, the node in PC-S can save a great deal of energy when it is idle and turns to sleeping mode. However, the node in 802.11p just switches to the idle state from overhearing, which led to only less than 20% energy savings, even when the load was light.

In addition, as shown in Figure 12a, the energy efficiency of PC-S with different θ came close when load was not high. On the other hand, larger θ resulted in better energy efficiency performance. However, according to Figure 12b, when γ was larger, the improvement of this performance was clearly less with the increment of λ.

If some packets are lost because of the channel error, the node must retransmit them, which means the arrival rate of the node becomes a little larger than before. Based on Figure 12, the larger λ, the less energy is saved. Thus, if channel error occurs, the energy efficiency should be reevaluated under the new arrival rate λ. In this case, the energy efficiency performed more poorly than that of the unaffected system.



(**a**) Energy efficiency when $N = 10, \gamma = 1$



(**b**) Energy efficiency when $N = 20, \gamma = 3$

Figure 12. Comparisons of node energy efficiency in different λ, γ, ζ, and N

5.4. Discussion

All the experiments must be done under normalized stability conditions: $N\lambda(\beta + \gamma) < 1$. If the service time and the switch-over time are constant, then the maximum number of nodes in a subnet is calculated as follows:

$$Max(N) = [\frac{1}{\lambda(\beta + \gamma)}], \qquad \lambda, \beta, \gamma > 0 \tag{16}$$

Obviously, $Max(N)$ is decreasing with the increment of λ after β and γ adjustment. For example, if $\beta = 9$ slots and $\gamma = 1$ slot, then the maximum number of nodes in the coverage of a RSU is $Max(N) = 1/10\lambda, 0 < \lambda \leq 0.1$, which is decided by λ.

When $N\lambda(\beta + \gamma) \geq 1$, it means the system is oversaturated and ineffective. As a result, the data packets piled up in the nodes will increase in number and the RSU will not be able to transmit them on time> This means that the mean cyclic period, the average waiting time, and the queue length will become enormously high, as shown clearly in Figures 4–9.

If the AP chooses to activate the sleeping option on and turns to sleep, it will not wake up until the sleeping time is expired, even if some nodes are awakened by new packet arrivals. Considering the QoS requirement, the sleeping period of the AP should be less than the maximum latency of the packet, which is related to the moving speed, the packet type, etc.

Nevertheless, by introducing the sleeping factor caused by passive vacation, the calculation errors of performance parameters were reduced from more than 9% to almost 0. Experimental results also verified the correctness and effectiveness of the theoretical analysis model.

6. Conclusions

Polling-based proposals in autonomic wireless communication are meaningful when they also consider QoS performance while dealing with energy savings. Towards this end, PC-S appears as the first solution that theoretically addresses sleep state in the system's mathematical model for the autonomic V2I communication in VANETs and at the same time considers performance. Combined with passive vacation, this paper established a k-limited ($k = 1$) analysis model as an expanding protocol that can be used in VANETs for smart cities by employing the embedded Markov chain theory and the probability generating function. For the first time, the exact expressions of first-order and high-order performance characteristics with the sleeping factor were obtained (i.e., the precise expressions of the mean cyclic period, mean waiting time, and mean queue length are achieved). The influence of the sleep mechanism caused by zero-arrival state on the system performances was also analyzed theoretically. Experiments showed that the system model with sleep state caused by the passive vacation of zero-arrival was more suitable for the real scenes than those without zero-arrival state or sleep state. Furthermore, they showed that zero-arrival state and the following sleep state should not be ignored in the theoretical analysis. Meanwhile, compared with IEEE 802.11p, PC-S was more energy-efficient, regardless of whether the load was light or heavy. The longer the sleeping time of a node without data transmission request, the more energy can be saved , and the less electromagnetic interferences from neighbors is , which is an extra benefit of turning off radio transceivers.

Although energy is not the key factor for OBU because it can be easily charged, for those nodes set by roadsides, their energy should be considered carefully. Even if the sleeping option is closed and the OBUs are allowed to keep idle when there are no transmission requests, the suggested mathematical model is still more satisfactory. This is because it pays particular attention to the passive vacation caused by zero-arrival of nodes that often happens, and their precision is verified.

In order to validate the performance of PC-S in some more realistic environments, ongoing work is aimed at implementing PC-S with communication errors involved in the programmable wireless platforms.

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Appendix A

The generation function of N-dimensional distributions of $\xi_i(n+1)$ is:

$$\begin{aligned}
&G_{i+1}(z_1, z_2, ..., z_i, ..., z_N) = \lim_{n\to\infty} E[\prod_{k=1}^{N} z_k^{\xi_k(n+1)}] \\
&= R_i[\prod_{k=1}^{N} A_k(z_k)]\{\frac{1}{z_i} B_i[\prod_{k=1}^{N} A_k(z_k)][G_i(z_1, ..., z_N) - G_i(z_1, ..., z_N)|_{z_i=0}] \\
&+ G_i(z_1, ..., z_N)|_{z_i=0}\} + S[A_i(z_i)]G_i(0, ..., 0) \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad i = 1, ..., N.
\end{aligned}$$

The expressions of the first derivative of $G_i(\mathbf{z})$ are:

$$g_{i+1}(j) = g_i(j) + \beta_i\lambda_j[1 - G_i(\mathbf{z})|_{z_i=0}] + \gamma_i\lambda_j, \qquad i \neq j \tag{A1}$$

$$g_{i+1}(i) = g_i(i) + \beta_i\lambda_i[1 - G_i(\mathbf{z})|_{z_i=0}] - [1 - G_i(\mathbf{z})|_{z_i=0}] + \gamma_i\lambda_i + \zeta\lambda_i G_i(\mathbf{0}) \tag{A2}$$

Let $G_i^{(0)}$ denote $G_i(\mathbf{z})|_{z_i=0}$, which means the system status when $\xi_i(n) = 0$ at t_n, calculate $\sum_{j=0}^{N} g_{i+1}(j)$, the relationship is given by:

$$[1 - G_i^{(0)}] = \frac{\sum_{j=1}^{N} \gamma_j\lambda_j + \zeta\lambda_i G(\mathbf{0})}{1 - \sum_{j=1}^{N} \beta_j\lambda_j}.$$

Define θ as the mean cyclic period that the average time the AP takes to serve all the demanding nodes for a round. Assume the system is symmetrical, i.e., $\lambda_i = \lambda$, $\beta_i = \beta$ $(i = 1, ..., N)$, then we have:

$$\lambda\theta_{PC-S} = \frac{\sum_{j=1}^{N} \gamma_j\lambda_j + \zeta\lambda_i G(\mathbf{0})}{1 - \sum_{j=1}^{N} \beta_j\lambda_j} = \frac{\sum_{j=1}^{N} \gamma\lambda + \zeta\lambda G(\mathbf{0})}{1 - \sum_{j=1}^{N} \beta\lambda} \tag{A3}$$

Further, the expressions of the second derivative of $G_{i+1}(\mathbf{z})$ are:

$$\begin{aligned}
&g_{i+1}(j, l) = \lim_{z_1,\cdots,z_i,\cdots,z_N\to 1} \frac{\partial^2 G_{i+1}(\mathbf{z})}{\partial z_j \partial z_l} \\
&= R''(1)\lambda^2 + \lambda^2\gamma + [B''(1)\lambda^2 + 2\lambda^2\beta\gamma + \lambda^2\beta][1 - G_i^{(0)}] + (\lambda\beta + \lambda\gamma)[g_i(j) + g_i(l)] \\
&-\lambda\beta[g_{i0}(j) + g_{i0}(l)] + g_i(j, l) \qquad\qquad i \neq j \neq l,\ j = 1, 2, ..., N
\end{aligned} \tag{A4}$$

$$\begin{aligned}
&g_{i+1}(j, i) = \lim_{z_1,\cdots,z_i,\cdots,z_N\to 1} \frac{\partial^2 G_{i+1}(\mathbf{z})}{\partial z_j \partial z_i} \\
&= R''(1)\lambda^2 + \lambda^2\gamma + [B''(1)\lambda^2 + 2\lambda^2\beta\gamma + \lambda^2\beta - \lambda\beta - \lambda\gamma][1 - G_i^{(0)}] + (\lambda\beta + \lambda\gamma)[g_i(j) + g_i(i)] \\
&-\lambda\beta[g_{i0}(j) + g_{i0}(i)] - g_i(j) + g_{i0}(j) + g_i(j, i) \qquad\qquad i \neq j,\ j = 1, 2, ..., N
\end{aligned} \tag{A5}$$

$$\begin{aligned}
&g_{i+1}(j, j) = \lim_{z_1,\cdots,z_i,\cdots,z_N\to 1} \frac{\partial^2 G_{i+1}(\mathbf{z})}{\partial^2 z_j} \\
&= R''(1)\lambda^2 + A''(1)\gamma + [B''(1)\lambda^2 + A''(1)\beta + 2\lambda^2\beta\gamma][1 - G_i^{(0)}] + 2(\lambda\beta + \lambda\gamma)[g_i(j) + g_{i0}(j)] \\
&+2\lambda\gamma g_{i0}(j) + g_i(j, j) \qquad\qquad i \neq j,\ j = 1, 2, ..., N
\end{aligned} \tag{A6}$$

$$
\begin{aligned}
&g_{i+1}(i,i) = \lim_{z_1,\cdots,z_i,\cdots,z_N\to 1} \tfrac{\partial^2 G_{i+1}(\mathbf{z})}{\partial^2 z_i} \\
&= R''(1)\lambda^2 + A''(1)\gamma + [B''(1)\lambda^2 + A''(1)\beta + 2\lambda^2\beta\gamma - 2\lambda\beta - 2\lambda\gamma + 2][1 - G_i^{(0)}] + 2\lambda\gamma g_{i0}(i) \\
&+2(\lambda\beta + \lambda\gamma)[g_i(i) + g_{i0}(i)] - 2[g_i(i) + g_{i0}(i)] + g_i(i,i) + [S''(1)\lambda^2 + A''(1)\zeta]G_i^{(0)} \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad i = 1,2,\ldots,N
\end{aligned} \tag{A7}
$$

$$
\begin{aligned}
&g_{i+1}(i,l) = \lim_{z_1,\cdots,z_i,\cdots,z_N\to 1} \tfrac{\partial^2 G_{i+1}(\mathbf{z})}{\partial z_i \partial z_l} \\
&= R''(1)\lambda^2 + \lambda^2\gamma + [B''(1)\lambda^2 + 2\lambda^2\beta\gamma + \lambda^2\beta - \lambda\beta - \lambda\gamma][1 - G_i^{(0)}] + (\lambda\beta + \lambda\gamma)[g_i(i) + g_i(l)] \\
&-\lambda\beta[g_{i0}(i) + g_{i0}(l)] - g_i(l) + g_{i0}(l) + g_i(i,l) \qquad\qquad i \neq l,\ l = 1,2,\ldots,N
\end{aligned} \tag{A8}
$$

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