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Sustainable Smart Cities and Smart Villages Research

Edited by

Miltiadis D. Lytras and Anna Visvizi

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Cover image courtesy of Anna Visvizi.

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About the Special Issue Editors

Miltiadis D. Lytras, Ph.D., Research Professor at Deree College—The American College of Greece and Visiting Researcher at Effat University; researcher, editor, lecturer and consultant. Dr. Lytras' expertise covers issues pertinent to the broad field defined by cognitive computing, information systems, technology-enabled innovation, social networks, computers in human behavior, and knowledge management. In his work, Dr. Lytras focuses on bringing together advances in ICT and knowledge management to advance socio-economic sustainability and citizens' wellbeing.

Anna Visvizi, Ph.D., Associate Professor at Deree College—The American College of Greece, Greece and Visiting Researcher at Effat University; researcher, editor, policy advisor and lecturer. Dr. Visvizi's expertise covers issues pertinent to the intersection of politics, economics and ICT, which translates in her research and advisory role in such areas as international safety and security, international collaboration, international organizations (especially the OECD and the EU), smart cities and smart villages, politics and policy of migration, and innovation promotion.

Preface to "Sustainable Smart Cities and Smart Villages Research"

Research on smart cities matures and new interdisciplinary approaches to the study of smart cities are proposed. At the same time, problems pertinent to communities inhabiting rural areas are being addressed, only as part of discussions in contigious fields of research, be it environmental studies, sociology, or agriculture. Even if rural areas and countryside communities have previously been a subject of concern for robust policy frameworks, such as the European Union's Cohesion Policy and Common Agricultural Policy, the concept of 'the village' has been largely absent in the debate. As a result, when advances in sophisticated information and communication technology (ICT) led to the emergence of a rich body of research on smart cities, the application and usability of ICT in the context of a village have remained underdiscussed in the literature.

The idea to launch a concept-driven, practice-based and policymaking-oriented discussion on smart villages was first sketched during the Editors' field research and the realization that depopulation of rural areas and its implications for villages and their inhabitants have several short- and long-term implications, which should be taken very seriously. The follow-up conversations with experts and practitioners from all over the world led to the consolidation of these ideas and them taking the form of research and papers presented in this volume.

The picture featured on the cover of the book depicts the Konitsa bridge, Epeiros, Northern Greece, stretching over the Aoos river. Built in 1870, it enabled travelers to pass over the river safely. Clearly, it is also a masterpiece of engineering and architecture of local craftsmen. Around 160 arched bridges of this kind were built in the greater area of Zagori during the 18th and 19th centuries suggesting the scale of demand. Today, few of these bridges have been preserved as demand dropped substantially with the density of population in the area being only four inhabitants per square kilometer. The case of Zagori is not unique and, as several chapters included in this volume outline, it is imperative to reflect on the implications of progressing depopulation of once thriving areas. Moreover, it is necessary to suggest ways of addressing the complex negative of this process.

Set against this backdrop, this volume delivers on four objectives. It delineates the conceptual boundaries of the concept of 'smart village'. It highlights in which ways 'smart village' is distinct from 'smart city'. It examines in which ways smart cities' research can enrich smart villages research. Finally, it sheds light on the smart village research agenda as it unfolds in European and global contexts.

This book is dedicated to all the elderly people we, the Editors, met and had the opportunity to listen to during our field research in the Greek periphery. Their smiling faces, stories from the past, and not a single word of complaint for the intolerable levels of hardship they go through on a daily basis, serve as key motivation to pursue the research agenda this book outlines.

Miltiadis D. Lytras and Anna Visvizi
Special Issue Editors

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Editorial

It's Not a Fad: Smart Cities and Smart Villages Research in European and Global Contexts

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Abstract: Research on smart cities matures and new interdisciplinary approaches to the study of smart cities are proposed. At the same time, problems pertinent to communities inhabiting rural areas tend to be addressed, as if by the way, i.e., as a part of discussions in neighboring fields of research, be it environmental studies, sociology, or agriculture. Arguably, the concept of 'the village' has been largely absent in the academic debate, even if rural areas and countryside communities have been a subject of concern for robust policy frameworks, such as the European Union's Cohesion Policy and Common Agricultural Policy. As a result, when advances in sophisticated information and communication technology (ICT) led to the emergence of a rich body of research on smart cities, the application and usability of ICT in the context of a village remained underdiscussed in the literature. Through this Special Issue, and the Editors' earlier research on this topic, the Editors hope that the idea of the 'smart village' will be introduced into the debate. Against this backdrop, the objective of this opening review is three-fold: (i) to outline the conceptual boundaries of the term *smart village*, (ii) to highlight the thrust of the challenge inherent in *smart villages research*, and (iii) to shed light on the *smart village research* agenda as it unfolds. The relevance and validity of these claims are supported by references to research submitted to the Special Issue titled "Sustainable Smart Cities and Smart Villages Research".

Keywords: smart city; smart village; smart cities research; smart villages research; ICT; sustainability; best practice sharing; policymaking

1. Introduction

Research on smart cities matures and new interdisciplinary approaches to the study of smart cities are proposed. At the same time, problems pertinent to communities inhabiting rural areas tend to be addressed, as if by the way, i.e., as a part of discussions in neighboring fields of research, be it environmental studies, sociology, or agriculture. Arguably, the concept of 'the village', as an independent subject of inquiry, has been largely absent in the academic debate—even if rural areas and countryside communities have been a subject of concern for robust policy frameworks, such as the European Union's Cohesion Policy and Common Agricultural Policy. As a result, when advances in sophisticated information and communication technology (ICT) have led to the emergence of research on smart cities, the application and usability of ICT in the context of a village remained underdiscussed in the literature. Today, this Special Issue, and related research [1], essentially introduce the idea of the 'smart village' into the debate. Against this backdrop, the objective of this opening review is three-fold: (i) To outline the conceptual boundaries of the term smart village, (ii) to highlight the thrust of the challenge inherent in smart villages research, and (iii) to shed light on the smart village research agenda as it unfolds.

2. The Conceptual Boundaries of the Smart Village

The conceptual boundaries of the smart village are defined by the following assumptions and claims: (i) A village is an ecosystem of a limited size, a community that is driven by specific mechanisms and dynamics that are the product and the outcome of multi-level interaction among all stakeholders. (ii) Smart village is conceptually different that the aggregate construct of a 'rural area' or 'country side'. (iii) A village is conceptually and empirically distinct, and so the question of and corresponding research on the value-added ICT can garner in the space of a village has its own characteristics, different from research on smart cities. (iv) By focusing on a village as a concept ontologically different from that of a city, a way is paved to smart villages research as a field separate from smart cities research. (v) By reifying the village in the analysis, the focus of analysis in smart village research shifts to inhabitants of a given village, be it plural or individual. What follows is that (vi) the delimited research on smart villages employs insights from the debate on ICT, to engage in conceptually-sound, empirically-focused, and ethically-conscious exploration of problems, challenges, and opportunities that villages and their inhabitants incur in the 21st century.

In this view, smart villages research has a very strong pragmatic orientation in that it seeks to diagnose a problem and, by reference to ICT, offer a way of bypassing it. Accordingly, an opportunity is created for research on smart villages to go beyond the ICT-hype and embark on a problem-driven, solution-oriented, pragmatic research. In this way, research on smart villages stands to avoid the loop of 'normative bias' [1] characteristic to considerable body of smart cities research. Indeed, all too frequently, research on smart cities builds upon the assumption that smart city services will contribute to wellbeing and quality of life of cities' inhabitants, thus disregarding the basic fact that the assumed users of services that advances in ICT make feasible are unwilling or unable to use them [2]. If the sustainability of research on smart cities is a function of its relevance and usability, then more pragmatism needs to be induced into this research [2]. As research on smart villages is still nascent, and its disciplinary origins different than those of smart cities, the prospect is that, by focusing first, on problems and challenges villages face, and only afterwards on what ICT can offer, the temptation to do the opposite might be prevented.

3. Challenges, Opportunities and the Value-Added of Smart Villages Research

The focus of this Special Issue has a pragmatic background, derived from the Guest Editors' field research in the Greek province. The outcomes of that research suggested that Greek villages (frequently considered outspokenly beautiful, by all international standards) are depopulating at an alarming pace and that, if no action to reverse that tendency is taken today, there will be no villages in 10 years from now. The relevance of this topic across the Europe and elsewhere has been confirmed by the number of submissions to this Special Issue, and the need to launch another one. Moreover, the topicality of issues covered by the initial call for papers has been reaffirmed by a similar initiative launched nearly concurrently by the members of the European Parliament. This initiative led to the signing of the Bled Declaration for a Smarter Future of the Rural Areas in EU in April 2018 [3]. Hopefully, the voices of academia and policymakers will merge now to mutually reinforce each other, for the sake of villages and the wellbeing of their inhabitants.

Clearly, research on smart villages is not geared solely toward addressing the problem and implications of decreasing populations in villages. However, depopulation seems to be the most poignant challenge of all as it bears several implications. This needs to be addressed as soon as possible if their adverse outcomes are to be preempted. The temporal dimension in the discussion on smart villages is vital; it highlights the issues at stake and the urgency of the matter. The list of challenges and issues is long, but they all form a logical thread. The following is a brief typology of issues and challenges, and the corresponding urgency of action (see Table 1).

Table 1. Smart villages: typology of challenges and the corresponding urgency of action.

	Temporal Dimension	Status of the Challenge	The Thrust of the Challenge	Prescribed Action	Type of Action
1	Short-term	Emergency	Question of life and death, incl. safety and security	Action needed at this moment	What smart services, provided by whom, how and at what cost could be provided to ease the situation?
2	Mid-term	Urgent	Question of wellbeing and quality of life	Planning and action need to begin today, action needed today	
3	Long-term	Very important	Question of cultural heritage, governability, the cost of inaction	Planning needs to begin today, action needed in the near-future	

Short-term challenges: Emergency, i.e., action is needed at this moment: Depopulating villages tend to be inhabited by elderly people, usually single, in need of medical care, help with cooking and food preparation, and simple company. These people tend to be deprived of the means for living, and can hardly use electronic devices (should internet and electricity be available in their village). The nature of this challenge goes beyond the question of wellbeing and quality of life. It is in fact a question of life and death; a question of these citizens' safety. Risks to their safety include the risk of burglary, assault, fire, and flooding. What smart services, provided by whom, how and at what cost could be provided to ease the situation?

Mid-term challenges: Urgent, i.e., planning and action need to begin today, action is needed today: Depopulating villages frequently lack basic infrastructure, such as roads, reliable electricity grids, doctor, school, affordable groceries. This affects the wellbeing and quality of life in villages for its current inhabitants. It also creates disincentives for possible newcomers, and incentives for current inhabitants to leave. What smart services, provided by whom, how and at what cost could be provided to ease the situation?

Long-term challenges: Important, i.e., planning needs to begin today, action is required in the near-future: Depopulating villages frequently embody artefacts of inimitable cultural heritage, in terms of architecture, tradition (rites, habits), and oral history. After a village's current population is gone, so is that cultural heritage. Long-term implications of increasingly depopulated villages and rural areas highlight the question of the state's ability to exert its control over those areas. Practice suggests that organized crime tends to thrive under those conditions. As long-term implications are diverse, the bigger question here is what the cost of today's inaction is, and what can be done today to limit that cost tomorrow. Again, the question is: What smart services, provided by whom, how and at what cost could be provided to ease the situation?

Arguably, the downside of rapid urbanization is depopulation of rural areas. Life in cities seems to bear greater promise than in the countryside, and so the romanticized image of pastoral village life fades. Certainly, the problem of depopulation of rural areas has several facets worldwide—it displays diverse dynamics, and clearly several country- or region-specific factors contribute to its evolution. In other words, research on smart villages should be geared to questions of declining quality of life and wellbeing, the emergence of risks to safety and security, growing inequalities, and other externalities in the form of strain on cultural heritage, environment, the cost of non-growth, and lost opportunities in general. In this view, the unique value proposition inherent in the concept of smart village is that it seeks to do much more than to showcase how sophisticated ICT can be employed in a village context. Research on smart villages is meant to address a variety of issues and problems, which inhabitants of villages face in the 21st century. Notably, these issues and problems are qualitatively different than those cities' inhabitants experience daily. This research is meant to trigger debate that will lead to evidence-based coherent strategies and action-plans designed to address short-, medium- and long-term challenges that villages face.

4. How Research on Smart Cities Can Fertilize Research on Smart Villages?

As argued elsewhere significant differences exist between the research on smart cities and smart villages [1], yet both fields can benefit from each other. This review seeks to delineate the conceptual boundaries of the concept, and shed light on the corresponding field of research, while highlighting issues and topics that should be prioritized in research and policymaking. The twenty-four papers included in this Special Issue offer a good insight into which directions the research on smart villages might follow in the future. These issues and topics include:

- How to pre-empt nascent risks and threats in villages by mapping, planning, and managing the development of villages and rural areas?
- How to address challenges to wellbeing and quality of life in villages?
- What is the value-added of the big data paradigm in the smart village context and how to exploit this value responsibly?
- How to maintain and promote environmental sustainability in the smart village context?
- How to promote socio-economic sustainability in the smart village context?
- How to account for and conceptualize of transformation and change in the smart village context?

The following sections details how papers included in this volume add to the debate and how smart villages research may benefit from them. In the final section the emerging issues are outlined.

4.1. How to Pre-Empt Nascent Risks and Threats in Villages by Mapping, Planning and Managing the Development of Villages and Rural Area?

These questions, still in connection to cities and urban areas, have been addressed in detail by several authors contributing to this Special Issue.

Patrik Silva and Lin Li, in their paper titled "Mapping Urban Expansion and Exploring Its Driving Forces in the City of Praia, Cape Verde, from 1969 to 2015" [4], pay attention to the impact of urban expansion on the natural environment. By examining the case of Praia, the capital city of Cape Verde, over the period 1969–2015, their paper offers a very detailed insight into how urban planning and policy making can balance urban economic development and natural resource protection in locations as specific as that of the city of Praia.

The implications of "Accelerated Urban Expansion in Lhasa City and the Implications for Sustainable Development in a Plateau City' are discussed by Wei Tang, Tiancai Zhou, Jian Sun, Yurui Li and Weipeng Li [5]. They explore the question of challenges urbanization causes for a plateau city of Lhasa. By examining the determinants of the urban development process, the authors provide insightful suggestions for urban management and planning for Lhasa.

Elmira Jamei, Michael Mortimer, Mehdi Seyedmahmoudian, Ben Horan and Alex Stojcevski focus on the application of virtual reality (VR) solutions in the context of smart cities [6]. In their paper, titled "Investigating the Role of Virtual Reality in Planning for Sustainable Smart Cities", the authors review the capacity of VR to address current challenges in creating, modelling, and visualizing smart cities through material modelling and light simulation in a VR environment. Their study can assist urban planners, stakeholders, and communities to further understand the roles of planning policies in creating a smart city, particularly in the early design stages.

4.2. How to Address Challenges to Wellbeing and Quality of Life in Villages?

Kevin Dean, Claudia Trillo and Erik Bichard, in their article titled "Assessing the Value of Housing Schemes through Sustainable Return on Investment: A Path towards Sustainability-Led Evaluations?", look closely at the link between environmental and social sustainability in urban spaces. From this perspective they look at the issue of housing in cities [7]. To this end, they demonstrate how sustainable return on investment can successfully describe and analyze a range of externalities, related to the sustainable value generated by social housing regeneration schemes.

José Maria Codosero Rodas, José Manuel Naranjo Gómez, Rui Alexandre Castanho and José Cabezas, in their paper titled "Land Valuation Sustainable Model of Urban Planning Development: A Case Study in Badajoz, Spain", explain that urban planning development process in urban territories has multiple consequences, not only in spatial structure but also in land valuation patterns [8]. The economic value of land encompassed in municipal planning, which is associated with a certain urbanized use, increases as the planning processes evolve over these lands. The land valuation model they develop may be of use also in the context of smart villages research as a piece and parcel of a greater strategy aimed at boosting development and growth in a given village.

Jin-Wook Lee and Jong-Sang Sung in their paper titled "Conflicts of Interest and Change in Original Intent: A Case Study of Vacant and Abandoned Homes Repurposed as Community Gardens in a Shrinking City, Daegu, South Korea", take a very rare view of the issue of gardens in the context of a smart city [9]. By focusing on an urban policy designed to revive South Korea's shrinking cities, vacant residential structures are being demolished and the resulting empty plots transformed into public spaces. The authors examine this process through the lens of conflicts it ignites. They argue that to overcome problems caused by rivalry and discord, the following actions are required: A change in perspective among policy practitioners; a governance structure that consists of a public/private/community partnership; consensus among community members; and equitable welfare through programs based on inclusivity and public interest.

Kwok Tai Chui, Wadee Alhalabi, Sally Shuk Han Pang, Patricia Ordóñez de Pablos, Ryan Wen Liu and Mingbo Zhao in their work titled "Disease Diagnosis in Smart Healthcare: Innovation, Technologies and Applications", argue that smart city implies a global vision that merges artificial intelligence, big data, decision making ICT, and the internet-of-things (IoT). In their paper, disease diagnosis in smart healthcare is reviewed and examined in the context of smart cities [10].

4.3. What Is the Value-Added of the Big Data Paradigm in the Smart Village Context and How to Exploit This Value Responsibly?

Shiann Ming Wu, Tsung-chun Chen, Yenchun Jim Wu and Miltiadis Lytras, in their paper titled "Smart Cities in Taiwan: A Perspective on Big Data Applications", examine the development of smart cities in Taiwan. The authors offer a detailed insight into how big data may be useful in this regard [11].

From a different angle, by reference to Business Performance Management (BPM) technologies, Bram Pieket Weeserik and Marco Spruit, in their paper "Improving Operational Risk Management Using Business Performance Management Technologies", make a case for the use of big data to manage operational risk. They argue that several combined technologies, including work flow, data warehousing, (advanced) analytics, reporting, and dashboards, can be integrated with an organization's planning and control cycle and related to strategic objectives, thus substantially easing the operational risk [12].

Radek Doskočil and Branislav Lacko, in their paper "Risk Management and Knowledge Management as Critical Success Factors of Sustainability Projects" examine the key aspects of sustainability projects, namely advanced risk management and project knowledge. The authors research, based on a thorough examination of projects implemented in the Czech Republic, confirms the arguments outlined in the previous paper, and thus allows to make a case for advanced risk analysis methods [13].

Lihuan Guo, Dongqiang Guo, Wei Wang, Hongwei Wang and Yenchun Jim Wu, look into crowdfunding [14]. In their paper titled "Distance Diffusion of Home Bias for Crowdfunding Campaigns between Categories: Insights from Data Analytics", the authors examine online crowdfunding campaigns and specifically investors' behavior as seen from the home bias perspective. The value of this study for the field of research on smart villages is that since it provides a theoretical basis to examine online investment and to improve the promotion of crowdfunding campaigns, it could be of great use for smart village oriented crowdfunding campaigns.

4.4. How to Maintain and Promote Environmental Sustainability in the Smart Village Context?

These four papers that address the question of environmental sustainability and/or energy efficiency focus predominantly on cities/urban areas. However, issues that each of these papers dwells on and research findings can well be applicable in the smart villages context, be at the micro-level of increasing energy efficiency of public utility buildings, decreasing energy cost for individual consumers or improving the overall environmental profile of a municipality.

Specifically, Samuel de Alencar Bezerra, Francisco Jackson dos Santos, Plácido Rogerio Pinheiro and Fábio Rocha Barbosa in their article titled "Dynamic Evaluation of the Energy Efficiency of Environments in Brazilian University Classrooms Using DEA", focus on the question of whether energy efficiency of indoor spaces can be improved [15]. By the same token, Jaclason M. Veras, Igor Rafael S. Silva, Plácido R. Pinheiro and Ricardo A. L. Rabêlo, examine the question of consumers' energy consumption profiles in view of minimizing the electricity costs for the final consumers [16]. In their paper titled 'Towards the Handling Demand Response Optimization Model for Home Appliances", the authors suggest that decrease in the electricity cost is possible.

In their paper "Digitalization and Environmental Aims in Municipalities", Tina Ringenson, Mattias Höjer, Anna Kramers and Anna Viggedal examine how digitalization can aid municipalities to achieve environmental aims. By reference to two EU directives that are relevant for municipal environmental goals, the authors suggest how to reach the directives' goals and hence attain the goal of more environmentally savvy performance at the municipality level. Even if, as the authors note, much more needs to be done to encourage dialogue among municipalities and ICT developers, the content of the paper is of particular relevance for smart villages research [17].

From a different perspective, Chien-wen Shen, Phung Phi Tran and Pham Thi Minh Ly "Chemical Waste Management in the U.S. Semiconductor Industry", highlight the problem of managing high-purity organic and inorganic compounds involved in manufacturing of semiconductors. As they note, the outcomes of their study are of great value for city governments as they try to employ suitable policies to reduce the negative impacts of the chemical waste from regional semiconductor companies [18].

4.5. How to Promote Socio-Economic Sustainability in the Smart Village Context?

The question of socio-economic sustainability in a smart village context is perhaps one of the key issues that define the prospect of survival of a given village community. More research pertinent to this question is needed if the general question of smart villages sustainability is to be effectively addressed. At the moment, the Special Issue reviewed here features three papers that deal with that imperative, either directly, as in the case of sustainable farming in Spain, or indirectly, by exploring different forms of business organization, such as social enterprise, or by rethinking the spatial organization of production. Each of the papers discussed briefly beneath offers an important insight of great value to the smart villages debate.

Carmen De-Pablos-Heredero, Jose Luis Montes-Botella and Antón García-Martínez in their paper titled "Sustainability in Smart Farms: Its Impact on Performance" explore the question of sustainability in farms. Their research suggests that farms face tremendous challenge of failing sustainability. By reference to selected case-studies from Spain, the authors suggest how the challenge can be bypassed [19]. Certainly, smart villages and the production process is not only about farming. Social enterprises might be one of the alternatives to employment suitable in the smart villages context.

Yung Chang Wu, Yenchun Jim Wu and Shiann Ming Wu examine social enterprises and their role in economic development in Taiwan [20]. By showcasing the intricacies of social enterprises, the paper titled "Development and Challenges of Social Enterprises in Taiwan—From the Perspective of Community Development", may in fact offer useful cues into how to transpose the concept of social enterprise into the context of smart village.

Yizhou Wu, Peilei Fan and Heyuan You, in their paper titled "Spatial Evolution of Producer Service Sectors and Its Influencing Factors in Cities: A Case Study of Hangzhou, China", examine the connection between location changes and the motives of producer service sectors in cities. Given the rapid development of producer service sectors in developing countries, this study examines changes in the distribution of producer service sectors over the past decade and factors influencing them in a case study using the city of Hangzhou in China. Results show that Hangzhou's producer service sector is still mainly concentrated in the central business district (CBD). However, a distinct trend of diffusion to suburban areas was observed, which formed several secondary clusters on the periphery of the city [21].

4.6. How to Account for and Conceptualize Transformation and Change in the Smart Village Context?

Urban space is subject to continuous transformations. Advances in ICT and the resulting smart cities research are part of these transformations as they influence both the city space and its inhabitants, as well as, unavoidably, the institutions of social interaction.

José Luis Carrasco-Sáez, Marcelo Careaga Butter and María Graciela Badilla-Quintana explore the transition of cities towards what they term 'smart human cities'. Their paper, "The New Pyramid of Needs for the Digital Citizen: A Transition towards Smart Human Cities", examines how the cultural transition towards knowledge society impact citizens' expectations regarding what a given city should provide. The authors argue that this transition is characterized by a growing diversification of the use of technologies in most of the economic, political, educational, social, and cultural activities of different human groups [22].

Jintao Li, Yuanyuan Yang and Ning Jiang, in their paper titled "County-Rural Transformation Development from Viewpoint of "Population-Land-Industry" in Beijing-Tianjin-Hebei Region under the Background of Rapid Urbanization", the authors focus explicitly on the question of rural transformation and its implications. They examine the spatial-temporal characteristics of county-rural transformation development through drawing into the transformation degree (TD) and coordination degree (CD) from the viewpoint of "population-land-industry" (PT-IT-LT) in the Beijing-Tianjin-Hebei region [23].

Libang Ma, Xiaodong Guo, Yaya Tian, Yongli Wang and Meimei Chen discuss the outcomes of a "Micro-Study of the Evolution of Rural Settlement Patterns and Their Spatial Association with Water and Land Resources: A Case Study of Shandan County, China". They argue that the balance between population, and water and land resources is an important part of regional sustainable development. It is also significant for the ecological civilization in China and can help solve 'the three rural issues' (agriculture, countryside and farmers) in China. In their paper, they examine the temporal-spatial differentiation of rural settlement patterns in Shandan County of Hexi Corridor and study the spatial association between rural settlements and water-land resources [24].

Hege Westskog, Tanja Winther and Marianne Aasen, in their paper titled "The Creation of an Ecovillage: Handling Identities in a Norwegian Sustainable Valley", explore the question of the making of an ecovillage. As the authors argue "the concept of ecovillage is continuously refined both internally on an individual level and in the village, and in mainstream society. At stake is the question of ecovillage identity and what this should entail" [25].

The practice-driven discussion in the Special Issue reviewed here culminates in the paper titled "Smart Villages: Comprehensive Review of Initiatives and Practices". The authors, Veronika Zavratnik, Andrej Kos and Emilija Stojmenova Duh, map the most recent initiatives geared toward implementing the concept of smart village in the EU context [26].

5. Smart Villages Research: Defining the Research Agenda

As the body of research on smart cities matures and gradually displays its own methodological and research toolkit, a very specific set of questions is subject to academic debate. Even if, what we term, an interdisciplinary turn in the research on smart cities is under way [1,3], and paves the way toward more interdisciplinary approaches in smart cities research, this research represents a relatively well-delineated field. To retain its sharpness, relevance and usability, a careful reflection on the research agenda is needed today. Indeed, Miltiadis Lytras and Anna Visvizi, in their paper titled "Who Uses Smart City Services and what to Make of It: Toward Interdisciplinary Smart Cities Research", make a case for interdisciplinary smart cities research. The authors look at the smart cities debate from the complex perspective of, on the one hand, citizens' awareness of applications and solutions considered 'smart' and, on the other hand, their ability to use these applications and solutions. Drawing from the outcomes of their empirical research, the authors argue that more pragmatism needs to be induced in smart cities research if its findings are to remain useful and relevant for all stakeholders involved [2].

In this context, smart villages research is a newcomer, that has the option to bypass the weaknesses that are specific to smart cities research. The six issue areas that the papers included in this Special Issue explore do not exhaust the topic. Table 2 offers an overview of these issues, and demonstrates that these should always be seen as a function of the specific challenge at hand and its urgency. Similarly, Table 2 outlines that a variety of ICT-enhanced ways of addressing a given challenge may exist, yet, there is no *one size fits all* solution. Policies and strategies need to be evidence-based and coherent, ye, different, actors and stakeholders will deal with them differently. Responses will vary depending on the issue area. Ethical considerations will have to be taken into account too. Overall, the so defined field of smart villages research is complex and fertile.

Table 2. Smart villages research: The emerging research agenda.

<table>
<tr><th>Nature of the Challenge</th><th>Key Research Questions</th><th>ICT-Enhanced Strategies</th><th>Policy-Frameworks and Strategies</th></tr>
<tr><td rowspan="2">Questions of life and death</td><td>How do we pre-empt nascent risks and threats in villages by mapping, planning and managing the development of villages and rural areas?</td><td rowspan="6">big data, data analytics, data mining, sensors, virtual reality, augmented reality, 5G technologies</td><td>dialogue and evidence-based policymaking</td></tr>
<tr><td>How do we address challenges to wellbeing and quality of life in villages?</td><td>actors/stakeholders</td></tr>
<tr><td rowspan="2">Questions of wellbeing and quality of life</td><td>What is the value added of big data in smart village context and how do we exploit this value responsibly?</td><td>sources of funding</td></tr>
<tr><td>How do we maintain and promote environmental sustainability in the smart village context?</td><td>ethical dimension</td></tr>
<tr><td rowspan="2">Questions of preservation of cultural heritage, governability, cost of inaction</td><td>How do we promote socio-economic sustainability in smart village context?</td><td>data analytics</td></tr>
<tr><td>How do we account for and conceptualize of transformation and change in the smart village context?</td><td>emerging issues</td></tr>
</table>

Advances in ICT, including big data, data analytics, data mining, sensors, virtual reality, augmented reality, 5G technologies, etc., redefine the landscape of our daily life. They have profound impact on how we live, work, spend our free time, travel. They influence the way we receive our medical treatment, the degree of safety we experience (not only online), the way we communicate, etc. Arguably, this snapshot of applications will be equally relevant in villages too. The concept of the smart village and, indeed, the smart village research agenda, goes beyond the techno-hype. Research on smart villages derives from a genuine concern for the fate of villages, be it in Europe or elsewhere, and their inhabitants. It builds on the conviction that ICT may be a part of greater strategies aimed at addressing challenges and problems villages and their inhabitants face on a daily basis. Smart villages research reifies the village and its inhabitants as an independent subject of research, ontologically distinct from smart city. Smart villages research draws on the experience and body of findings pertinent to smart cities research. At the same time, it benefits from fields largely irrelevant in debates on smart cities, such as farming and agriculture, to mention just the most obvious ones.

The excellent contributions from all over the world included in this Special Issue highlight diverse issues and topics that form the evolving fields of smart cities and smart village research. Thanks to this Special Issue, a substantial streamlining of research on smart cities has been promoted, while the concept of smart villages, smart villages research focus and smart villages research agenda have been delineated. Today, the imperative is to encourage research geared toward developing smart villages research own sound methodological and conceptual toolkit apt to explore issues and challenges villages and their inhabitants face. It's not a fad. These challenges and problems are real.

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References

1. Visvizi, A.; Lytras, M.D. Rescaling and refocusing smart cities research: From mega cities to smart villages. *J. Sci. Technol. Policy Manag.* **2018**, *9*, 134–145. [CrossRef]
2. Lytras, M.D.; Visvizi, A. Who Uses Smart City Services and What to Make of It: Toward Interdisciplinary Smart Cities Research. *Sustainability* **2018**, *10*, 1998. [CrossRef]
3. European Commission, European Parliament. *BLED DECLARATION for a Smarter Future of the Rural Areas in EU*; European Commission: Bled, Slovakia, 2018; Available online: http://pametne-vasi.info/wp-content/uploads/2018/04/Bled-declaration-for-a-Smarter-Future-of-the-Rural-Areas-in-EU.pdf (accessed on 29 July 2018).
4. Silva, P.; Li, L. Mapping Urban Expansion and Exploring Its Driving Forces in the City of Praia, Cape Verde, from 1969 to 2015. *Sustainability* **2017**, *9*, 1434. [CrossRef]
5. Tang, W.; Zhou, T.; Sun, J.; Li, Y.; Li, W. Accelerated Urban Expansion in Lhasa City and the Implications for Sustainable Development in a Plateau City. *Sustainability* **2017**, *9*, 1499. [CrossRef]
6. Jamei, E.; Mortimer, M.; Seyedmahmoudian, M.; Horan, B.; Stojcevski, A. Investigating the Role of Virtual Reality in Planning for Sustainable Smart Cities. *Sustainability* **2017**, *9*, 2006. [CrossRef]
7. Dean, K.; Trillo, C.; Bichard, E. Assessing the Value of Housing Schemes through Sustainable Return on Investment: A Path towards Sustainability-Led Evaluations? *Sustainability* **2017**, *9*, 2264. [CrossRef]
8. Codosero Rodas, J.; Naranjo Gómez, J.; Castanho, R.; Cabezas, J. Land Valuation Sustainable Model of Urban Planning Development: A Case Study in Badajoz, Spain. *Sustainability* **2018**, *10*, 1450. [CrossRef]
9. Lee, J.; Sung, J. Conflicts of Interest and Change in Original Intent: A Case Study of Vacant and Abandoned Homes Repurposed as Community Gardens in a Shrinking City, Daegu, South Korea. *Sustainability* **2017**, *9*, 2140. [CrossRef]
10. Chui, K.; Alhalabi, W.; Pang, S.; Pablos, P.; Liu, R.; Zhao, M. Disease Diagnosis in Smart Healthcare: Innovation, Technologies and Applications. *Sustainability* **2017**, *9*, 2309. [CrossRef]
11. Wu, S.; Chen, T.; Wu, Y.; Lytras, M. Smart Cities in Taiwan: A Perspective on Big Data Applications. *Sustainability* **2018**, *10*, 106. [CrossRef]
12. Pieket Weeserik, B.; Spruit, M. Improving Operational Risk Management Using Business Performance Management Technologies. *Sustainability* **2018**, *10*, 640. [CrossRef]
13. Doskočil, R.; Lacko, B. Risk Management and Knowledge Management as Critical Success Factors of Sustainability Projects. *Sustainability* **2018**, *10*, 1438. [CrossRef]
14. Guo, L.; Guo, D.; Wang, W.; Wang, H.; Wu, Y. Distance Diffusion of Home Bias for Crowdfunding Campaigns between Categories: Insights from Data Analytics. *Sustainability* **2018**, *10*, 1251. [CrossRef]

15. de Alencar Bezerra, S.; Jackson dos Santos, F.; Rogerio Pinheiro, P.; Rocha Barbosa, F. Dynamic Evaluation of the Energy Efficiency of Environments in Brazilian University Classrooms Using DEA. *Sustainability* **2017**, *9*, 2373. [CrossRef]
16. Veras, J.; Silva, I.; Pinheiro, P.; Rabêlo, R. Towards the Handling Demand Response Optimization Model for Home Appliances. *Sustainability* **2018**, *10*, 616. [CrossRef]
17. Ringenson, T.; Höjer, M.; Kramers, A.; Viggedal, A. Digitalization and Environmental Aims in Municipalities. *Sustainability* **2018**, *10*, 1278. [CrossRef]
18. Shen, C.; Tran, P.; Minh Ly, P. Chemical Waste Management in the U.S. Semiconductor Industry. *Sustainability* **2018**, *10*, 1545. [CrossRef]
19. De-Pablos-Heredero, C.; Montes-Botella, J.; García-Martínez, A. Sustainability in Smart Farms: Its Impact on Performance. *Sustainability* **2018**, *10*, 1713. [CrossRef]
20. Wu, Y.; Wu, Y.; Wu, S. Development and Challenges of Social Enterprises in Taiwan—From the Perspective of Community Development. *Sustainability* **2018**, *10*, 1797. [CrossRef]
21. Wu, Y.; Fan, P.; You, H. Spatial Evolution of Producer Service Sectors and Its Influencing Factors in Cities: A Case Study of Hangzhou, China. *Sustainability* **2018**, *10*, 975. [CrossRef]
22. Carrasco-Sáez, J.; Careaga Butter, M.; Badilla-Quintana, M. The New Pyramid of Needs for the Digital Citizen: A Transition towards Smart Human Cities. *Sustainability* **2017**, *9*, 2258. [CrossRef]
23. Li, J.; Yang, Y.; Jiang, N. County-Rural Transformation Development from Viewpoint of "Population-Land-Industry" in Beijing-Tianjin-Hebei Region under the Background of Rapid Urbanization. *Sustainability* **2017**, *9*, 1637. [CrossRef]
24. Ma, L.; Guo, X.; Tian, Y.; Wang, Y.; Chen, M. Micro-Study of the Evolution of Rural Settlement Patterns and Their Spatial Association with Water and Land Resources: A Case Study of Shandan County, China. *Sustainability* **2017**, *9*, 2277. [CrossRef]
25. Westskog, H.; Winther, T.; Aasen, M. The Creation of an Ecovillage: Handling Identities in a Norwegian Sustainable Valley. *Sustainability* **2018**, *10*, 2074. [CrossRef]
26. Zavratnik, V.; Kos, A.; Stojmenova Duh, E. Smart Villages: Comprehensive Review of Initiatives and Practices. *Sustainability* **2018**, *10*, 2559. [CrossRef]

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Who Uses Smart City Services and What to Make of It: Toward Interdisciplinary Smart Cities Research

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Abstract: As research on smart cities garners increased attention and its status consolidates as one of the fanciest areas of research today, this paper makes a case for a cautious rethink of the very rationale and relevance of the debate. To this end, this paper looks at the smart cities debate from the perspectives of, on the one hand, citizens' awareness of applications and solutions that are considered 'smart' and, on the other hand, their ability to use these applications and solutions. Drawing from a detailed analysis of the outcomes of a pilot international study, this paper showcases that even the most educated users of smart city services, i.e., those arguably most aware of and equipped with skills to use these services effectively, express very serious concerns regarding the utility, safety, accessibility and efficiency of those services. This suggests that more pragmatism needs to be included in smart cities research if its findings are to remain useful and relevant for all stakeholders involved. The discussion in this paper contributes to the smart cities debate in three ways. First, it adds empirical support to the thesis of 'normative bias' of smart cities research. Second, it suggests ways of bypassing it, thereby opening a debate on the preconditions of sustainable interdisciplinary smart cities research. Third, it points to new avenues of research.

Keywords: smart cities; 'normative bias' of smart cities research; sustainable development; privacy; services; smart villages; innovation clusters; innovation networks; data protection; value adding services; international technology transfer

1. Introduction

Even though over the past few decades, smart cities research has transformed into a multidisciplinary field, housing a variety of domains and disciplines, it is still heavily based on computer science and engineering, with an explicit focus on how technological advances may be applied in urban spaces. As the body of literature on smart cities has developed, novel issues have been brought to the analysis, and new uses of technology have been proposed. Given the apparent relevance and usability of the findings produced in the field, and thus, the implicit policy-making potential that is inherent in the smart cities debate, it has been embraced by policy-makers at influential fora, such as the United Nations (UN), the European Union (EU), and the Organization for Economic Co-operation and Development (OECD). As a result, the status of smart cities research has consolidated as one of the fanciest research areas today.

Whereas, generally, increased interest in a given research problem indicates its potential to enhance our exploratory and explanatory capacities, this article makes a case for a cautious rethink of the very foundations and rationale behind smart cities research. Owing to its origins, smart cities research remains dominated by insights from broadly-conceived computer science and engineering. Clearly, however, it naturally lends itself to interdisciplinary (using insights and methods from more than one discipline) and multidisciplinary (using insights from different disciplines in parallel, not in conjunction) [1] approaches and strategies. Both require conceptual precision if research outcomes are to be valid and usable. Above all, attempts to explore a field as complex as that of smart cities requires questions about the ontology (what is that that exists) and epistemology (how we know about it) to be seriously considered. In contemporary smart cities research, this particular plea has very practical implications. These can be divided into two groups. On one hand, there is a considerable body of literature offering a detailed account of the uses and applications of highly sophisticated information and communication technologies (ICT) in urban contexts [2–5]. On the other hand, an equally vibrant debate has emerged around issues and topics more frequently associated with social sciences and humanities [6–8].

The challenge is that research originating in humanities and social sciences tends to reduce the centrality of ICT in smart cities research and, therefore, the depth and breadth of implications that emerge at the intersection of innate social problems and ICT in urban space remain underexplored. At the same time, the ICT-oriented literature [9–11] frequently resorts to, what has been termed elsewhere as, the 'normative bias' of smart cities research [12]. That is, owing to its disciplinary origins and, hence, respective authors' literacy in advanced sophisticated technologies, this body of research tends to focus on the promise that sophisticated technological advances hold for urban space at the expense of the basic consideration of factors that hamper and/or facilitate their implementation. Attempts at dwelling at this intersection exist [13–16]. Nevertheless, much more needs to be done to fully exploit it and hence, promote sustainable interdisciplinary smart cities research [17–21].

Against this backdrop, this paper looks at the smart cities debate from the complex perspective of, on one hand, citizens' awareness of applications and solutions considered 'smart' and on the other hand, their ability to use these applications and solutions. The discussion in this paper adds to the smart cities debate in two ways. First, it adds empirical support to the thesis of 'normative bias' of smart cities research. Second, it suggests ways of bypassing it and thereby, paves the way towards sustainable interdisciplinary smart cities research. To accomplish this, a multidimensional survey was constructed. It was preceded by a smaller international pilot study aimed at streamlining the foci of the larger survey. This article presents the outcomes of that pilot survey to make a case that the end users' awareness of and ability to use applications and solutions considered 'smart' in urban space are not to be taken for granted.

Indeed, the discussion in this paper highlights that even the most educated users of smart city services, i.e., those arguably most aware of and equipped with skills to use these services effectively, express very serious concerns regarding the utility, safety, accessibility and efficiency of those services. This, in turn, suggests that more pragmatism needs to be included in smart city research if its findings are to remain useful and relevant for all stakeholders involved. Against the backdrop of a novel typology of smart city services users, is argued that the value added from smart cities research is a function of the end users, i.e., citizens', ability to use the opportunities that advances in ICT bring. This includes a distinct set of skills and a particular mind-set, as well as, factors as trivial and basic as the existence of basic infrastructure, including, not only Wi-Fi, but also electricity, devices, etc.

The remainder of this paper is structured as follows. Section 2 outlines the research methodology pertaining to the survey and introduces the research model developed to pursue this study. Section 3 presents the outcomes of the survey. The key findings are discussed in Section 4. Conclusions and directions for future research are detailed in Section 5.

2. Research Methodology

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

- Is it possible to establish links between different user profiles and their abilities to use certain clusters of smart city services/applications?
- How different users of smart city services/applications perceive them and the value that they add?
- How important for smart city efficiency are questions and concerns about security, privacy, ethics and others?

- Which are the examples of good practices of smart city services based on associated and perceived value from users?
- What are the perceptions of smart city users regarding the impacts of advanced ICT on the quality, reliability and sustainability of smart city infrastructure?
- What are the sustainability and policy-making implications for an evolutionary maturity model of smart city research?

To address these research objectives, a survey was developed (see [22]). This study discusses the sample collected in the pilot stage of this study. At that point, 102 responses from very clearly defined target focus groups of respondents inhabiting 28 countries had been collected. The focus group included highly educated respondents who were likely to have used smart city services over the past year. The hypothesis behind this definition of our target group was that presumably there is a positive direct correlation between the level of a respondent's education and his/her awareness and ability to use smart city services and applications. To develop the questionnaire, a research model (see Figure 1) was developed.

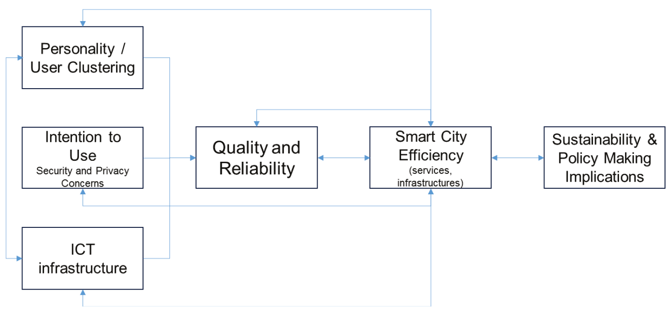

Figure 1. The research model.

As Figure 1 depicts, six research variables were identified to streamline our research. These included the following:

- **The user profile**, including the level of education and hence, the propensity to be aware of and use smart city services and applications and to assess their utility was used to classify users of smart city services. This pilot study targeted a focus group including highly educated respondents. In this way, this variable of research was constant in this pilot study.
- **Intention to use** was the second variable integrated in our research model and dealt with the aggregation of limitation factors and concerns that have impacts on the willingness of citizens to use smart city services. For the measurement of this variable, several Likert-type questions were integrated into one research tool to measure the favorable disposition of users to use smart city services.
- **ICT infrastructure** is related to numerous emerging and streamline technologies that serve as enablers of sophisticated smart city services. The research objective was to understand how real world smart city users value and understand this technology, and which types of technology have real impacts on value perceptions.
- **The quality and reliability of smart city infrastructure** is a variable that integrated the qualitative features of user interpretations for the provision and adoption of smart city services. To measure these features, several open questions and Likert-type questions were added to the research tool. Some of them aimed to record the best, good and worst smart city practices experienced by respondents of the survey.

- **The smart city efficiency** integrated several of the previous variables as prerequisites and served as a Key Performance Indicator (KPI) for the overall efficiency of the human and technological factors of smart city infrastructure. To measure this variable, we adopted a qualitative research approach by examining respondents' opinions and ideas.
- **Sustainability and policy-making implications** was the last research variable. The overall idea of this variable was to provide a hermeneutic analysis of the required sustainability and policy-making implications though developmental, maturity models. To measure and elaborate this research variable, we used a meta-analysis and interpretation of key findings related to the previous five variables.

These variables defined the content of the survey. Its outcomes, pertaining to the following four major issues—smart city user profiles, infrastructures and services for smart cities, policy making and participation, future smart city applications—are summarized in the following section.

3. Analysis and Main Findings: A New Typology of the Users of Smart City Services

3.1. Demographics and Smart City User Profiles

The first section of our research was dedicated to the collection of personal data and smart city user profiles. The main interest in this was related to the future analysis and comparisons between the perceptions and attitudes of users based on personality characteristics and different demographics. In our study, the focus was on users of smart city services with higher educational levels. As depicted in Table 1, almost 94% of the respondents were PhD or Master's degree holders. The implication of this feature has a direct impact on the findings of the study. Users of smart city services with higher educational levels are more aware of technology and overall, are more prone to use smart city services and applications. Their computer literacy is higher than that of people with lower educational levels and so, their ability to use smart city services is higher.

Table 1. Educational level.

PhD	Master's Degree	Bachelor's Degree	Undergraduate
66%	28%	4%	2%

One more key characteristic of the sample included in our research related to its international coverage. Our intention was to create a sample of respondents from different countries to assess their technological maturity and the penetration of smart city services in citizens' lives and businesses. Table 2 summarizes the continents that our respondents were located in. One third of the respondents were from Asia, 44% were from Europe and almost 10% of respondents were from the Americas and the Arab Peninsula, mostly Saudi Arabia. Two percent of the respondents came from Australia. In Table 3, a detailed overview of the respondents' countries of origin is presented. Individuals from China, Spain, Greece, Taiwan, Saudi Arabia, Pakistan, Brazil and Czech Republic represented 70% of the sample (see Table 3).

Table 2. Continent coverage.

Continent	% in Sample
Americas	11%
Arab Peninsula	9%
Asia	34%
Australia	2%
Europe	44%

Table 3. Typology of users of smart city services.

	Smart City User Clusters/Profiles		
Feature	**Apathetic User**	**The Concerned User**	**The Advocate**
Frequency of Use	Not often/seldom	Selective	Too often and wishes to use as many of these services as possible
Typical Services	Governmental, librarian, transportation and entertainment services	Variety based on preferences	Early adopter, variety of services
Key Concerns	Legal rules of services Low availability of services Limited awareness Technical problems	Data protection and security Real effectiveness of the concept Availability Sustainability Response rate Unauthorized access Misuse of collected information	Interoperability of data and systems Security Interface quality
Perceived Value Added	Friendliness of services	Automation and intelligence compared to traditional services	High satisfaction

One of the key objectives of this preliminary research study was to understand the adoption and diffusion of smart city services by the sample respondents. Given the high educational level of the sample, a key finding for further analysis was the rather high number of respondents that had not used a smart city service in the last year. In fact, 18% of the sample stated that they had not used any smart city service over the past year, while an additional 8% had used smart services to a limited extent. The confirmed users of smart city services included 74% of the sample. This is an adequate community of users of smart cities services.

Overall, users (97%) were pleased to use smart city services; only 3% were not. It is quite interesting from this perspective to investigate the required conditions based on users' preferences and prerequisites. Another critical objective of our analysis was the classification of smart city user profiles. In Table 4, we summarize the initial findings of the qualitative aspects of three major smart city services user profiles.

Table 4. Smart city infrastructures.

Networks	Application Domains	Value-Adding Services	Policy-Making
Broadband cheap Internet—Wi-Fi	Smart transportation services	Mobility	One-stop shop, single access points
Socially reliable networks	Energy consumption services	Simplicity	Big Data analytics
Interoperable sensor Nnetworks	Traffic control systems	Cloud services	Soft skills / ICT skills
Good electrical infrustructure	Environment design	Connectivity	Information quality; ease of use
Internet of Things	Waste collection systems	Advanced ICT	Broad access
Cutting edge ICT	Health ICT	Omnipresent infrastructures	Large mobile penetration
	Automatic fraud detection systems	Real-time data ecosystems	Linked interoperable services
	Platforms for participatory decisions	Security technology	Global access to any information developed in a smart city
		Privacy capability	Digital literacy
		Local storage of Big Data	Urban planning and design

The main criteria used for the classification were related to the frequency of use, typical preferred services, and main concerns. Based on the findings of our survey, the following typology of users was devised: concerned users, early adopters/advocates of smart city services, and apathetic users. Table 3 offers an overview of the key features defining these three respective groups of users of smart city services. A detailed elaboration follows.

One of the key findings was that most respondents were concerned users (Table 5). They are aware of the information technologies that support smart city services but are also very selective in their use of the services. Their main concerns are related to the data protection and security issues of smart city applications. Additionally, they feel the need to assess the effectiveness of the concept of smart cities by associating its value to relevant services. They are very much interested in the availability and sustainability of the services, while a low response rate, and misuse of collected sensitive personal information worry them the most.

Table 5. Smart city services: typology of users—the Concerned Users.

Patterns of Action	What They Say?
• Big Data services awareness: the main concern is (personal) data protection and security. • There is awareness of existing technologies, but there is also consensus and concerns about the real effectiveness of the concept. • Key perception of smart city services: smart city services are services that provide automation and intelligence compared to traditional services • Key consideration: cost effectiveness and accessibility • Issues raised: human–computer interactions; sustainability; the availability of these services and continuity (major issue); low response time; lack of access; and availability • Perceived problems: unauthorized access and security issues.	• "Linking the access to the mobile number definitely increases the security, but it makes it very vulnerable once the mobile phone device is lost or exposed and reachable by a hacker. Some of the problems that occurred such as access to those services were tied up with local mobile phone verification which made it difficult to access at sometimes especially if the user is overseas". • "My main concern is technology development". • "In general, I don't like that so much information is collected and (could be) misused." • "My main concern is bugs in the app, which prevents me from taking full advantage of the service and makes me go to the physical facilities." • "Moving toward centralization for smart cities is still not done fully." • "If the system is down, will users be able to perform their tasks manually using traditional methods?"

Another significant profile was related the advocates of smart city services (Table 6). These individuals use smart city services extensively and promote the diffusion of advanced services for further use. The interoperability of data and systems is perceived as a value integrator towards maturity and sustainability. Last, but not least, advocates consider the quality of interfaces to be a key component for the successful adoption of smart city services. The following details the outcomes of our survey and thus, offers the full profile of the smart city services advocate.

Table 6. Smart city services: typology of users—the Advocates.

Patterns of Action	What They Say?
• Uses smart city services regularly. • Wishes to use as many smart city services as possible. • High satisfaction from selected services. • Early adopter, enthusiast, engaged in technological projects that span city smartness. • Typical services include governmental services and services to see the events happening in the city; tourism applications provided by the city; electronic payments to city councils; shared bicycle and online hotel reservations; administrative services (citizen registration data, etc.); public service reservations; traffic information; license applications; real-time bus information systems and U-bike system s, etc.	• "My main concern is about interoperability of data and systems and security." • "Open to the use of smart city technology if it makes my life easier. I use online banking and government services and services related to entertainment." • "The major problems are that the websites are not very friendly." • "I use the Taoyuan bus car, the free Wi-Fi from the government in Taiwan, etc." • "I have used smart city services such as e-government (services) in cities in the Middle East such as Dubai and Riyadh. The e-government services that have been recently introduced to the citizens helped to reduce the pollution as well as the traffic and waste."

Apathetic users constituted another interesting group of respondents in our sample (Table 7). These individuals rarely use smart city services and the ones that they use, in most cases, are related to governmental and municipality processes and simple applications related to library archives and entertainment. Their main concerns are the legal terms pertaining to the use of smart city services and their limited awareness about the availability of services. Additionally, they perceive that only few of the available services are related to them. Technical problems and low-quality designs limit their willingness to use smart city services.

Table 7. Smart city services: typology of users—the Apathetic Users.

Patterns of Action	What Do They Say?
• Aware of technology options, but have limited usage, for example, accessing cloud archives or accessing iPhone cameras installed at home while away from home only for safety purposes (e.g., when they have to leave their child at home with the maid). • Major problems encountered: services are not regularly updated, nor fully exploited in terms of potential.	• "I know what a smart city service is but I seldom use any of the services. I like the idea but I'm worried about the privacy and being manipulated too." • "Occasional user; user friendliness is key." • "Rather average user of smart cities services." • "Use a smartphone and some applications related to booking on services by municipality." • "I also use some notifications about social and taxation services." • "I am really worried about (sharing) my data over smart cities services and about my privacy." • "I am a low intensity user. My main use is in the payment of public services (electricity, water supply, taxes). I also use public Wi-Fi connections in the University for various tasks. The main difficulty we face is the low speed and availability of Internet that we have in the city." • "Smart city services are still at the beginning (stages) (in many cases), I use some services but sometimes, the (legal) rules for use are not clear; the municipal authority is not ready enough for such services (there are a lot of technical problems, data protection is a challenge too, etc.)." • "Hard to say, it's a new term for me."

3.2. Infrastructures and Services for Smart Cities

Another key objective of our research study was to analyze the key technologies that are perceived by respondents as the key enablers of the so-called smart city infrastructure. In Table 8, an initial analysis of findings is presented. The majority of respondents indicated that open access to the Internet and broadband is a key requirement for the realization of smart city infrastructure. Overall, networks and relevant technologies have a critical contribution to the smart city vision.

In the same basic infrastructure of networks, respondents also highlighted the importance of having reliable social networks, interoperable sensor networks, good electrical infrastructure, Internet of Things technology and cutting-edge ICT, related mostly to sensors and distributed networks. Such a finding is important and must be integrated in any maturity model for smart city evolution. At the policy-making level, this networking component must be supported by relevant policies, such as broad access programs, digital literacy, and ease of use.

Table 8. Smart city service good practice.

Scenario	Description
1.	"In Hong Kong, we have bus mobile apps. The major functions are (i) arrival time estimation; (ii) arrival and drop off alerts; and (iii) route search."
2.	"I really enjoy location aware services circulating information about nice things happening in my city through my smartphone."
3.	"I am working in a foreign country and issued (a) visa for my family using smart services without visiting an office."
4.	"I was pretty happy to get a car I rented using my mobile phone for (the entire)rental procedure, including opening the doors of the car with no need for any other person to check the procedures."
5.	"In Brussels, I have recently been happy to use my smartphone to pay for parking just for the time I have been parked (in) that spot."
6.	"I booked a play online at a local theatre. It was fast, easy, and reliable, and I could do it through my phone, and all I had to do was show the email at the door and scan the code given."
7.	"During my studies at Indiana University Blooming tonight, I was very happy with the online system that provides real-time status of city transport."
8.	"The Rio de Janeiro meteorological information application provides real-time weather information and alerts, informing 6M inhabitants in the metropolitan area."
9.	"During my trip to Japan, I was amazed by the bike parking service which (located)the place to park for us and also brought (the car back) back automatically."
10.	"I was happy to be able to renew my passport using my mobile phone in Saudi Arabia."
11.	"The fact that one no longer has to visit governmental or private offices for matters of social security or health services such as booking appointments with doctors. The fact that in most cases, one knows the waiting time for transportation media."
12.	"I use my smart card to enter the subway, light rail, pick a shared bicycle or Bus rapid transit (BRT); it is very convenient."
13.	"Tele-health care for the elderly in Trikala, Greece."
14.	"Mobile applications oriented to traffic congestion and measure the air quality in the Mexico City, as well as the web site of open data of the local government."

The other critical component of smart city applications is related to a bunch of thematic applications. The provision of services for smart transportation, energy consumption, traffic control, environmental sustainability and design, waste collection systems, personalized healthcare, automatic fraud detection systems and platforms for participatory decisions has a key impact on the development and evolution of smart city infrastructure. From a policy-making perspective, the key question, given the limited resources, is determining which the required transformative and integrated plans for radical or continuous improvement initiatives within a city are. It is also important to communicate that a key requirement is the sustainability of all of these thematic and targeted services. A longitudinal strategic planning for smart cities has to provide a reliable framework for the effective management of resources, including data, services, applications and infrastructures.

One key finding of our research study was associated with the perceptions of value-adding services. The enhancement of mobility within a smart city, the advanced connectivity between citizens, applications and infrastructures as well as the interoperability of systems are promoted as key priorities for value diffusion. Ubiquitous and omnipresent infrastructures also promote the sustainability perspective of smart city infrastructure, while cloud services and local storage of Big Data increase the satisfaction of smart city infrastructure users. The simplicity of services and their user friendliness improves their adoption, while real-time data ecosystems with advanced analytics capability improve the efficiency of smart city infrastructure. Most of the respondents also stated that they require privacy capability and advanced security components.

Respondents also shared the main implications for policy-making; a one-stop shop for smart city services, single access points to network services, Big Data analytics for advanced decision-making, and required soft skills/ICT skills for the understanding and real use of services were proposed (see Table 9).

Additionally, the smart city infrastructure vision has to be integrated into broad access plans to Wi-Fi and free internet, large mobile penetration plans, linked interoperable services between various applications as well as the provision of global access to any information developed in a smart city. Perhaps one of the most important concerns is related to the so-called digital literacy and sophisticated urban planning and design. One of our planned publications will elaborate these initial findings further.

Long term planning for smart city services has to deal with several concerns of citizens. In our research, we tried to enlighten this aspect by asking our respondents to share their key concerns and fears. In Figure 2, a preliminary analysis is provided without further reference to user profiles and clusters. The main finding was that six factors are hermeneutic for this phenomenon, namely, security and protection (45%), data privacy (25%), transparency of services (8%), ethical concerns (6%), required soft skills (5%), third party awareness (5%) and the complexity of services (4%) set some limiting factors and psychological barriers for the adoption of smart city services by users. It is a challenge for any urban design to take into consideration all of these concerns and to support an integrated strategy.

Table 9. Smart city service concerns/scenarios.

Scenario	Description
1.	"I dislike (it) when I register to smart city services and then other parties knock my door (to also use) their services. I think there is a violation of my privacy."
2.	"I have been using a third party app to get train schedules that was just an upper layer to the one provided by the train company. (I) wonder what they do with the data they collect."
3.	"I registered my mobile phone number and I was worried about information leakage."
4.	"I tried to use the online national library service and it couldn't (find) my profile. The people in the library couldn't access theirs either so it seems the system was down."
5.	"There is certainly room for improvement in transport ticket reservation (in) many cities (that I have been to)."
6.	"I used a parking app outside of my city and I paid an amount of money but I couldn't get the money back (when) I didn't spend the whole amount."
7.	"Cameras everywhere."
8.	"I installed an app that allows free internet access in a community. My main concern was unauthorized access control."
9.	"Worried about leaving LinkedIn application data to protect my business's whereabouts."
10.	"The data privacy and security issues of Wechat."
11.	"I worry (about) the cost of Internet connection outside my country."
12.	"Personal data can be sold and misused by private corporations. Governments should prevent this."
13.	"The address was linked with my local ID number which makes me worry about any hackers as they will be able to obtain all my personal information, such as address and DOB, as well as controlling some of the functionality without my approval."
14.	"Once I bought a ticket to visit the Statue of Liberty in New York and the website was so confusing that I paid twice and I couldn't visit it inside."
15.	"I booked an online ticket from Frankfurt to Zurich from a rail service provider, The train number allotted to me never goes to Zurich."
16.	"When using financial applications, I am always worried about security and data protection."
17.	"Recently, I extended my health insurance policy. The agent on the phone asked me to provide my Master Card and CSV number which I did. Clients usually provide this information through IVR but not directly. I was concerned about the misuse of this information."
18.	"I installed, in Taichung city, an application for a smart healthcare cloud from a third party provider and felt worried about the data that this application could access/record about me."
19.	"All the third party applications require to (much) personal data."
20.	"Many smart city apps are made for locals only and the knowledge that a foreigner or visitor has is not enough to use (them)."
21.	"Air BnB reservation in Brussels where I felt worried about the data privacy and reliability of service as a whole."
22.	"I am concerned some applications are tracking my location. It doesn't feel good."

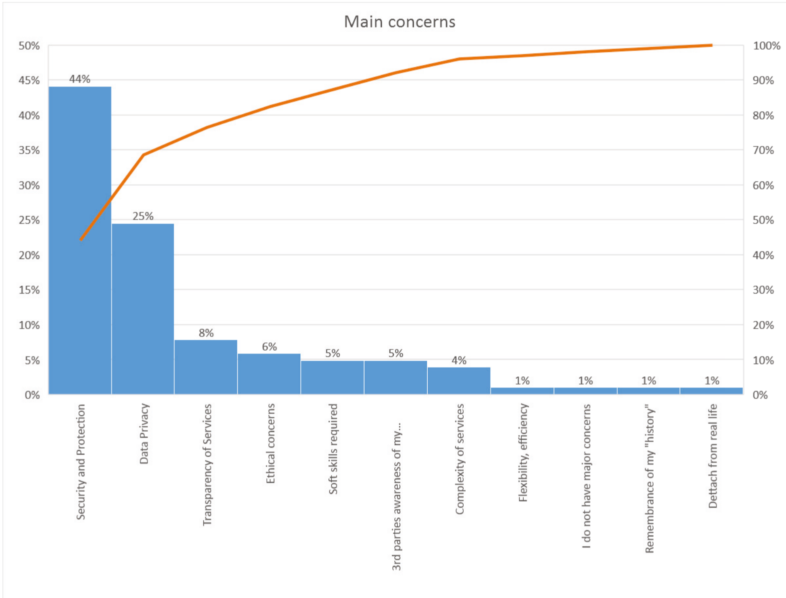

Figure 2. Main concerns of smart city users.

3.3. Policy-Making and Participation

The anchoring of policy-making and active participation in the smart city vision requires a deep understanding of users' perceptions and beliefs about the efficiency of the services. While technocrats and experts have developed extensive strategic models for value diffusion, the end users are the ones who interpret and feel the value of these services in their lives. In our study, we tried to interpret some best practices scenarios for the provision of smart cities to our respondents. In the next section, we provide a qualitative analysis of their responses.

To allow the classification and better discussion of these findings, we decided to integrate two value dimensions, as follows:

- **Time/space dependency:** The interpretive analysis of responses revealed that value perceptions of smart city services are associated with different contexts of exploitation that are highly or partly dependent on time and space.
- **Data/knowledge structure:** The second value dimension for the understanding of smart city services that are highly valued by the respondents of our study was related to the knowledge flow structure in terms of service provision. Our respondents implicitly and explicitly promoted the idea of knowledge flow structure as a critical differentiation factor.

With reference to these two dimensions, in Figure 3, we provide a preliminary and incomplete view of the perceptions of respondents for the clusters of value-adding services based on best practices. It is obvious from the qualitative analysis that four clusters are informing user behavior in regard to the adoption of smart city services and their user satisfaction.

1. **Low time/space dependency and structured knowledge flow:** In this quadrille, the smart city services are not time or space dependent and the provision of services is based on structured knowledge flows. The list of following applications was provided by our respondents as key examples of good practices; however, they do not provide an exhaustive list: the issuing of

documents from a distance, distant activation of services, online ticketing, certificate issuing services, and open linked data applications. It is a critical challenge at the policy-making level to support and enhance these types of applications in different domains of human, social and business activities.

2. **High time/space dependency and structured knowledge flow:** In this quadrille, the smart city services are time or space dependent and the provision of services is based on structured knowledge flows. Typical examples include location-aware services for targeted content and service provision; real-time ticketing, smart health/traffic/finance services and electric car charging, etc. The most significant category was related to the location and context-aware services, and extensive research on this domain needs to be based on advanced profiling and advanced cognitive computing and analytic techniques and methods.
3. **Low time/space dependency and unstructured knowledge flow:** In this quadrille, the smart city services are not time or space dependent and the provision of services is based on unstructured knowledge flow. The notion of unstructured knowledge refers directly to microcontent contributions over social, sensor, IoT or distributed networks that require extensive data and text mining or advanced social engineering and social networks analysis methods. Our respondents emphasized two types of services directly related to this cluster: accessibility monitoring and social mining and collaboration. The continuation of our qualitative ongoing research in the near future will provide numerous more applications in this cluster.
4. **High time/space dependency and unstructured knowledge flow:** In this quadrille, the smart city services are time or space dependent and the provision of services is based on unstructured knowledge flow.

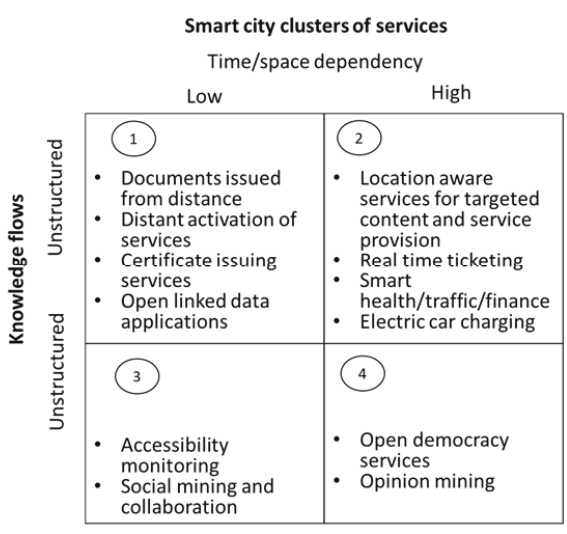

Figure 3. Smart city clusters of value-adding services based on experienced good practices.

4. Findings of Our Research

- **Research objective 1:** Is it possible to establish a link between different user profiles and their abilities to use certain clusters of smart city services/applications?
    - Key finding 1: Based on the qualitative analysis and interpretation of respondents' answers, [22] we concluded that three basic user clusters exist and provide different

contexts for the exploitation of smart city services, namely: the apathetic user, the concerned user and the advocate. For these three clusters, special features and behavior characteristics were recognized.

- Further research direction 1: Sophisticated matching of a variety of smart city services to these clusters to understand the preferences of users for specific services
- Policy-making and sustainability implication: The development of guidelines and strategies for the holistic support of all clusters and for the evolution of the users in the more advanced clusters.

• **Research objective 2:** How different users of smart city services/applications perceive them and the value that they add?

- Key finding 2: Most respondents were in favor of the use of smart city services. It is evident though that several barriers related to technical, behavioral, and policy-related issues limit the penetration and adoption of smart city services. There are issues related to security and privacy concerns as the poor quality of infrastructures limits the added value and perception of smart city research. It is encouraging that several smart city services are happily exploited by users, and this promotes the willingness of citizens to explore more value-adding services.
- Further research direction 2: Analysis of the disruptive capacity of smart city technology in citizens' lives is required, and this is an ongoing task in our research area. In our research, we found that the more the added value associated to the use of a smart city service, the greater the user satisfaction is.
- Policy-making and sustainability implication 2: It is evident that value perception is integrated and closely related to users' experiences and soft skills. From this perspective, a key objective of our future research is to analyze the soft skills required for the enhancement of the capacity of citizen to use smart city services. Additionally, we would like to exploit the perceptions of businesses and organizations since the use of smart city services in businesses is an emerging research domain with limited contributions.

• **Research objective 3:** How important for smart city efficiency are questions and concerns about security, privacy, ethics and others?

- Key finding 3: A bold finding of our research study is that six factors are hermeneutic for the phenomenon of smart city application adoption, namely security and protection (45%), data privacy (25%), transparency of services (8%), ethical concerns (6%), required soft skills (5%), third party awareness (5%) and the complexity of services (4%). These factors set some limitations and psychological barriers for the adoption of smart city services by users.
- Further research direction 3: It is necessary to further analyze these factors and to understand how all these are related to the intention to use smart city services. In regard to this purpose, we are already working on the collection of additional data to inform our research model including various aspects, such as security, ethics and quality of services.
- Policy-making and sustainability implication: The six factors revealed provide a context for policy consultation and design. Several policies at the macro, mezzo and micro levels are required in order to transform the concerns of users regarding opportunities for sustainable smart city services and applications.

• **Research objective 4**: What are the examples of good practices of smart city services based on their associated and perceived value by users?

- Key finding 4: Our research study also revealed some good practices of smart city services. The following list summarizes the most significant enablers: mobility, simplicity, connectivity, omnipresent infrastructures, and real-time data ecosystems. The interpretation of these findings promotes the following profile of smart city services: users require the advanced mobility and availability of transparent ubiquitous services that are simple to use and allow advanced connectivity with users and other services. Additionally, the omni presence of services is highly valued.

- Further research direction 4: Further research on good practices in smart cities requires a case study approach that we intend to undertake for the realization of good practices in selected smart cities, including cities in Europe, Australia and the Far East.
- Policy-making and sustainability implication: Good practices and lessons learnt are good mechanisms to code and to disseminate methodologies, strategies and effective services in an international context. Local competencies can be benchmarked in the global context. From this point of view, one of the future research directions is to map country-specific competencies in terms of good practices for smart city research. In addition, this helps to set international benchmarks. One of the barriers in this regard is the different cultural, political, social and economic contexts of each country under investigation. Organizations like the OECD, the World Bank and the European Parliament can play key roles in this direction. A number of initiatives related to smart villages and smart city research worldwide have the potential to boost the employability, sustainability and to promote socially inclusive economic growth.

- **Research objective 5**: What are the perceptions of smart city users regarding the impact of advanced ICT on the quality, reliability, and sustainability of smart city infrastructure?

  - Key finding 5: The role of ICT in the provision of smart city services is a key priority for our ongoing research. In this preliminary study, we tried to determine the key technologies that are perceived by citizens as the critical backbone and infrastructure of smart city services. The main finding was that the following technologies are recognized as the critical components of smart city infrastructure: cheap broadband Internet (Wi-Fi), socially reliable networks, interoperable sensor networks, good electrical infrastructure, Internet of Things, and cutting-edge ICT (including business intelligence, Big Data and analytics).
  - Further research direction 5: In the era of Big Data, block chains, Internet of Things, and virtual and augmented reality, we also have to analyze the readiness of citizens and users to adopt more advanced smart city services. In addition, it is significant to understand the matching of different domains of human activity with different technologies. For this purpose, in our ongoing research, we aim to deploy an integrated qualitative and quantitative research approach to understand the impacts of emerging technologies in emerging smart city business models.
  - Policy-making and sustainability implication: Policy-makers have to understand that technology is not the panacea, and for their effective integration into smart city and smart village research, it is necessary to model, test and implement citizen-centric policies for new emerging smart city business models. In our research agenda, the first domains to be investigated are transportation, education, and international technology transfer. We also have a special interest in the One Belt, One Road initiative of the Chinese Government and the Kingdom 2030 vision in the Kingdom of the Saudi Arabia.

- **Research objective 6**: What are the sustainability and policy-making implications for an evolutionary maturity model of smart city research?

  - Key finding 6: The qualitative interpretation of responses shows that the quest of sustainability in smart cities and smart villages requires the development of an evolutionary model for sustainable growth related to different levels of smart city research maturity.

- Further research direction 6: One of our key priorities in the full research study is to justify this evolutionary sustainable growth model for smart city and smart village research. Our plan is to publish the main aspects of this model in a new research paper intended to appear in late 2018 in a peer reviewed academic journal.
- Policy-making and sustainability implication: The integration of policy-making and sustainability in holistic smart city research and application strategies is a vital factor for social inclusive economic growth.

5. Discussion and Conclusions

This paper calls for a cautious rethink of the focus and rationale behind the smart cities debate from the complex perspective of the awareness and ability of citizens to use smart city services. Against the backdrop of a pilot study targeting a focus group of citizens considered to be the most ardent users of smart city services, the discussion in this paper sought to add empirical backing to the argument that smart cities research suffers from a 'normative bias', i.e., that the ICT-enhanced vision of what is technically possible does not always match the on-the-ground reality. Indeed, the outcomes of the study suggest that even among the most educated individuals, and therefore the most apt users of smart city services, several concerns clouded their willingness to use these services. A careful analysis of the respondents' profiles suggested that it is possible to divide the users of smart city services into three groups: the advocates, the concerned users and the apathetic users of smart city services. In other words, even the most educated users of smart city services, i.e., those arguably most aware of and equipped with skills to use these services effectively, express very serious concerns regarding the utility, safety, accessibility, and efficiency of those services. By querying the notion of end users' awareness of and ability to use applications and solutions considered 'smart' in the urban space, the discussion in this paper implicitly highlights that if smart cities research is to be sustainable, it also needs to be interdisciplinary. This, in turn, requires greater attention to be paid to conceptual precision, methodological meticulousness, and above all, metatheoretical awareness in smart cities research.

The research, research findings and discussion presented in this paper build on the recognition that smart cities research has great exploratory and policy-making potential and the stake, i.e., well-being of a city's inhabitants is high. Moreover, the argument in this paper builds on the assumption that a rethink of the field is necessary if dialogue between ICT- and humanities/social sciences-inclined research is to be established and consolidated in a sustainable manner. From a different angle, the argument in this paper is influenced by our conceptual work that queried the scalability of smart cities research and dwells on the added value of smart city research for the examination of the specificity of villages in view of opening the debate to smart village research [12]. What follows is that implicitly, this paper, similarly to our broader research agenda in this field, flags up the 'normative bias' inherent in smart cities research and underlines the importance of integrating smart cities and smart villages research with policy-making geared towards sustainable and inclusive growth and development. Finally, the arguments about the scalability of smart cities research and policy-making considerations places the findings of our study in the broader context of the debate on connectivity and collaboration in local, regional and global contexts. Depending on the focus of the analysis, this point of departure allows the interpretation of the findings of our research through the lens of either (i) specific policies and strategies aimed at developing infrastructure, boosting innovation and creating incentives for sophisticated entrepreneurship and entrepreneurship networks, or (ii) developments implemented around the worlds including development strategies and visions, such as the Single Market, the One Belt One Road initiative, the Saudi Arabian Kingdom 2030 Vision and many more.

The continuation of this research study is planned to appear in our edited book in Elsevier [23] and in our next special issue: Special Issue "Rethinking Security, Safety, Well-being and Happiness in Smart Cities and Smart Villages Research" http://www.mdpi.com/journal/sustainability/special_issues/smart_cities_smart_villages.

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References

1. Warleigh-Lack, A. Greening the European Union for legitimacy? A cautionary reading of Europe 2020. *Innov. Eur. J. Soc. Sci. Res.* **2011**, *23*, 297–311. [CrossRef]
2. Lytras, M.D.; Raghavan, V.; Damiani, E. Big data and data analytics research: From metaphors to value space for collective wisdom in human decision making and smart machines. *Int. J. Semant. Web Inf. Syst.* **2017**, *13*, 1–10. [CrossRef]
3. Lytras, M.D.; Mathkour, H.I.; Abdalla, H.; Al-Halabi, W.; Yanez-Marquez, C.; Siqueira, S.W.M. Enabling technologies and business infrastructures for next generation social media: Big data, cloud computing, internet of things and virtual reality. *J. Univers. Comput. Sci.* **2015**, *21*, 1379–1384.
4. Lytras, M.D.; Mathkour, H.I.; Abdalla, H.; Al-Halabi, W.; Yanez-Marquez, C.; Siqueira, S.W.M. An emerging—Social and emerging computing enabled philosophical paradigm for collaborative learning systems: Toward high effective next generation learning systems for the knowledge society. *Comput. Hum. Behav.* **2015**, *5*, 557–561. [CrossRef]
5. Angelidou, M.; Psaltoglou, A.; Komninos, N.; Kakderi, C.; Tsarchopoulos, P.; Panori, A. Enhancing sustainable urban development through smart city applications. *J. Sci. Technol. Policy Manag.* **2017**. [CrossRef]
6. Lytras, M.D.; Mathkour, H.; Torres-Ruiz, M. Innovative Mobile Information Systems: Insights from Gulf Cooperation Countries and All over the World. *Mob. Inf. Syst.* **2016**, *2016*, 2439389. [CrossRef]
7. Keim, D.A. Visual exploration of large data sets. *Commun. ACM* **2001**, *44*, 38–44. [CrossRef]
8. Höjer, M.; Wangel, J. Smart sustainable cities: Definition and challenges. *Adv. Intell. Syst. Comput.* **2014**, *310*, 333–349.
9. Bi, S.; Liu, Z.; Usman, K. The influence of online information on investing decisions of reward-based crowdfunding. *J. Bus. Res.* **2017**, *71*, 10–18. [CrossRef]
10. Yin, C.; Xiong, Z.; Chen, H.; Wang, J.; Cooper, D.; David, B. A literature survey on smart cities. *Sci. China Inf. Sci.* **2015**, *58*, 1–18. [CrossRef]
11. Bibri, S.E.; Krogstie, J. On the social shaping dimensions of smart sustainable cities: A study in science, technology, and society. *Sustain. Cities Soc.* **2017**, *29*, 219–246. [CrossRef]
12. Visvizi, A.; Lytras, M.D. Rescaling and refocusing smart cities research: From mega cities to smart villages. *J. Sci. Technol. Policy Mak.* **2018**. [CrossRef]
13. Van de Voorde, T.; Jacquet, W.; Canters, F. Mapping form and function in urban areas: An approach based on urban metrics and continuous impervious surface data. *Landsc. Urban Plan.* **2011**, *102*, 143–155. [CrossRef]
14. Lytras, M.D.; Aljohani, N.R.; Hussain, A.; Luo, J.; Zhang, X.Z. Cognitive Computing Track Chairs' Welcome & Organization. In Proceedings of the Companion of the Web Conference, Lyon, France, 23–27 April 2018.
15. Ishida, T.; Isbister, K. *Digital Cities: Technologies, Experiences, and Future Perspectives*; Springer: Berlin, Germany, 2002.
16. Visvizi, A.; Mazzucelli, C.; Lytras, M. Irregular migratory flows: Towards an ICT' enabled integrated framework for resilient urban systems. *J. Sci. Technol. Policy Manag.* **2017**, *8*, 227–242. [CrossRef]
17. Chui, K.T.; Alhalabi, W.; Pang, S.S.H.; Pablos, P.O.; Liu, R.W.; Zhao, M. Disease Diagnosis in Smart Healthcare: Innovation, Technologies and Applications. *Sustainability* **2017**, *9*, 2309. [CrossRef]
18. Guo, L.; Guo, D.; Wang, W.; Wang, H.; Wu, Y.J. Distance Diffusion of Home Bias for Crowdfunding Campaigns between Categories: Insights from Data Analytics. *Sustainability* **2018**, *10*, 1251. [CrossRef]
19. Wu, S.M.; Chen, T.-C.; Wu, Y.J.; Lytras, M. Smart Cities in Taiwan: A Perspective on Big Data Applications. *Sustainability* **2018**, *10*, 106. [CrossRef]

20. Visvizi, A.; Lytras, M.D. Editorial: Policy Making for Smart Cities: Innovation and Social Inclusive Economic Growth for Sustainability. *J. Sci. Technol. Policy Mak.* **2018**, *9*, 1–10.
21. Carrasco-Sáez, J.L.; Careaga Butter, M.; Badilla-Quintana, M.G. The New Pyramid of Needs for the Digital Citizen: A Transition towards Smart Human Cities. *Sustainability* **2017**, *9*, 2258. [CrossRef]
22. Smart Cities Research: Contemporary Issues in Smart Cities Research. 2018. Available online: https://docs.google.com/forms/d/e/1FAIpQLSciGvQE78AWnUcHqt4Q_MLFC6FT52UQskZSSNlZzOBJNQTdkA/viewform (accessed on 10 June 2018).
23. Visvizi, A.; Lytras, M.D. *Transitioning to Smart Cities: Mapping Political, Economic, and Social Risks and Threats*; Elsevier-US: New York, NY, USA, 2019.

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Mapping Urban Expansion and Exploring Its Driving Forces in the City of Praia, Cape Verde, from 1969 to 2015

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Abstract: Urban expansion is the outcome of intensive human activity within a certain natural environment and may cause ecological and environmental problems, especially on small islands where land is a scarce resource. Praia is the capital city of Cape Verde, located on such an island. Understanding urban expansion will provide good knowledge for urban planning and policy making in balancing urban economic development and natural resource protection. According to available data, the urban expansion in Praia between 1969 and 2015 is observed in four phases (1969–1993, 1993–2003, 2003–2010, and 2010–2015). In order to integrate various data sources, this study applies an available method to coordinate and calibrate map data with different scales and forms into a consistent dataset and then introduces some improvements in the delineation of urban areas. With this data, the driving forces in each phase are explored using regression analysis, by which the main urban expansion processes are presented. We found a decrease in annual growth rate (AGR) of urban expansion after the year 2003 and a parallel stabilization of urban utilization density (UD) and land consumption per capita (LCR). This study also indicates that population is not always the persistent driving factor for urban expansion and the majority of horizontal expansion has occurred in zones with less infrastructure.

Keywords: urban expansion; regression analysis; ordinary least squares; Praia; Cape Verde

1. Introduction

In the near future, urban population growth in developing countries will be 16 times that of developed countries [1,2], especially in Africa and Asia [3]. By 2030, the population of cities in developing countries (i.e., >100,000 inhabitants) may double, while their built-up areas will triple due to a decrease in population density [1]. In addition, such demographic pressure may promote rapid urban expansion and cause irreversible implications for the soil and land use, compromising areas for recreation, food production, renewable energy, and resource extraction [4]. In many cases, urban expansion has been unsustainable (e.g., landscape fragmentation, deforestation), especially when it is dispersed [5], causing high soil consumption, soil sealing, increases in the cost and need for infrastructure [6], and impoverishment of the urban fringe [7]. The situation worsens when planning, control, and fiscal resources are limited [8].

In small island developing states (SIDS), about 59% of the population lives in urban settlements [9]; in some countries (e.g., Singapore, Nauru), the rate is 100%. Their small size creates intense competition between land use options [10]. As a result, their urban land cover as a percentage of total arable land is generally higher than the world average for developing countries [11], showing limited land and arable soil. Cape Verde has a high urban growth rate (2.1%) when compared to the world average (1.7%) [12] and limited arable land (10%). As a response, the Praia Master Plan (PDM) [13] and National Institute of Territory Management of Cape Verde (INGT) [14] have shown great concern over excessive land consumption and changes in urban pattern by defining as priorities the containment of the urban perimeter and its extension into potential agricultural land, the reduction of travel costs, increased accessibility to public services, and the promotion of urban infill growth. Furthermore, the PDM of Praia has prescribed the minimum number of floors permitted for residential construction as being two, in order to minimize such urban expansion. This requirement will be controlled using remote sensing techniques in semi-automatic form. In 2010, the Praia Municipality Council (CMP) created the municipal guard service in order to reinforce the supervision and monitoring of illegal construction in the capital city. The CMP aims to implement the municipal housing policies in order to reduce the habitational deficit based on vertical construction, reducing the demand and the pressure on the land [13].

Urban expansion as a dynamic process requires deep understanding of its historical evolution and driving forces. Such analysis is important for decision makers in order to predict the amount of land to allocate to accommodate the fast increase in population [5] and minimize its adverse environmental and socioeconomic effects [15]. Recently, different approaches have been used in order to examine the effects of driving forces on urban expansion. Bivariate [16], logistic [15,17], and multivariate regression [18–21] are most widely used in such studies, especially in large cities. Usually, such studies are conducted at static points of view or short time periods, instead of examining its multi-temporal changes.

The common driving forces in urban expansion studies are grouped as proximity, site-specificity and neighborhood characteristics [17]. Nevertheless, this list of factors can be updated as new driving forces are revealed. Most such driving forces are related to actual lifestyles and dwellers' preferences [22,23].

On the other hand, for small scales of analysis, quantifying multi-temporal urban expansion require detailed multi-temporal datasets to delineate urban areas, which are sometimes limited in some areas [24]. This limitation persists even if we consider the satellite imagery data, which is often used for this purpose [25,26], (e.g., non-coverage for early times and a lack of consistent spatial resolution). Beyond this, satellite data from earlier generations is not ideal for the delineation of urban areas on such a scale of analysis [27] unless we use posterior commercial high-resolution satellite images [28]. Consequently, finding solutions to coordinate and calibrate different data types at different scales into a consistent dataset is a challenge.

Alternatively, aggregation of vector data is used to delineate built-up areas [29,30] by analyzing the density and layout of road networks [31] and aggregation of building footprints [6] using a GIS algorithm [32]. Such techniques were often applied at regional scales [33], primarily to identify the urban boundary, without the discrimination of the elements of urban areas (e.g., roads and small vacant land) [31]. Hence, at large scales, the challenge is to make a clear delineation of built-up areas by including all human structures, with as little generalization as possible.

Urban areas include building footprints (i.e., residential, commercial, and industrial areas) and road networks [34]. Research at small scales of analysis that uses both building footprints and roads in the delineation of urban areas is sparse. However, roads within the cluster of urban settlements should be considered part of urban areas [27,30,35]. The methodology proposed by Ferreira [27] is still generic for small scales of analysis and does not include some basic ideas. For example, even if they are between urban settlements, roads that interconnect zones passing through vacant land should not be considered part of urban areas if they do not have any buildings on either side. If a road has some buildings close to it, this entire road should not be a part of the urban area, but only of the roads closest to it. For larger scales, building footprints and roads are well detailed. Therefore, in order to capture more detail, less generalization and more adjustments are necessary for urban area delineation.

The main objective of this paper is to delineate, map, and analyze the dynamics of urban expansion in the city of Praia between 1969 and 2015 using vector data, and then explore which factors may have contributed to such expansion in each period (1969–1993, 1993–2003, 2003–2010, and 2010–2015) using Ordinary Least Squares (OLS) regression. We also introduce some improvements in the delineation of urban areas at large scales, using vector data. The main approach in this delineation is to include roads with certain conditions as a part of built-up areas, using GIS techniques.

The rest of the paper is organized as follows, Section 2 describes the city of Praia (Section 2.1), cartography and alphanumeric data preparation (Section 2.2), delineation of urban areas and mapping urban expansion (Section 2.3), selection of driving forces of urban expansion (Section 2.4), and OLS regression requirements (Section 2.5). Section 3 presents the results of urban expansion and historic driving forces of urban expansion in Praia city. Finally, Section 4 discusses the results obtained, and Section 5 gives the conclusion of this research.

2. Study Area, Materials and Methods

2.1. Study Area: The Praia City

The 10 islands of Cape Verde are located on the West African Coast, 450 km from Senegal (Figure 1). The island of Santiago has only 24.5% of the national territory and is home to 56% of the entire population, with nine of the 24 Cape Verdean cities, including the capital city of Praia. Praia is the main economic and political center of Cape Verde, located on the southeasternmost end of the Santiago Island. The mean elevation is 71 m and the slope is 7 degrees.

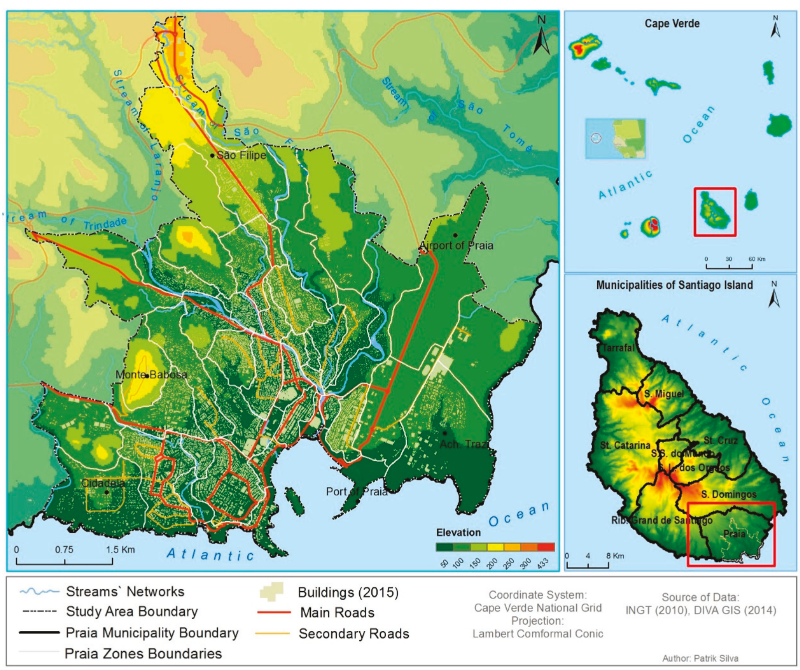

Figure 1. Study area location.

The city of Praia is the most problematic in Cape Verde in terms of territory management [36]. In 2010, it had 26% of the Cape Verdean population, 42% of Cape Verde's urban population, and 76.7% of Santiago Island's population—all this in only 0.25% of the national territory [37]. Moreover, only 20% of the buildings have received formal planning approval and half of the housings have only one floor. The city of Praia is also dominated by informal and spontaneous construction [13].

The Praia municipality earns 39% of the Cape Verdean Gross Domestic Product (GDP) and 74% of Santiago Island's GDP [38]. The population of Praia has increased rapidly over the last few decades (3% annually) [13], starting from 38,564 in 1980 to 94,048 in 2000, and about 145,290 for the year 2015. The reason for this fast population growth is internal migration (from other islands and Santiago's municipalities) and migration from other African countries [39], especially by young people and adults. One draw is the presence of more employment opportunities, which have been generated as a result of foreign and domestic investment.

The extent of the study area is 33.2 km^2 and includes 42 zones, mostly residential.

2.2. Materials and Methods

2.2.1. Cartographic Data

The delineation of urban areas requires only two datasets: the building footprints and the roads, in polygon format. Vector data that represent all the human structures of the city of Praia, including building footprints and roads, were used for the years 1993, 2003, and 2010. For the year 1969, we used topographic maps to obtain such data (Figure 2a). The said data were acquired from INGT.

Firstly, we pre-processed the data to arrive at the building footprints and roads for each period of analysis (1969, 1993, 2003, 2010, and 2015) (Figure 2a). For the years 1993, 2003, and 2010, we exported the building footprints and road layers and converted them to polygon format. For 1969, historic datasets were not available in digital format. Therefore, we georeferenced national topographic maps of Praia (1969) and then overlaid and digitized the building footprints and roads backwards in time, starting from the base layer of 1993.

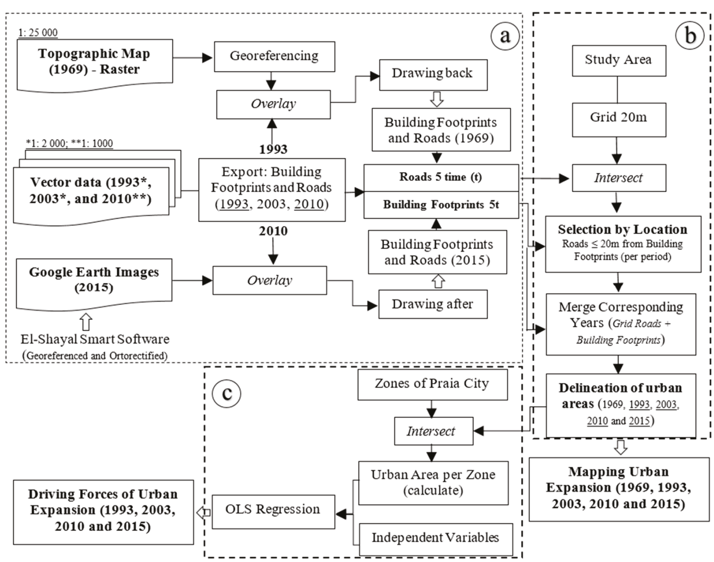

Figure 2. Flowchart of the research methodology: (**a**) data preparation; (**b**) mapping urban expansion; and (**c**) exploring the driving forces of urban expansion.

We used El-Shayal Smart GIS software [40] to get high-resolution Google Earth images, taken in December 2015. By overlaying the 2010 building footprints and roads, we manually digitized forward in time, and, as a result, obtained the building footprints and roads for 2015. Both methodologies used to obtain building footprints and roads are conservative in that they allow us to preserve the scale and accuracy of the data. However, this process creates some imprecision and error in the results.

The width of roads for the year 1969 was optimized by manually digitizing all the roads centerline using the base national topographic maps and delineated a three-meter buffer for each side of the main roads, and a two-meter buffer for secondary roads, according to the exploratory datasets analysis and historic literature review. To explore the driving forces, the independent variables shown in Table 1 were used. These data and their calculations are presented in Appendix A (Table A1).

Table 1. Candidate explanatory variables used in the OLS model.

Variables	1993	2003	2010	2015	Description
Population	x	x	x	x	The absolute difference between the population for each zone from time i to time $i-1$.
Road density	x	x	x	x	Area of zonal roads per total area of zone (Appendix A).
Age of zones	x	x	x	x	The difference in year between the year of analysis and the estimated date that the zone emerged $^{+}$.
Distance to center	x	x	x	x	Euclidian distance between the centroid of changed urban areas for each zone in time i and the centroid to the historic center (Platô).
Distance to coast	x	x	x	x	Euclidian distance between the centroid of changed urban areas for each zone in time i and the coastal line.
Distance to arterial road	x	x	x	x	Euclidian distance between the centroid of changed urban areas for each zone in time i and the arterial road (arterial roads do not include roads that give access for the zones).
Distance to industrial zones	x	x	x	x	Euclidean distance between the centroid of changed urban patches to the closest industrial zone.
Distance to urban perimeter			x	x	Euclidean distance between the centroid of changed urban patches to the urban perimeter boundary for the interior.
Distance to university			x	x	Euclidian distance between the centroid of changed urban patches for each zone in time i and the closest university.
Mean elevation	x	x	x	x	Mean elevation of the changed urban patches for each zone in time i.
Mean slope	x	x	x	x	Mean slope of the changed urban patches for each zone in time i.
Socioeconomic variables		x	x	x	Number of people in percentage that live in each zone with indicators that show high quality of life $^{++}$.
Price of soil			x	x	Average price of soil per changed urban patches in each zone in 2010; and per zone for the year 2015 $^{+++}$ (Appendix A).
Average nbr of floors			x	x	Average of number of floors per changed urban patches in each zone in 2010, and per zone for the year 2015 $^{++++}$ (Appendix A).
Number of infrastructure			x	x	Number of the main public infrastructure that require daily commuting and security to the population (schools, universities, police station, main states institutions, hospitals and health centers).
Industrial zone	x	x	x	x	Dummy variable (0, 1), 1 for zones that have industrial areas, 0 otherwise.
Land available	x	x	x	x	The amount of land available in hectares for urban expansion. Geophysical barriers were removed from areas where we have no built-up areas in each zone (Appendix A).
Neighb. land available			x	x	Average of land available in neighboring zones, in hectares.
Neighb. average Socioecon. Indic.			x	x	Average of socioeconomic factors in neighboring zones, in percentage. (See Appendix A)
Neighb. number of infrastructure			x	x	Average number of infrastructure in neighboring zones. (See Appendix A)
Neighb. average price of soil			x	x	Average of soil price in neighboring zones, in Cape Verdean escudos (ECV).

OBS: The year 1969 was not considered in the OLS because the number of observations is insufficient (<30) and it does not meet the autocorrelation test assumptions.

Source: $^{+}$ Historical maps were obtained from National Library of Portugal; $^{++}$ Data from INE-CV—2000 and 2010 census. Data from 2000 census was used for the year 2003; $^{+++}$ Product from CMP [41]; $^{++++}$ The same 2010 data used in the delineation of urban areas, with information of number of floor in each single building footprints.

2.2.2. Population Data

The data about the population for each zone of Praia were available for the years 1970, 1980, 1990, 2000, and 2010 and were obtained from the National Institute of Statistics of Cape Verde (INE-CV) censuses. However, the data do not match all our cartography data, with the exception of the year 2010. For 1969, we considered the population data from the year 1970. Using this time series census data and assuming a linear growth rate, we estimated the population for all zones of the city of Praia for the years 1993 and 2003, using the AGR.

We used the Praia PDM projected population for the year 2020 to estimate the population for the year 2015, also using the AGR. Notably, one limitation that was identified in the projected data was that they assumed linear population growth for all the zones with an AGR of 3%. Therefore, for zones with a decreasing population, it is not recommendable to use the linear projection method [42]. For example, Platô, which has always recorded a decreasing population, showed an increase in such projection data. In order to solve this problem, one modification was made. We applied the geometrical method, using the same data, to project the population for 2020 for zones that have a decrease in population over time. The population for the year 2025 was also projected.

2.3. Delineation of Urban Areas and Mapping Urban Expansion

According to our definition, urban areas include building footprints, roads within 20 m of such buildings, and all the vacant land located between the roads and building footprints within a 20-m distance. The aggregation of such data is based on a GIS algorithm, using aggregation distance. In this research, the aggregation distance was 20 m, implemented in aggregate polygons tools in ArcGIS software. The input data for this procedure should only be one dataset, thereby merging roads and building footprints (Figure 2b).

To include only the roads within a 20-m distance of the building footprints, a shapefile fishnet of 20 m by 20 m was created and then intersected with the roads for each year. The results are the same as road input, but split into small sections. This technique allows us to select by location only the parts of roads within a certain distance of building footprints (Figure 3a).

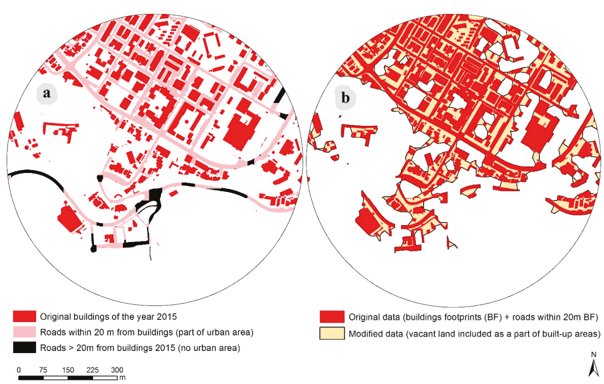

Figure 3. Delineation of built-up areas: (**a**) selected roads as a part of urban areas in pink, roads within 20 m of building footprints; rejected roads as a part of urban areas in black, roads more than 20 m from building footprints; (**b**) outputs of urban areas delineation (both the yellow and the red areas are considered as built-up areas).

Proceeding in this away, we delineated, mapped, and quantified the urban expansion of the city of Praia from 1969 to 2015 by overlapping the different time-series urban patches and calculating the corresponding areas in a GIS environment. Subsequently, we calculated the built-up areas within each zone of Praia, applying intersection operation. Thereafter, we calculated the land consumption per capita (LCR) [16] and utilization density of urban areas (UD) [6].

2.4. Urban Expansion and Its Candidate Driving Forces

Besides population, other factors may influence urban expansion [43,44], influencing in different manners for each period [15]. The candidate driving forces shown in Table 1 were chosen by analyzing historical documents for Praia city and the literature (i.e., [45,46]). Using OLS regression, we explored the relationship between the built-up area (changed urban area from one period to another) and such candidates' explanatory variables. Independent variables were calculated based on patches of changed urban areas in each zone and for each year separately, but not for accumulative urban patches. This was done in order to reduce the subjectivity of Euclidean distance due to the disparities of size of zones (Appendix A (Table A1)). This method was not used to calculate the road density. Euclidean distance was considered in the distance variables, and DEM generated from one-meter distance contour (INGT) was used in the calculation of elevation and slope. The neighborhood variables were calculated using the ArcGIS polygon neighbors tool, which creates a table with statistics based on polygon contiguity (coincident edges).

Industrial areas were erased before the calculation of changed built-up areas. The socioeconomic indicators, price of soil, and average number of floors used as candidate variables for the year 2015 are the same as for 2010. However, we used the zone average number of floors and soil price instead of patches of changed urban areas (Table 1).

2.5. OLS Regression Requirements

A properly specified OLS regression can predict the variability in the dependent variable [47] since it meets all of the following requirements: (i) coefficients for model explanatory variables, which are statistically significant and have the expected sign; (ii) explanatory variables free of multicollinearity; (iii) model not biased (heteroscedasticity); (iv) residuals normally distributed; (v) no missing key explanatory variables; (vi) residuals free of spatial autocorrelation; and (vii) enough adjusted R-Squared to explain the variability of the dependent variable [48–51]. The exploratory regression tool (ArcGIS 10.1 (Esri, Redlands, CA, USA) helped us to find a good OLS model by attempting every possible combination for a set of explanatory variables; we selected the one that met all of the requirements of the OLS method and, notably, had a high-adjusted R^2 [52].

3. Results

3.1. Assessment of Urban Expansion

Figure 4 shows the borders of urban areas (UA) in the city of Praia in the years 1969, 1993, 2003, 2010, and 2015. The total urban areas for the five respective times were estimated at 97, 232, 760, 913, and 1028 ha (Table 2). Analysis of the annual rate of change between the four study periods (1969–1993, 1993–2003, 2003–2010, and 2010–2015) showed that the area expanded by 12.7% (12.3 ha/year), 9.4% (36.8 ha/year), 2.9% (21.8 ha/year), and 2.5% (22.9 ha/year) respectively, with an average rate of 20.9% (20.2 ha/year) for the whole study period, from 1969 to 2015 (Table 2).

Table 2. Dynamic of urban expansion in the city of Praia (1969, 1993, 2003, 2010 and 2015).

Periods	Range (years)	Changed UA (ha)	Pop. Growth (persons)	Annual UA Growth (ha)	Annual pop. Growth (persons)	Rate of Change in UA (%)	Rate of Change in Pop. (%)
1969–1993	24	295	47,368	12.3	1974	304.1	205.2
1993–2003	10	368	32,751	36.8	3275	93.8	46.5
2003–2010	7	153	21,525	21.8	3075	20.1	20.9
2010–2015	5	114	18,866	22.9	3773	12.5	15.1

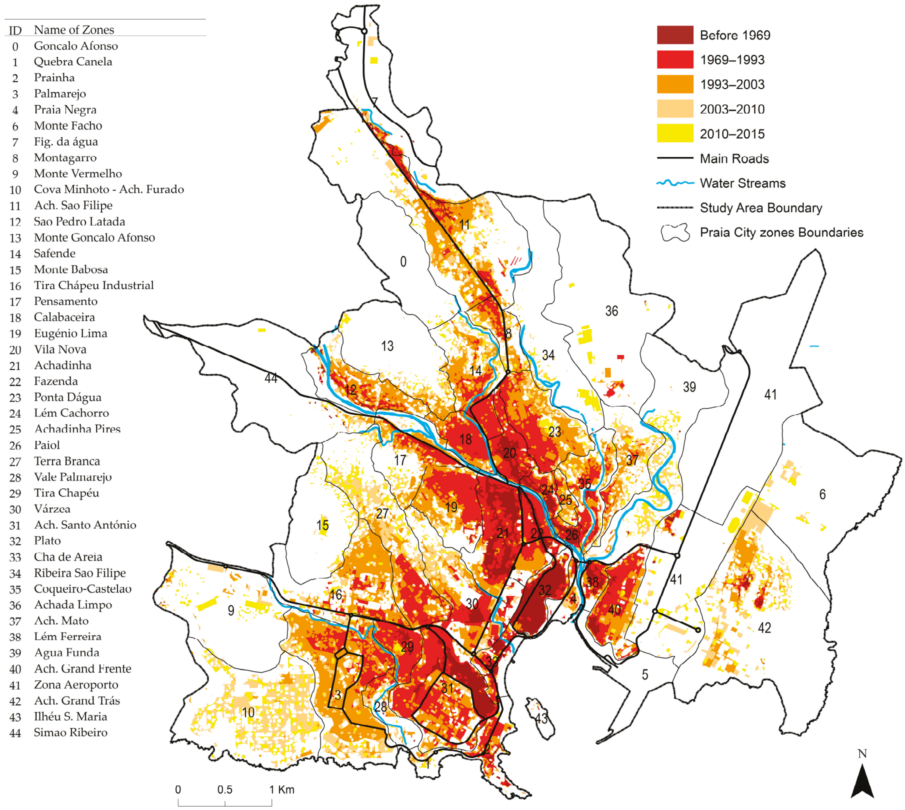

Figure 4. Built-up areas expansion at five points in time at the city of Praia: 1969, 1993, 2003, 2010, and 2015 (source: built-up areas in 1993, 2003, 2010: planimetric data—vector datasets (INGT), built-up areas in 1969: own digitization based on national topographic maps at the scale 1:25,000 (INGT), built-up areas in 2015, own digitization based in Google Earth images obtained from El-Shayal Smart software (Smart GIS, Cairo, Egypt).

In parallel we registered, for the annual rate of change in population of Praia city for the corresponding five respective periods, an increase of 8.6% (1974 people/year), 4.7% (3275 people/year), 2.9% (3075 people/year), and 3% (3773 people/year) (Table 2), with an average rate of 11.3% (2620 people/year) for the whole study period. Therefore, we noted a small decrease in inhabitants per year for 2003–2010 and a slight increase for 2010–2015, the same as in urban areas. The rate of change in urban areas from 1969 until 2003 was much higher than the rate of change in population. After this time, the opposite was noted (Table 2, Figure 5b).

Table 3 shows that LCR generally increased from 42.1 m^2/person in 1969 to 71.6 m^2/person in 2015, but more or less constantly from 2003 to 2015 (73.7 vs. 71.6 m^2/person). In contrast, we assessed a decrease in UD of −41.2% from 1969 (238 people/ha) to 2015 (140 people/ha) and an annual growth rate of −0.9%. Nevertheless, we noted a consistency over the last 12 years (136, 137, and 140 people/ha for 2003, 2010, and 2015, respectively).

Table 3. The relationship between urban area and population in the study area over time (1969, 1993, 2003, 2010 and 2015): urban area per person and population per unit of urban area (hectare).

Years	Urban Area (ha)	Population (persons)	Urban Area per Person (m^2)	Person per Unit of Urban Area (ha)
1969	97	23,082	42.1	238
1993	392	70,450	55.7	180
2003	760	103,201	73.7	136
2010	913	124,726	73.2	137
2015	1028	143,592	71.6	140

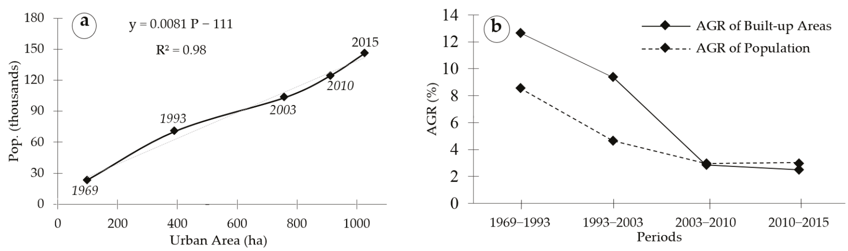

Figure 5. (**a**) The relationship between built-up areas and population (Pop.) during a 46-year period in the city of Praia, from 1969 to 2015 (including industrial areas); (**b**) annual growth rate of built-up areas and population in the city of Praia for 1969–1993, 1993–2003, 2003–2010, and 2010–2015.

Figure 5a shows that total population and urban area have a robust linear relationship with time in the study area (R^2 = 0.98, $\alpha < 0.05$). Using the equation plotted in Figure 5a, we predicted that the size of urban areas will be 1462 ha by 2025.

At zonal levels, the scenario varies across the period of study. For instance, older zones tended to be higher in density than recent zones, although some had a decline in population during that time. Zones like Platô (the historic center) are not a part of this trend, because it is a commercial and service zone. In 2015, Platô had only 19.9% of the 1969 population, a loss of about 3490 residents. Moreover, lower UD and higher LCR (Figure 6) occur due to a concentration of infrastructure that does not require housing (e.g., sports facilities, government institutions, commercial and industrial spaces with warehouses, military barracks). A higher UD during the period of analysis was observed for the years 1969 (Platô, Fazenda, Lém Ferreira, Achadinha, Achada Santo António, Paiol, and Tira Chapéu) and 1993 (Achada Grande Trás, Achada São Filipe, Achada Mato, Achadinha, Paiol, and Tira Chapéu).

Montagarro, Calabaceira, and Lém Cachorro have always shown an increase in UD from 1969 to 2015, unlike Platô, Cova Minhoto-Achada Furada, Ribeira São Filipe, Água Funda, and Achada Grande Trás, which have always decreased. Most of the remaining zones have shown a decline in UD.

Even though the population is strongly correlated with urban areas (Figure 5a), this relationship is not necessarily reflected for all zones in the study area. Therefore, further analysis should be done to verify that in fact the change in built-up area occurs in zones where the population has increased. Thus, in order to understand this phenomenon, we applied regression analysis, using said explanatory variables (Table 1).

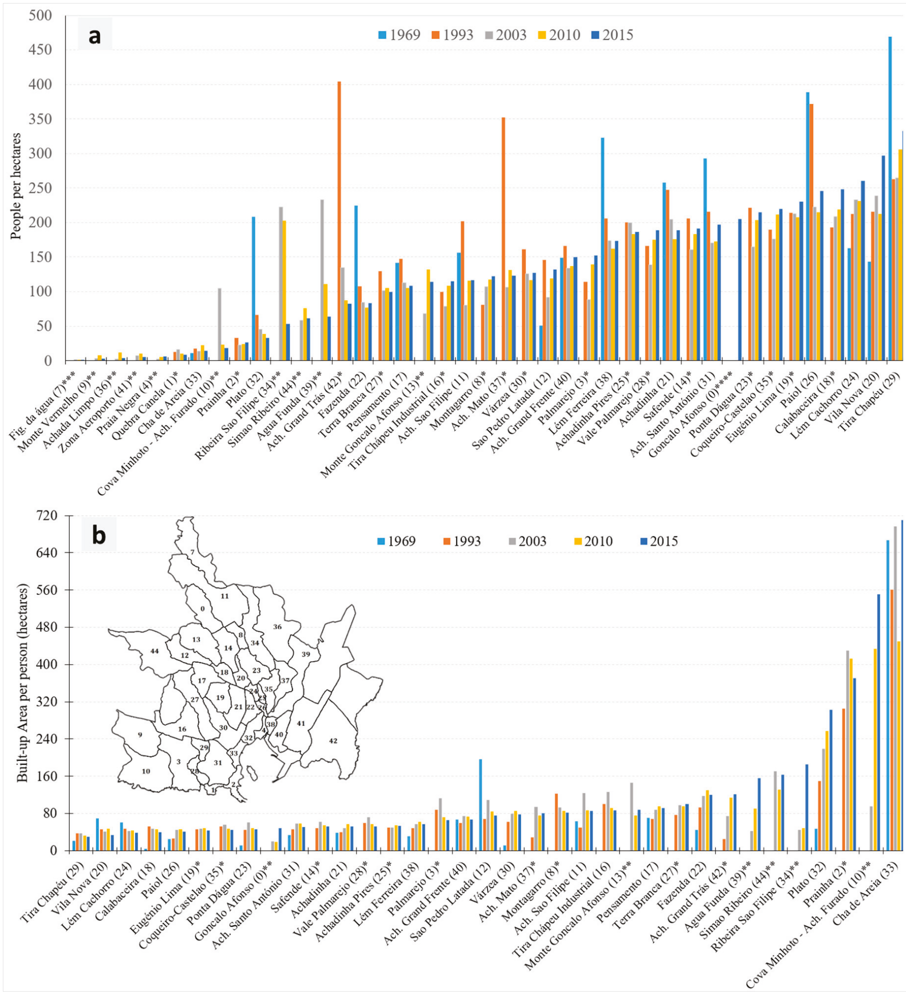

Figure 6. (**a**) Population per hectares of built-up areas (UD) at zonal levels at five points in time from 1969 to 2015; (**b**) urban areas per person (LCR) in the city of Praia at zonal levels at five points in time from 1969 to 2015. * indicates missing data in one time step, and **** indicates missing data in four time steps, respectively.

3.2. Driving Forces of Urban Expansion in the Study Area

The population, age of zones, road density, distance to industrial zones, socioeconomic indicators, distance to arterial roads, neighborhood land available, neighborhood socioeconomic indicators, and distance to center have a positive relationship with urban expansion in Praia from 1993 to 2015. However, the combination of driving forces varies over time.

Table 4 shows how different factors have been driving urban expansion in different manners at different times. For instance, for 1993, only two variables, population and road density, explained 90% of variation in urban expansion; 81% was explained by population, distance from industrial zones, and road density in the year 2003; and 63% was explained by distance to arterial roads, road density, and extent of infrastructure in the year 2010. Meanwhile, distance to coast, road density, number of infrastructure, distance to urban perimeter, and industrial areas explained 65% of variation in urban expansion for the year 2015. Such variables have preserved their positive effect on the expansion of urban areas over time (Appendix B). On the other hand, variables such as distance to the coast, slope, average number of floors, extent of infrastructure, industrial zones, and distance to the urban perimeter have shown a consistent negative relationship with urban expansion.

Variables such as distance to the university, soil price, neighborhood soil price, and neighborhood extent of infrastructure were a part of some model with no defensible relationship and with a weak R^2 (< 0.60). Elevation does not have a statistically significant relationship with urban expansion in our study area.

Table 4. Higher adjusted R2 OLS passing models outputs at five points in time (1969, 1993, 2003, 2010 and 2015).

Summary OLS—1993 (B)		*n* = 32; *variable* = 2			
Variable	**Coefficient**	**Std-error**	***t*-statistic**	**Probability**	**VIF**
Intercept	3985.820589	6785.842575	0.587373	0.561498	
Population	31.809366	2.517843	12.633579	0.000000 *	1.108274
Road density	12,100.056800	7.480310	7.480310	0.009483 *	1.108274
Adjusted R^2	0.907012				
R^2	0.913011				
AICc	745.776307				
F-statistic	152.187464	Prob(>*F*), (2, 29) degrees of freedom:			0.000000 *
Wald statistic	518.634477	Prob(>chi-squared), (2) degrees of freedom:			0.000000 *
Koenker (BP) statistic	2.417524	Prob(>chi-squared), (2) degrees of freedom:			0.298567
Jarque–Bera statistic	0.303049	Prob(>chi-squared), (2) degrees of freedom:			0.859397
Summary OLS—2003 (C)		*n* = 38; *variable* = 3			
Variable	**Coefficient**	**Std-error**	**t-statistic**	**Robust_Pr**	**VIF**
Intercept	−44,427.098031	16,544.293472	−2.685343	0.016221 *	
Population	76.301495	8.050794	9.477511	0.000000 *	1.149402
Distance from industrial zone	38.399808	15.376331	2.497332	0.032221 *	1.018675
Road density	15,919.911821	3605.625972	4.415298	0.003162 *	1.160896
Adjusted R^2	0.814749				
R^2	0.829769				
AICc	936.490199				
F-statistic	55.242897	Prob(>*F*), (3, 34) degrees of freedom:			0.000000 *
Wald statistic	74.820247	Prob(>chi-squared), (3) degrees of freedom:			0.000000 *
Koenker (BP) statistic	15.385867	Prob(>chi-squared), (3) degrees of freedom:			0.001515 *
Jarque–Bera statistic	0.672661	Prob(>chi-squared), (2) degrees of freedom:			0.714387
Summary OLS—2010 (D)		*n* = 41; *variable* = 3			
Variable	**Coefficient**	**Std-error**	**t-statistic**	**Robust_Pr**	**VIF**
Intercept	−15,060.608501	9754.185620	−1.544015	0.064277	-
Distance to arterial roads	60.146585	15.354631	3.917163	0.003010 *	1.015134
Road density	18,220.520796	2613.066032	6.972851	0.000506 *	1.677798
Number of infrastructure	−13,913.000078	3234.758763	−4.301094	0.008496 *	1.659595
Adjusted R^2	0.631806				
R^2	0.659420				
AICc	979.427171				
F-statistic	23.879429	Prob(>*F*), (3, 37) degrees of freedom:			0.000000 *
Wald statistic	25.943000	Prob(>chi-squared), (3) degrees of freedom:			0.000010 *
Koenker (BP) statistic	16.152417	Prob(>chi-squared), (3) degrees of freedom:			0.001055 *
Jarque–Bera statistic	1.836169	Prob(>chi-squared), (5) degrees of freedom:			0.399283

Table 4. *Cont.*

Summary OLS—2015 (E)		n = 41; *variable* = 5			
Variable	**Coefficient**	**Std-error**	**t-statistic**	**Probability**	**VIF**
Intercept	67,497.851765	13,740.383921	4.912370	0.000021 *	-
Distance to coast	−10.771943	4.029534	−2.673247	0.011336 *	3.303922
Road density	9695.252926	1500.361755	6.461944	0.000000 *	1.894193
Number of infrastructure	−6261.266625	1804.017556	−3.470735	0.001397 *	1.890089
Industrial area (binary variable)	−34,236.263490	9810.436301	−3.489780	0.001325 *	1.502953
Distance to urban perimeter	−37.700956	7.200143	−5.236140	0.000008 *	3.135334
Adjusted R^2	0.657658				
R^2	0.700451				
AICc	931.208517				
F-statistic	16.368468	Prob(>*F*), (5,35) degrees of freedom:			0.000000 *
Wald statistic	71.455642	Prob(>chi-squared), (5) degrees of freedom:			0.000000 *
Koenker (BP) statistic	5.562527	Prob(>chi-squared), (2) degrees of freedom:			0.351138
Jarque–Bera statistic	2.876546	Prob(>chi-squared), (2) degrees of freedom:			0.237337

* Statistically significant at 0.05 level. The variance inflation factor (VIF) is a measure of the redundancy or multicollinearity among explanatory variables. This measure should be less than 7.5. The independent variables were statistically significant at the 0.05 level and their coefficient represents their strength and type of relationship with urban expansion. The F-statistic value and its associated p-value show the statistical significance of the models. When the Koenker (BP) Statistic test is statistically significant (p < 0.05), the relationships modeled are not consistent—either due to non-stationarity or heteroscedasticity. Robust Probabilities (Robust_Pr) determine coefficient significance and the Wald Statistic determines overall model significance, when the Koenker statistic is statistically significant. The Jarque–Bera Statisic test is not statistically significant (p < 0.05) in any model, showing normally distributed residuals. The R-Squared and Akaike's Information Criterion (AICc) measure the model fit [52].

3.3. OLS Results Interpretation and Validation

Table 4 shows all the results of the selected OLS passing models for each year of analysis (1993, 2003, 2010, and 2015) and their interpretation. Passing models are those that satisfied all the OLS regression requirements, as previously discussed. The aim was to reconcile higher R^2 and explanatory variables with a defensible variable relationship with urban expansion for each period of analysis.

3.4. Historic Driving Forces of Urban Expansion

For 1993, we verified a positive relationship between population and urban expansion. The results show that the denser the roads, the more built-up the areas. Other models with high adjusted R^2 were selected (Appendix B) in order to appreciate how the combination of other variables helps to explain the urban expansion process in the said period. For example, the association of slope, distance to the coast, and population explains about 75% of the variation in built-up growth. Both slope and distance to the coast interact negatively with urban expansion.

For the year 2003, the model with higher adjusted R^2 (0.81) contains, apart from population and road density variables, the distance from industrial zones. The population and road density variables kept their relationship with urban expansion. The distance from industrial zones variables coefficient suggested that urban expansion tends to occur further from industrial areas. Other groups of models that report satisfactory adjusted R^2 (> 0.70) with a certain explanatory power and defensible relationship are shown in Appendix B. For example, model C2 suggests that an increase in socioeconomic indicators positively impacts urban expansion, when associated with the population, distance from industrial zones and mean slope variables. In all four models (i.e., C1, C2, C3, and C4), population kept its positive relationship with urban expansion. In model C3, the age of the zone also reported a positive relationship, when associated with population, distance from industrial zones, and slope—the same as model C4.

For 2010, 63% of the variability in urban expansion may be explained by only three variables (Table 4). The population is not statistically significant, although we expected the contrary. Another model with a lower R^2 (Appendix B, Table A2 (D2)) shows that, besides the distance to arterial roads, road density, and neighborhood land available, the number of floors and neighborhood socioeconomic indicators influenced the trend of urban expansion in the city of Praia. Among these variables, only number of floors has a negative relationship with urban expansion. These facts will be clarified in the discussion section. For the subsequent period, 2010–2015, the distance to the coast and road density kept their positive relationship with urban expansion. By contrast, the extent of infrastructure kept its negative relationship with urban expansion, as expected (Table 4E), e.g., Água Funda, Monte Vermelho, and Terra Branca. The last three variables associated with industrial areas (dummy variables) and distance to urban perimeter together explain about 65% of the urban expansion of the city of Praia.

This is similar to the second chosen model, which shows another combination of explanatory variables, with distance to center instead of extent of infrastructure. We noticed that from 1993 to 2015, all the statistically significant explanatory variables have kept their relationship with urban expansion over time, suggesting some consistency.

4. Discussion

4.1. Urban Expansion and Comparison with Other Studies

Rapid urban expansion in the city of Praia started in 1975 after the national independence. With a succession of years of drought and the emergence of industrial clusters, people eventually moved from rural areas and other islands to the capital city [46]. Therefore, the majority of urban expansion in the study period 1969–1993 was concentrated during the interval 1975–1993. For the year 1969, the higher UD (238 people/ha) compared to the subsequent periods may justify the lower annual expansion of urban areas (12.3 ha/year) and the compact growth (Figure 3). Although we registered a decrease in UD from 1969 to 1993, the annual decrease is less than in the period 1993 to 2003 (approx. 2 people/ha vs. approx. 4 people/ha). From 1993 to 2003, this decrease in UD represents an unnecessary increase of urban area to accommodate 1472 new people, which can explain the higher urban expansion in that period. However, the absence of jobs data is a weakness of this metric.

The approval of the first law for the policy on territorial management and urbanism in 1993 (*LBOTPU–Lei no. 85/IV/93*) and the extensive revision of the law of soil in 2007 (*DLeg. no. 2/2007*) have changed the regulation and control of land use, e.g., the obligation to develop urban plans for municipality councils. In the city of Praia, the development of such plans was more significant after the year 2000, which may be associated with the decline in urban expansion from 2003 to 2015. In addition, the impact of the multi-family buildings project "Casa para todos—Housing for Everybody" started in 2010, which led to the construction of 2100 dwellings to reduce the housing deficit and pressure on the land [13].

The built-up area of Praia city increased 10-fold from 1969 to 2015, while the population increased 6-fold, indicating an increase in soil consumption. Angel et al. [22] have found the same trend in 120 cities, while Gao et al. [53] observed it in 438 small Chinese cities. The annual decrease rate in UD in the city of Praia is 0.9% versus the 1.7% reported by Angel.

Praia recorded rapid horizontal expansion. The 97 ha of built-up area in 1969 grew to 1028 ha in 2015 at an average growth rate of about 21% (20 ha/year). Literature on the urban expansion rate at the scale of this study is scant as most previous studies focused on larger cities [6]. However, Haregeweyn et al. [16] reported an annual growth rate of urban areas of 31% (88 ha/year) in Bahir Dar city, Ethiopia, for the period 1957–2009, while Gao et al. [53] reported a 10.8% growth rate in China during the period 1990–2010. Cape Verde, a small territory (4033 km^2) compared to the said countries, recorded only 10% of arable land. The total urban areas of Praia in 2015 represent 11.2% of the total urban built-up area in Cape Verde (9178 ha), the latter of which was projected by Angel [5], and approximately 1% of the Santiago Island surface.

4.2. Historical Driving Forces and Comparison with Other Studies

Although the driving forces did not necessarily constantly influence urban expansion for all four periods of analysis (Table 4 and Appendix B), their effect on urban expansion was maintained over time.

Previous studies have shown population growth as a primary driving force of urban expansion [54,55]. However, our findings show that population growth did not always influence urban expansion in Praia city. The population strongly influenced urban expansion in Praia city only until 2003. Nevertheless, this relationship became weaker after that period (not statistically significant). This means that, even though the urban areas of Praia grew linearly with population (Figure 5a), such growth did not occur in the zones where we verified population growth. This fact may be associated with the desire for second homes [23]: by constructing a new house and keeping the permanent residence in the habitual zones is quite common in Praia. For example, in Cova Minhoto-Achada Furada (*ID* = 10 on the map), even though we registered a faster urban expansion (Figure 7), we registered lower UD, similar to Palmarejo (*ID* = 3).

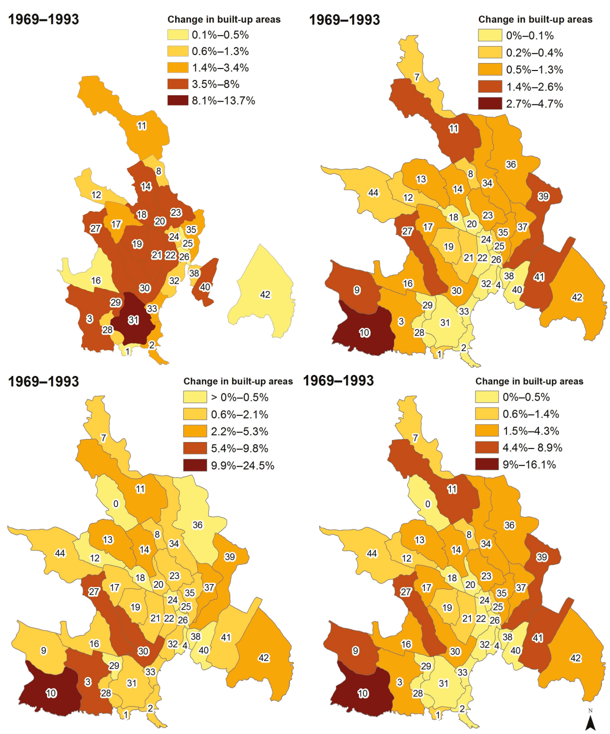

Figure 7. Percentage of change in the built-up area in each zone relative to the total change of built-up area in the city of Praia in time *i* in four periods (1969–1993, 1993–2003, 2003–2010 and 2010–2015).

From 1993 to 2003, zones further from industrial areas have registered more urban expansion than those close to them, and zones with industrial areas tend to have less urban expansion. Although this appears contradictory to previous studies [54,56], it may be related to locations of mostly industrial areas between zones with consolidated urban areas (e.g., Praia Negra) and zones located far from public easements (e.g., Zona Aeroporto, Achada Grande Trás, and Achada Grande Frente), which negatively affect urban expansion. Such zones are also located in urban periphery with relatively weak public transport. On the other hand, large portions of land in such zones have been reserved by the government for future port and airport expansion [13]. As mentioned previously, industrial built-up areas were removed as part of urban areas (dependent variable) in order to approximate our understanding of residential behavior.

Our findings show that, for the period 2003–2010, zones with less infrastructure and further from arterial roads registered more expansion. This fact is contradictory to Pravitasari et al. [56] but, in the present study area, this was expected because a large part of the urban expansion in Praia occurs in peripheral zones (Figure 7). This is because Praia was dominated by edge-expansion growth (Figure 4) in the said period, but also because zones closer to the arterial roads were already consolidated. These zones have a prevalence of poverty and scarcity of basic infrastructure and weak land-use controls (e.g., Água Funda, Achada Mato, Terra Branca, and Varzea) [36]. Additionally, even Cova Minhoto-Achada Furada, which is a prime zone, lacks infrastructure. The majority of Praia urban plans were more interested in producing lots of land, without ensuring the availability of basic infrastructure [13].

The higher socioeconomic indicators in the surroundings positively influence urban expansion in Praia. This means that people tend to live closer to areas that offer more opportunities for employment, urban infrastructure, and accessibility. We also observed, similar to previous studies [23], that neighborhood land availability has influenced urban expansion, showing a people's preference for living in open spaces in Praia.

Our results suggest that the fewer floors there are in buildings, the more urban expansion is recorded. This means that low-rise buildings promote more construction and consequently horizontal expansion. In fact, vertical construction of buildings allows for an improvement in the utilization of land, with more people living in the same space, thereby preserving open and natural spaces [57,58].

Sometimes due to the irregularity of topography and coast lines, some zones seem to be close to the center if we consider the Euclidian distance. However, such zones are merely peripheral zones and not really close if we consider the road network. Therefore, it is useful to include both variables, distance to the center and distance to the urban perimeter, to reduce the subjectivity of the center effect, since they do not present multicollinearity problems.

Few studies have been conducted regarding urban expansion in SIDS, although they have been experiencing rapid urban expansion in contrast to their limited arable soil [9]. This study fills these gaps and will also be of particular interest to those who aim to use vector data to delineate urban settlements. This technique can also be applied after high-resolution image classification in order to smooth the outputs. In addition, it can be a helpful instrument for policy-makers in the urban planning process.

Most studies have used accumulative built-up area as a dependent variable in the regression models for the exploration of their driving forces [11,16], which has often shown a strong correlation between urban area and population. However, we believe that urban area for some zones cannot be a result of population, especially where we registered a decrease in population. For example, Platô was totally consolidated in 1993 (Figure 4), when it had approximately 1561 inhabitants. Therefore, it is not factual to relate such urban areas from the year 1993 with 867 inhabitants from the year 2015, assuming some relationship that does not exist. Therefore, our method allows us to better capture variations over time and better relate the built-up areas and population by considering both changes over the same period of time.

This study has its limitations. Although the technique used to obtain building footprints for the year 2015 is useful, specifically for urban scales where high spatial resolution images are a concern, it is still limited where urban areas have significant vegetation that may render it difficult to define the boundaries of the building footprints.

5. Conclusions

Based on the integration of multi-temporal data into the consistent vector dataset, we observed a rapid urban expansion in Praia during the period 1969–2015. The urban land increased by 960%, from 97 ha to 1028 ha. The majority of Praia's built-up areas (62.8%) have emerged in the last 22 years, showing the fast urbanization process in recent decades. However, the period 1993–2003 was more dynamic (36.8 ha/year). The UD had decreased (238 people/ha to 140 people/ha), with a consequent increase in LCR (42.1 m^2/person to 71.6 m^2/person).

Different factors have driven the urban expansion in Praia in different periods. The population has influenced the urban expansion from 1993 to 2003. From this time until 2015, significant urban expansion did not occur in zones where we verified population growth. Therefore, population and density of roads showed a positive relationship with urban expansion and distance to the coast and slope, but a negative relationship in the period 1969–1993. Population, distance from industrial zones, density of roads, socioeconomic indicators, and age of zones positively influenced urban expansion during 1993–2003, while slope negatively influenced it. The distance to arterial roads, density of roads, neighborhood land available, and socioeconomic indicators positively influenced the urban expansion during the period 2003–2010. The infrastructure and number of floors have a negative relationship. After this period until 2015, the density of roads and distance to center had a positive effect on urban expansion. The distance to the coast, infrastructure, industrial zone, and distance from urban perimeter have also influenced urban expansion, but with a negative relationship.

Planners and policy-makers should consider the increase in land consumption in their urban plans, by qualifying the spaces for future urban expansion, promoting vertical construction, coverage for infrastructure, and improvement of accessibility in the periphery while improving the quality of life of the inhabitants. This study can provide useful data that will contribute to decision makers' understanding of urban expansion and predictions of land area for future planning.

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Appendix A. Calculation of Explanatory Variables

Table A1. Calculation of some explanatory variables.

Variables	Description
Socioeconomics variables	Socioeconomic variables are the average of percentage of population in each zone living in the following conditions (based on our calculation): Source of water resources: Domiciliary water connection and auto-tank; Source of energy for cooking: Gas, electricity; Source of energy for illumination: Electricity (2003 and 2010) Sanitation: domiciliary connection to septic tanks or sewage system (2003); Possession of goods and services: Refrigerator, television (2003) in addition to stove, washing machine, air conditioning, automobile, telephone, computer, cable TV, Internet (2010); and level of education: High school, higher education, (2003); Comfort level: Median, high and very high (2010). We considered these variables as indicators of level of social life in each zone.
Average price of soil	A shapefile that includes the delimitation of price of soil in the city of Praia, was intersected with the administrative zonal boundaries to calculate the average price of soil for each zone using the right formula: Where, *ASP* is the average of price of soil in zone *i*; SP_1 is the soil price in the zone *i*; ASP_1 is the area occupied by the soil price *i*; *AZ* is the area of the zone (or changed urban area) where ASP_1 is located. $ASP = \sum_{i=1}^{n} SP_1 \times \frac{A_{SP_1}}{AZ}$

Table A1. *Cont.*

Variables	Description	
Avg. number of floors	The number of floors shapefile were intersected with the administrative zones of Praia (2015) or patches grown for the year 2010 and then we summarized the average number of floors for each zone using ArcGIS.	
Number of infrastructure	The number of infrastructure was obtained by georeferencing and digitizing the map of infrastructure (CMP, 2014).	
Land available	For the calculation of land available for future urban expansion, we excluded the areas considered as not feasible for the construction of buildings. Such areas include geophysical limitations: mountains, water streams, slope steeper than 45°.	
Road density	The roads were classified as arterial roads, main roads, and secondary roads. Arterial roads are the highways. Main roads include arterial roads and all the roads that give access to each zone in particular.	$Drd = \frac{0.7AMrd+0.3ASrd}{AZ}$
	Secondary roads are roads that allow the circulation inside each zone. So, the density of roads for each zone was calculated by area weighted by type of roads (70% for main roads and 30% for secondary roads). Where, *Drd* is road density index, *AMrd* is the area (m^2) of the main roads in zone *i*, *ASrd* is the area (m^2) of secondary roads in the zone *i* and *AZ* is the size of zone.	

Appendix B. OLS Model Results

Table A2. Other interesting models: summary.

Summary OLS—1993 (B2)	***n* = 32; *variable* = 3**				
Variable	Coefficient	Std-error	t-statistic	Robust_Pr	VIF
Intercept	65,668.825059	18,085.944265	3.630932	0.006256 *	
Population	36.541527	3.944321	9.264340	0.000000 *	1.049561
Distance to coast	−8.731622	6.129818	−1.424450	0.043948 *	1.009154
Mean slope	−3185.661099	1808.962638	−1.761043	0.023930 *	1.053457
Adjusted R^2	0.759034				
R^2	0.782354				
AICc	777.949357				
F-statistic	33.549664	Prob(>*F*), (3, 28) degrees of freedom:			0.000000 *
Wald statistic	63.931454	Prob(>chi-squared), (3) degrees of freedom:			0.000000 *
Koenker (BP) statistic	8.321808	Prob(>chi-squared), (3) degrees of freedom:			0.039809 *
Jarque-Bera statistic	2.419131	Prob(>chi-squared), (2) degrees of freedom:			0.298327
Summary OLS—2003 (C2)	***n* = 38; *variable* = 4**				
Variable	Coefficient	Std-error	t-statistic	Robust_Pr	VIF
Intercept	3547.167864	25,570.606772	0.138721	0.810405	
Population	84.047560	8.371864	10.039288	0.000001 *	1.034508
Distance from industrial zone	51.133256	17.881194	2.859611	0.018732 *	1.146617
Mean slope	−7786.452316	2664.749176	−2.922021	0.004443 *	1.131716
Socioeconomic factors	9851.451136	4694.156520	2.098663	0.005870 *	1.058790
Adjusted R^2	0.777430				
R^2	0.801492				
AICc	945.164522				
F-statistic	33.309981	Prob(>*F*), (4, 33) degrees of freedom:			0.000000 *
Wald statistic	51.611040	Prob(>chi-squared), (4) degrees of freedom:			0.000000 *
Koenker (BP) statistic	16.308520	Prob(>chi-squared), (4) degrees of freedom:			0.002632 *
Jarque-Bera statistic	0.211597	Prob(>chi-squared), (2) degrees of freedom:			0.899606
Summary OLS—2003 (C3)	***n* = 38; *variable* = 4**				
Variable	Coefficient	Std-error	t-statistic	Robust_Pr	VIF
Intercept	12,879.160852	23,960.185097	0.537523	0.410583	
Population	88.365231	8.423218	10.490674	0.000001 *	1.031689
Age of Zone	568.907423	289.978593	1.961895	0.001423 *	1.131379
Distance from industrial zone	53.393931	18.336335	2.911919	0.011392 *	1.187829
Mean slope	−8310.379996	2737.885508	−3.035328	0.003002 *	1.176952

Table A2. *Cont.*

Adjusted R^2	0.774076				
R^2	0.798500				
AICc	945.732950				
F-statistic	32.692927	Prob(>F), (4, 33) degrees of freedom:			0.000000 *
Wald statistic	53.192196	Prob(>chi-squared), (4) degrees of freedom:			0.000000 *
Koenker (BP) statistic	17.325807	Prob(>chi-squared), (4) degrees of freedom:			0.001671 *
Jarque-Bera statistic	0.526457	Prob(>chi-squared), (2) degrees of freedom:			0.768566
Summary OL—2003 (C4)	***n* = 38; *variable* = 3**				
Variable	Coefficient	Std-error	t-statistic	Robust_Pr	VIF
Intercept	37,457.392394	24,768.187780	1.512319	0.061513	
Population	89.306533	9.296813	9.606145	0.000001 *	1.030170
Age of zone	341.587770	308.464408	1.107381	0.032554 *	1.049383
Mean slope	−5556.040099	2837.863428	−1.957825	0.033879 *	1.036475
Adjusted R^2	0.724377				
R^2	0.746725				
AICc	951.588354				
F-statistic	33.413816	Prob(>*F*), (3, 34) degrees of freedom:			0.000000 *
Wald statistic	41.233657	Prob(>chi-squared), (3) degrees of freedom:			0.000000 *
Koenker (BP) statistic	13.505063	Prob(>chi-squared), (3) degrees of freedom:			0.003662 *
Jarque-Bera statistic	3.505962	Prob(>chi-squared), (2) degrees of freedom:			0.173257
Summary OLS—2003 (C5)	***n* = 38; *variable* = 2**				
Variable	Coefficient	Std-error	t-statistic	Robust_Pr	VIF
Intercept	−16,641.976141	13,128.577735	−1.267615	0.136854	
Population	77.976537	8.602076	9.064851	0.000000 *	1.141424
Road density	14,753.736779	3.848730	3.848730	0.006231 *	1.141424
Adjusted R^2	0.787032				
R^2	0.798543				
AICc	940.227212				
F-statistic	69.367333	Prob(>*F*), (2, 35) degrees of freedom:			0.000000 *
Wald statistic	69.817332	Prob(>chi-squared), (2) degrees of freedom:			0.000000 *
Koenker (BP) statistic	10.162278	Prob(>chi-squared), (2) degrees of freedom:			0.006213 *
Jarque-Bera statistic	1.541636	Prob(>chi-squared), (2) degrees of freedom:			0.462635
Summary OLS—2003 (C6)	***n* = 38; *variable* = 2**				
Variable	Coefficient	Std-error	t-statistic	Robust_Pr	VIF
Intercept	46,550.009155	23,443.004139	1.985667	0.042692 *	
Population	87.899806	9.239340	9.513645	0.000001 *	1.010936
Mean slope	−5062.737893	2811.728063	−1.800579	0.047269 *	1.010936
Adjusted R^2	0.722595				
R^2	0.737590				
AICc	950.271901				
F-statistic	49.189541	Prob(>*F*), (2,35) degrees of freedom:			0.000000 *
Wald statistic	38.190853	Prob(>chi-squared), (2) degrees of freedom:			0.000000 *
Koenker (BP) statistic	11.661848	Prob(>chi-squared), (2) degrees of freedom:			0.002935 *
Jarque-Bera statistic	3.748749	Prob(>chi-squared), (2) degrees of freedom:			0.153451
Summary OLS—2010 (D2)	***n* = 41; *variable* = 5**				
Variable	Coefficient	Std-error	t-statistic	Robust_Pr	VIF
Intercept	−126,652.313013	37,469.726328	−3.380124	0.020394 *	
Distance to arterial roads	74.617275	17.078503	4.369076	0.001547 *	1.180858
Road density	14,318.952809	3392.340391	4.220966	0.001602 *	2.658833
Average number of floors	−34,505.961914	15,665.314281	−2.202698	0.010020 *	2.882851
Neighb. land available	0.065042	0.019144	3.397443	0.002504 *	2.053562
Neig. avg socioecon. indicat.	162.742782	42.136419	3.862283	0.006788 *	2.165538

Table A2. *Cont.*

Adjusted R^2	0.608417				
R^2	0.657365				
AICc	58.684142				
F-statistic	13.429898	Prob(>*F*), (5, 35) degrees of freedom:			0.000000 *
Wald statistic	23.205349	Prob(>chi-squared), (5) degrees of freedom:			0.000308 *
Koenker (BP) statistic	24.291281	Prob(>chi-squared), (5) degrees of freedom:			0.000191 *
Jarque-Bera statistic	3.896771	Prob(>chi-squared), (2) degrees of freedom:			0.142504
Summary OLS—2015 (E2)	***n* = 41; *variable* = 5**				
Variable	Coefficient	Std-error	t-statistic	Robust_Pr	VIF
Intercept	65,621.443897	13,909.629218	4.717699	0.000053 *	
Distance to left	14.197743	4.196104	3.383553	0.000543 *	2.561907
Distance to coast	−22.743622	4.950717	−4.594006	0.000317 *	4.923847
Road density	4894.662978	1229.073300	3.982401	0.006499 *	1.254978
Industrial area (binary variable)	−31846.651186	9884.405562	−3.221909	0.000304 *	1.506324
Distance to urban perimeter	−43.593186	7.053607	−6.180269	0.000003 *	2.970793
Adjusted R^2	0.653254				
R^2	0.696597				
AICc	931.732624				
F-statistic	23.879429	Prob(>*F*), (5, 35) degrees of freedom:			0.000000 *
Wald statistic	25.943000	Prob(>chi-squared), (5) degrees of freedom:			0.000000 *
Koenker (BP) statistic	16.152417	Prob(>chi-squared), (5) degrees of freedom:			0.002063 *
Jarque-Bera statistic	1.836169	Prob(>chi-squared), (2) degrees of freedom:			0.424394

* Statistically significant at 0.05 level.

References

1. Angel, S. The NYU Urban Expansion Program: A Primer. Available online: http://marroninstitute.nyu.edu/uploads/content/UEPrimer2015.pdf (accessed on 8 August 2017).
2. Brockerhoff, M.P. *An Urbanizing World*; Population Reference Bureau: Washington, DC, USA, 2000.
3. UNFPA. *State of World Population 2007: Unleashing the Potential of Urban Growth*; UNFPA: New York, NY, USA, 2007.
4. Jaeger, J.A.G.; Bertiller, R.; Schwick, C.; Kienast, F. Suitability criteria for measures of urban sprawl. *Ecol. Indic.* **2010**, *10*, 397–406. [CrossRef]
5. Angel, S.; Parent, J.; Civco, D.L.; Blei, A.M. *Atlas of Urban Expansion*; Lincoln Institute of Land Policy: Cambridge, MA, USA, 2012.
6. Nazarnia, N.; Schwick, C.; Jaeger, J.A.G. Accelerated urban sprawl in Montreal, Quebec City, and Zurich: Investigating the differences using time series 1951–2011. *Ecol. Indic.* **2016**, *60*, 1229–1251. [CrossRef]
7. Bhatta, B. *Analysis of Urban Growth and Sprawl from Remote Sensing Data (Advances in Geographic Information Science)*; Springer: Berlin, Germany, 2010.
8. UN-Habitat. *Urban Planning for City Leaders*; UN-Habitat: Nairobi, Kenya, 2013.
9. UN-Habitat. *Urbanization and Climate Change in Small Island Developing States*; UN-Habitat: Nairobi, Kenya, 2015.
10. UN-OHRLLS. *Small Islands Developing States:Small Islands Big(ger) Stakes*; UN-OHRLLS: New York, NY, USA, 2011.
11. Angel, S.; Parent, J.; Civco, D.L.; Blei, A.M.; Potere, D. *A Planet of Cities: Urban Land Cover Estimates and Projections for All Countries, 2000–2050*; Lincoln Institute of Land Policy: Cambridge, MA, USA, 2010.
12. UN-OHRLLS. *Small Island Developing States (SIDS) Statistics*; UN-OHRLLS: New York, NY, USA, 2012.
13. Câmara Municipal da Praia (CMP). *Proposta do Plano Director Municipal (Proposal of the Municipal Master Plan)*; CMP: Praia, Cape Verde, 2014.
14. Instituto Nacional de Gestão do Território (INGT). *Esquema Regional do Ordenamento do Território de Santiago (Regional Scheme of Territorial Planning for Santiago island)*; INGT: Praia, Cape Verde, 2010.
15. Li, X.; Zhou, W.; Ouyang, Z. Forty years of urban expansion in Beijing: What is the relative importance of physical, socioeconomic, and neighborhood factors? *Appl. Geogr.* **2013**, *38*, 1–10. [CrossRef]

16. Haregeweyn, N.; Fikadu, G.; Tsunekawa, A.; Tsubo, M.; Meshesha, D.T. The dynamics of urban expansion and its impacts on land use/land cover change and small-scale farmers living near the urban fringe: A case study of Bahir Dar, Ethiopia. *Landsc. Urban Plan.* **2012**, *106*, 149–157. [CrossRef]
17. Dubovyk, O.; Sliuzas, R.; Flacke, J. Spatio-temporal modelling of informal settlement development in Sancaktepe district, Istanbul, Turkey. *ISPRS J. Photogramm. Remote Sens.* **2011**, *66*, 235–246. [CrossRef]
18. Braimoh, A.K.; Onishi, T. Spatial determinants of urban land use change in Lagos, Nigeria. *Land Use Policy* **2007**, *24*, 502–515. [CrossRef]
19. Chen, J.; Chang, K.; Karacsonyi, D.; Zhang, X. Comparing urban land expansion and its driving factors in Shenzhen. *Habitat Int.* **2014**, *43*, 61–71. [CrossRef]
20. Lu, C.; Wu, Y.; Shen, Q.; Wang, H. Driving force of urban growth and regional planning: A case study of China's Guangdong Province. *Habitat Int.* **2013**, *40*, 35–41. [CrossRef]
21. Weilenmann, B.; Seidl, I.; Schulz, T. The socio-economic determinants of urban sprawl between 1980 and 2010 in Switzerland. *Landsc. Urban Plan.* **2017**, *157*, 468–482. [CrossRef]
22. Angel, S.; Sheppard, S.C.; Civco, D.L.; Buckley, R.; Chabaeva, A.; Gitlin, L.; Kraley, A.; Parent, J.; Perlin, M. *The Dynamics of Global Urban Expansion*; World Bank: Washington, DC, USA, 2005.
23. Ewing, R. Is Los Angeles-style sprawl desirable? *J. Am. Plan. Assoc.* **1997**, *63*, 107–126. [CrossRef]
24. Taubenböck, H.; Esch, T. Remote Sensing—An Effective Data Source for Urban Monitoring. 2011. Available online: https://earthzine.org/2011/07/20/remote-sensing-an-effective-data-source-for-urban-monitoring/ (accessed on 23 December 2016).
25. Deng, X.; Huang, J.; Rozelle, S.; Uchida, E. Growth, population and industrialization, and urban land expansion of China. *J. Urban Econ.* **2008**, *63*, 96–115. [CrossRef]
26. Kuang, W.; Liu, J.; Dong, J.; Chi, W.; Zhang, C. The rapid and massive urban and industrial land expansions in China between 1990 and 2010: A CLUD-based analysis of their trajectories, patterns, and drivers. *Landsc. Urban Plan.* **2016**, *145*, 21–33. [CrossRef]
27. Ferreira, J.A.; Condessa, B.; Castro, J.; Pinto, P. Urban settlements delimitation in low-density areas—An application to the municipality of Tomar (Portugal). *Landsc. Urban Plan.* **2010**, *97*, 156–167. [CrossRef]
28. Turker, M.; Koc-san, D. Building extraction from high-resolution optical spaceborne images using the integration of support vector machine (SVM) classification, Hough transformation and perceptual grouping. *Int. J. Appl. Earth Obs. Geoinf.* **2015**, *34*, 58–69. [CrossRef]
29. Harig, O.; Burghardt, D.; Hecht, R. A Supervised Approach to Delineate Built-Up Areas for Monitoring and Analysis of Settlements. *Int. J. Geo-Inf.* **2016**, *5*, 137. [CrossRef]
30. Millward, H. A vector GIS extension for generalization of binary polygon patterns. *Cartogr. Int. J. Geogr. Inf. Geovis.* **2004**, *39*, 55–64. [CrossRef]
31. Zhou, Q. Comparative Study of Approaches to Delineating Built-Up Areas Using Road Network Data. *Trans. GIS* **2015**. [CrossRef]
32. Carvalho, J.; Pais, C. A Ocupação Dispersa, à escala local, nas Cidades de Aveiro-Ílhavo e Évora: identificação e caracterização (The dispersed occupation at the local level, in the cities of Aveiro-Ílhavo and Évora: Identification and characterisation) in Portuguese. In Proceedings of the Seventh International Conference on Virtual Cities and Territories (7VCT), Lisbon, Portugal, 11–13 October 2011.
33. Silva, F.B.; Marques, T.S.; Delgado, C. Processos de expansão urbana e mudanças na paisagem: Ensaio metodológico (1950–2000) (Urban expansion process and change in the landscape: Methodological essay (1950–2000). In *Revista da Faculdade de Letras—Geografia*; Universidade do Porto: Porto, Portugal, 2012; pp. 161–183.
34. Jaeger, J.A.G.; Bertiller, R.; Schwick, C.; Cavens, D.; Kienast, F. Urban permeation of landscapes and sprawl per capita: New measures of urban sprawl. *Ecol. Indic.* **2010**, *10*, 427–441. [CrossRef]
35. Muhs, S.; Herold, H.; Meinel, G.; Burghardt, D.; Kretschmer, O. Computers, Environment and Urban Systems Automatic delineation of built-up area at urban block level from topographic maps. *CEUS* **2016**, *58*, 71–84. [CrossRef]
36. Tavares, C. *A Política de Solo na Política Urbana: A sua Relevância na Cidade Da Praia—Cabo Verde (The Urban Soil Policy: Its Relevance in the City of Praia—Cape Verde)*; Universidade Nova de Lisboa: Lisbon, Portugal, 2007.
37. Instituto Nacional de Estatistica de Cabo Verde (INE-CV). *Evolução da População Residente Urbana por Ilha e Concelho, Segundo os Censos de 1990–2010 (Evolution of the Urban Resident Population by Island and County, According to Censuses from 1990–2010)*; INE-CV: Praia, Cape Verde, 2010.

38. Instituto Nacional de Estatistica de Cabo Verde (INE-CV). *Produto Interno Bruto (PIB) por Ilha Série 2007–2012 (Gross Domestic Product (GDP) by Island, Series 2007–2012)*; INE-CV: Praia, Cape Verde, 2015.
39. Monteiro, S.; Veiga, É.; Fernandes, É.; Fernandes, H.; Rodrigues, J.; Cunha, L. Crescimento urbano espontâneo e riscos naturais na cidade da Praia (Cabo Verde)(Spontaneous urban growth and naturals hazards in the city of Praia—Cape Verde). *Cad. Geogr.* **2011**, *31*, 117–130.
40. El-Shayal, M.E.-S. First Arabian GIS software: A GIS, GPS, Database, Internet GIS software. In Proceedings of the International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences (GIS-IDEAS), Ho Chi Minh City (HCMC), Vietnam, 9–11 November 2006.
41. Câmara Municipal da Praia (CMP). *Que Altera os Preços de Alienação de Terrenos Municipais e Fixa a Fórmula de Cálculo de Ampliações e Mudanças de Uso (Amending the Sale of Municipal Land Price and the Fixed Magnifications of Calculation Formula and Land Use Change)*; Imprensa Nacional de Cabo Verde: Praia, Cape Verde, 2013; p. 17.
42. United Nations. *Methods of Estimating Total Population for Current Dates Methods of Estimating Total Population for Current Dates*; United Nations: New York, NY, USA, 1952.
43. Jaeger, J.A.G.; Schwick, C. Improving the measurement of urban sprawl: Weighted Urban Proliferation (WUP) and its application to Switzerland. *Ecol. Indic.* **2014**, *38*, 294–308. [CrossRef]
44. Wu, Y.; Li, S.; Yu, S. Monitoring urban expansion and its effects on land use and land cover changes in Guangzhou city, China. *Environ. Monit. Assess.* **2016**. [CrossRef] [PubMed]
45. Carneiro, L. Acerca do Crescimento Urbano no Terceiro Mundo: o caso de Cabo Verde visto através da Praia (About Urban Growth in the Third World: the case of Cape Verde seen through the Praia). *Garcia da Orta Série Geogr.* **1996**, *15*, 35–64.
46. Nascimento, J.M. La Croissante et le Systeme de Gestion et de Planification de la Ville de Praia, Rep. du Cap-Vert (Growth of the system of management and planning of the city of Praia, Cape Verde republic). Ph.D. Thesis, Université de Rouen, Rouen, France, 2009.
47. Haque, U.; Scott, L.M.; Hashizume, M.; Fisher, E.; Haque, R.; Yamamoto, T.; Glass, G.E. Modelling malaria treatment practices in Bangladesh using spatial statistics. *Malar. J.* **2012**. [CrossRef] [PubMed]
48. Poole, M.A.; Farrell, P.N.O.; Poole, A.; Farrell, N.O. The assumptions of the linear model regression. *Trans. Inst. Br. Geogr.* **1971**, *52*, 145–158. [CrossRef]
49. Brunsdon, C.; Fotheringham, A.S.; Charlton, M.E. Geographically Weighted Regression: A Method for Exploring Spatial Nonstationarity. *Geogr. Anal.* **1996**, *28*, 281–298. [CrossRef]
50. Scott, L.; Pratt, M. Answering Why Questions: An Introduction to Using Regression Analysis with Spatial Data. Available online: http://www.esri.com/news/arcuser/0309/files/why.pdf (accessed on 10 February 2017).
51. Esri Interpreting OLS Results. Available online: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-statistics-toolbox/interpreting-ols-results.htm (accessed on 4 November 2016).
52. Rosenshein, L.; Scott, L.; Pratt, M. Finding a Meaningful Model This Checklist Will Help You Evaluate Regression Models. Available online: http://www.esri.com/news/arcuser/0111/files/findmodel.pdf (accessed on 13 March 2017).
53. Gao, B.; Huang, Q.; He, C.; Sun, Z.; Zhang, D. How does sprawl differ across cities in China? A multi-scale investigation using nighttime light and census data. *Landsc. Urban Plan.* **2016**, *148*, 89–98. [CrossRef]
54. Hu, Z.; Du, P.; Guo, D. Analysis of Urban Expansion and Driving Forces in Xuzhou City Based on Remote Sensing. *J. China Univ. Min. Technol.* **2007**, *17*, 267–271. [CrossRef]
55. Seto, K.C.; Fragkias, M.; Güneralp, B.; Reilly, M.K. A Meta-Analysis of Global Urban Land Expansion. *PLoS ONE* **2011**, *6*, e23777. [CrossRef] [PubMed]
56. Pravitasari, A.E.; Saizen, I.; Tsutsumida, N.; Rustiadi, E.; Pribadi, D.O. Local Spatially Dependent Driving Forces of Urban Expansion in an Emerging Asian Megacity: The Case of Greater Jakarta (Jabodetabek). *J. Sustain. Dev.* **2015**, *8*, 108–119. [CrossRef]
57. Ali, M.M.; Al-Kodmany, K. Tall Buildings and Urban Habitat of the 21st Century: A Global Perspective. *Buildings* **2012**, *2*, 384–423. [CrossRef]
58. Pank, W.; Girardet, H.; Cox, G. *Tall buildings and sustainability*; Corporation of London: London, UK, 2002.

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Accelerated Urban Expansion in Lhasa City and the Implications for Sustainable Development in a Plateau City

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Abstract: Urbanization challenges regional sustainable development, but a slight expansion mechanism was revealed in a plateau city. We have integrated the urban expansion process and analyzed its determinants in Lhasa (Tibet), and we provide insightful suggestions for urban management and planning for Lhasa. The full continuum of the urban expansion process has been captured using time-series of high-resolution remote sensing data (1990–2015). Four categories of potential determinants involved in economic, demographic, social, and government policy factors were selected, and redundancy analysis was employed to define the contribution rates of these determinants. The results illustrate that considerable urban expansion occurred from 1990 to 2015 in Lhasa, with the area of construction land and transportation land increasing at rates of 117.2% and 564.7%, respectively. The urban expansion in the center of Lhasa can be characterized as temperate sprawl from 1990 through 2008, primarily explained by governmental policies and investment, economic development, tourist growth, and increased governmental investment resulting in faster urban expansion from 2008 to 2015, mainly occurring in the east, south, and west of Lhasa. In contrast with other cities of China, central government investment and "pairing-up support" projects have played an important role in infrastructure construction in Lhasa. The miraculous development of the tourism industry had prominent effects on this economic development and urbanization after 2006, due to the running of the Tibetan Railway. An integrative and proactive policy framework, the "Lhasa development model", having important theoretical, methodological, and management implications for urban planning and development, has been proposed.

Keywords: Lhasa; urban expansion; determinants; plateau city; policy framework

1. Introduction

Unprecedented urbanization, one of the most irreversible human impacts, has taken place globally in recent decades [1–3]. More than 50% of the global population now lives in cities, and this is expected to exceed 67% by 2050 [4,5]. Urbanization promotes social-economic development, which inevitably converts semi-natural and natural ecosystems into urban environments, which has enormous and inevitable effects on the surrounding area [6–9]. Thus, more attention should be paid to the drastic expansion of urbanization. Many studies have been conducted worldwide [1], including in regions of Africa [10], Europe [11], Latin America [12], North America [13], and Asia [14–16]. Previous studies have also explored the mechanisms of many cities, population and income related to urban expansion in the USA [17], social infrastructure in the Ulaanbaatar [18], and population, economics, and infrastructure in Freetown [19].

China has been undergoing dramatic urban expansion since the "Reform and Open Policy" in 1978 [20]. Many studies have investigated the spatiotemporal patterns of urban expansion at the national scale [21–31]. Moreover, the spatiotemporal trajectories and patterns of urban expansion have been investigated in "hot" cities in China, such as the megacities in Eastern China [32–39], Northeastern China [40], and Central China [41–44], in addition to a few metropolises in Western China [45–47]. Generally, the primary form of urban expansion in China has been edge-expansion around cities supported by infilling expansion in city centers; leapfrog expansion has been the form in a few metropolises [25].

The speed of urban expansion has fluctuated during different periods [27], and it has been necessary to understand the determinants for urban expansion in different periods [48–50]. Studies have indicated that marketization, globalization, and decentralization accounted for urban expansion in China [51]. However, the mechanisms of urban expansion have differed in different regions and periods [31]. Geographic location, population growth, economic development, and government policies, and the interaction of these factors, have been important drivers for urban expansion in the eastern coastal areas, such as Shenzhen [52,53], Shanghai [54], and Xiamen [55]. As for the resource-based cities, mining activities were considered as one of the most important factors in urban expansion, such as in the cities of Pingshuo and Shuozhou [42,43]. Government policies ("Revitalizing Old Industrial Base of Northeast China"), as well as high-technology, stimulated the re-expansion in Northeast China [40]. Similar situations are found in western cities under the "Development of the West Region" policy [4,56].

Urbanization in mountain cities has become somewhat differentiated from the processes experienced elsewhere. Although there are many studies on urbanization in general, only few studies focus on the urban expansion in mountain cities. In the French Alps, a rapid and continuous urban expansion at the expense of farm land was observed from 1998 to 2009 [57]. In the Peruvian Central Andes, not merely the urban rapidly growth, but also the human land use expanded for the reforestation, as well as range burning for economic development [58]. In the Himalayas, the develop model of urban in Thimphu combined the traditional elements for the site of political, as well as economic, power [59].

To seek the sustainable development (smart cities) in the process of urbanization, for policy-makers, policies should be linked to the reality of local urban expansion [31], encouraging local residents to get actively involved in decision-making processes [60]. Additionally, a compact pattern of urban expansion may be more friendly to ecology and the natural environmental than a dispersed pattern would be [61], and urban redevelopment is also an effective measure [62]. Moreover, stronger measures should be enforced to control inefficient utilization of land on the city fringes [33], promoting reasonable and sustainable transportation [48,54], while also improving citizens' continuous awareness of sustainable development [44,63]. In general, it is difficult to realize smart cities in mountain regions and creating a database (socio-economic data and GIS data) depends on the consistency of element contents. Modeling the urban expansion boundaries is regarded as an effective approach to guide urban smart growth [64]. More investment should be made for the development and construction of smart low-carbon cities in China [65].

As for the mountain city in China, Lhasa, the average elevation of Lhasa is approximately 3650 m, and solar radiation is strong. With diverse topography, as well as climate, it is rich in biodiversity. However, the natural environment is extremely harsh, with a fragile ecosystem that is extremely susceptible to the impacts of climate change and human activities [66]. In Tibet, Tibetan Buddhism, with its distinctive characteristics, and the politico-religious merged system of government that was established in the 17th century, played an important part in the development of cities and towns before 1951. In 1951, Lhasa was taken as the only urban lay settlement in Tibet; the population of Lhasa was less than thirty thousand, and the urban area was no more than 3 km^2. Nevertheless, after democratic reform in 1959, especially in the last three decades, Lhasa has been clearly expanding and transforming in the process of modernization. However, it is important to note that a limited number of studies have analyzed the urban expansion and its determinants in mountain cities in China, especially for Lhasa, which is the most important Tibetan city. This sparse attention has unavoidably created knowledge gaps and left numerous pivotal issues unaddressed and unclear. The mechanism of urban expansion might exhibit different characteristics in the plateau city; revealing the mechanism of urban expansion in the plateau city is essential to understand its environmental impacts and to protect the socio-ecological diversity.

Consequently, against this context, this study aims to reveal the spatial-temporal pattern of urban expansion and its determinants in Lhasa from 1990 to 2015, while simultaneously outlining policy suggestions containing relevant planning and guidelines for local development.

2. Materials and Methods

2.1. Study Area

Lhasa is not only the capital of Tibet, but also the its political, economic, cultural, and religious center (Figure 1). The city contains many archaeological sites that are listed as world cultural heritage sites: these include the Potala Palace, the Jokhang Temple, and Norbulingka. In the present study, the term "Lhasa" refers to the Lhasa urban area, comprised of Downtown Chengguan (DCG), Liuwu New District (LND), Dongcheng New District (DCND), and Dongga New District (DGND).

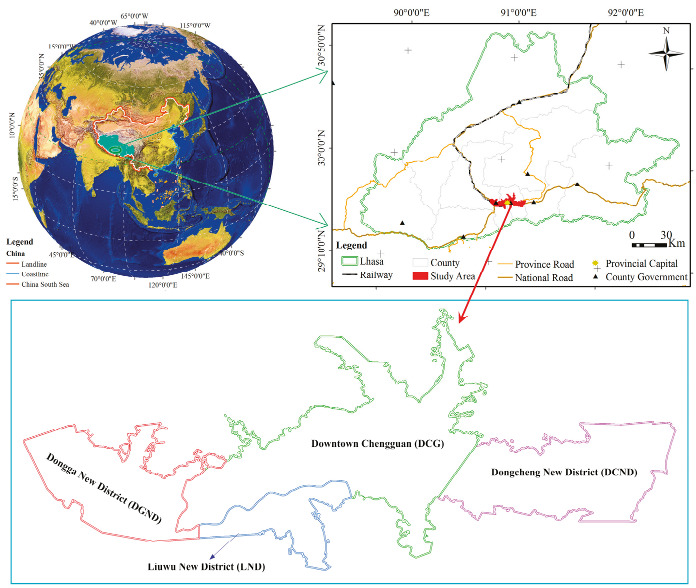

Figure 1. The study area, including the division districts of Lhasa: Downtown Chengguan (DCG), Liuwu New District (LND), Dongcheng New District (DCND), and Dongga New District (DGND).

Lhasa is an old city, with a history going back more than 1300 years. At the beginning of the 7th century, Songtsen Gampo established the first unified regime in the history of Tibet. In AD 633, he moved the capital of Tubo Dynasty from Shannan to today's Lhasa and ordered the construction of Potala Palace and the Jokhang and Ramoche Temples, turning Lhasa into the most populous town in Tibet. From the collapse of the Tubo Dynasty in the 9th century until the Ming Dynasty in the early 14th century, Lhasa lost its previous political status and developed slowly. Potala Palace was destroyed in warfare, but Lhasa remained an important place for Buddhists, because of the Jokhang

Temple. In the early 15th century, the importance of Lhasa as a holy site for Tibetan Buddhism became increasingly significant, following the founding of the "great three" (Ganden Monastery, Salad Monastery, and Drepung Monastery) Gelug university monasteries by Je Tsongkhapa. In the 17th century, with the support of the Qing Dynasty, the fifth Dalai Lama unified Tibet again and established a politico-religious merged system of government named Ganden Podrang. Following the liberation of Tibet in 1951, Lhasa became the capital of the Tibet Autonomous Region in 1965 and entered into a new age. Over the last 50 years, Lhasa has experienced rapid growth and development. Nowadays, Lhasa is still the political and cultural center in Tibet, and has retained its importance as a holy city for the entire realm of Lamaist Buddhism.

2.2. Satellite Images

To delineate the urban area more precisely, high-resolution remotely-sensed data SPOT1/4/5 and Word-View images (Appendix A) were used to acquire the time-series land-use information of Lhasa, covering four time periods (1990, 2001, 2008, and 2015). The preprocessing of the images included atmospheric correction and geometric rectification in ENVI. Then, we adopted the object-oriented method (a method that not only considers the spectral signature in classification but also evaluates the tone, texture, and shape, of image objects at the same time) to obtain the land-use categories, including the classifications of water (W), greenbelt (including natural grassland, GB), forest land (FL), plough land (PL, including arable areas and crops), unutilized land (UL), construction land (CL), transportation land (TL), and wetland (WL). Following classification, manual vectorization was conducted in ArcGIS 10.2 (ESRI, Inc., Redlands, CA, USA) to correct in accurate classifications. Via randomly stratified methods that overlapped the fact-finding points with the land cover maps, the final accuracy of the classification was evaluated. The total accuracy for four land cover maps was 90.1% for 1990, 91.2% for 2001, 92.5% for 2008, and 94.3% for 2015, respectively.

2.3. Determinants and Analysis Methods

Considering data representative and the availability of prior literature [31,42,48,52,67–70], we selected 12 potential determinants for urban expansion in Lhasa that were extracted from the corresponding statistical yearbook: these determinants are total population (TP), urban population (UP), country population (CP), number of foreign travelers (FT), number of domestic tourists (DT), gross domestic product (GDP), GDP in primary industries (GDPPI), GDP in secondary industries (GDPSI), GDP in tertiary industries (GDPTI), tourist income (TI), actual investment (AI), and investment in fixed assets (FA). In addition, the build-up area (BA) was selected to reflect the degree of urban expansion. The redundancy analysis is a linear canonical ordination method, which is advantageous to detect the pattern of dynamics in response variables [71]. The redundancy analysis is closely related to potential explanatory variables, which is effective to evaluate the relationships among multiple interacting variables [72,73]. Thus, the redundancy analysis of R software (Vegan) was employed to explore the relationships of BA with determinants (determinants were partitioned into four explanatory variable groups: TP (UP and CP), GDP (GDPPI, GDPSI and GDPTI), AI, and TI) and to identify the major factors influencing the expansion of Lhasa. The associations between the BA and the determinants with $p < 0.05$ were regarded as statistically significant.

3. Results

3.1. Land Cover Change of Lhasa (1990–2015)

From 1990 to 2015, Lhasa experienced considerable urban expansion. In all, 56.80% of the total land in the study area was urbanized; this urbanization was mainly distributed in the DCND, DGND, and LND (Figure 2D). The areas of CL and TL increased from 45.0 km^2 and 1.4 km^2, respectively, in 1990 to 97.7 km^2 and 9.0 km^2, respectively, in 2015, with increased rates of 117.2% and 564.7%, respectively. On the contrary, the areas of PL and GB decreased by 38.0 km^2 and 17.7 km^2, respectively.

Additionally, the increased TL was mainly found in the center of Lhasa (1990–2001, Figure 2A), the west of Lhasa (2001–2008, Figure 2B), and the east, the south, and the west of Lhasa (2008–2015, Figure 2C), with increased areas of 3.0 km^2, 2.1 km^2, and 2.6 km^2, respectively.

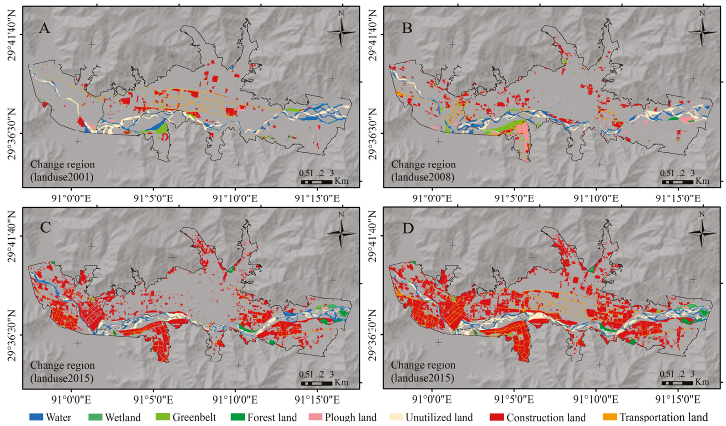

Figure 2. The changed regions of land cover in Lhasa. Graphs (**A**–**D**) represent the land-use changed area during 1990–2001, 2001–2008, 2008–2015, and 1990–2015, respectively.

Mutual transfer quantities of land-use were investigated using the overlay analysis and transition matrices in ArcGIS 10.2 (ESRI, Inc., Redlands, CA, USA) (Figure 3). The PL and CL were found to be the main land classes in 1990, while CL was the main land class in 2015. The most extensive and intensive transition occurred between the PL and CL, with approximately 35.1 km^2 (58.0%) of PL transferred into CL. Approximately 19.0 km^2 (86.7%) and 1.5 km^2 (6.5%) of GB and W, respectively, were transferred to CL from 1990 to 2015, and small areas of FL, UL, and TL were transferred to CL. Meanwhile, during the highest urban expansion period of 2008–2015, approximately 24.4 km^2 PL and 12.3 km^2 GB changed into CL. Moreover, almost 3.4 km^2 PL and 2.4 km^2 CL have been transferred into TL over the past 25 years.

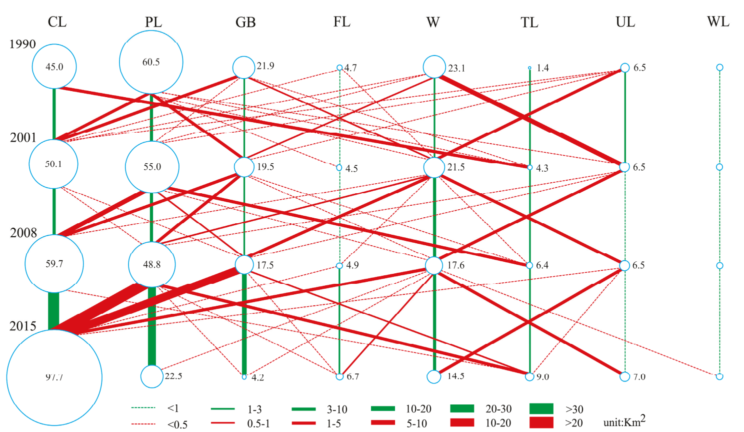

Figure 3. The transition process of classifications in Lhasa from 1990 to 2015. The circles present the area of each land cover in different year, and the blue lines represent the changed area in each land cover between the two periods; the red lines represent the changed area among classes during the two periods.

3.2. The Changes of the Main Socio-Economic Indicators of Lhasa (1990–2015)

3.2.1. Economic Development

During the past 25 years, the GDPSI and GDPTI reflected the economic development traits, and the GDPTI was the dominant economy for the growth of the economy in Lhasa. Figure 4 shows that GDP, GDPSI, and GDPTI grew continuously from 1990 to 2014, while GDPPI increased relatively slowly. As for GDP, a general linear model analysis showed that the year 2006 can be considered as a "tipping point", with slopes of 5.74×10^2 million/year (y = 5.74x − 11,423.29) and 2.90×10^3 million/year (y = 2.90x − 58,137.54), respectively, before and after 2006. Similarly, the rate of GDPSI sharply increased from 2007 to 2014 (slope = 12.98), whereas the process was slower from 1990 to 2006 (slope = 1.53), and the GDPSI accounted for 36.77% of the GDP in 2014. Meanwhile, the GDPTI has expanded continuously during the past 25 years; reaching up to 2.07×10^4 million Renminbi (RMB) in 2014, accounted for 59.51% of the GDP in that year. The GDPTI also demonstrated significantly increasing trends after 2005 (before 2005, the slope = 15.17; after 2005, the slope = 3.75).

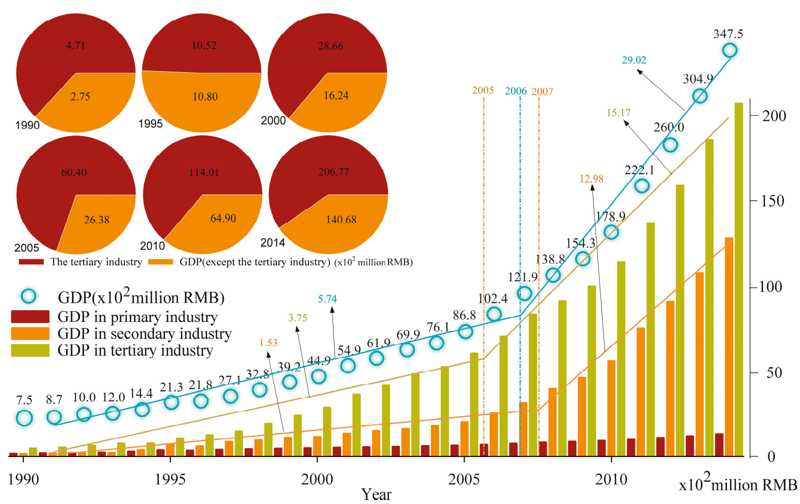

Figure 4. The gross domestic product (GDP), GDP in primary industries (GDPPI), GDP in secondary industries (GDPSI), GDP in tertiary industries (GDPTI), and the variations of GDP from 1990 to 2014.

3.2.2. Urban Population Growth

A growing trend of the total population in Lhasa from 1990 to 2014 was observed (Figure 5). The total population increased from 3.57×10^5 (1990) to 5.27×10^5 (2014), with a rate of increase equal to 47.87%. Incredibly, a sharp expansion of the total population occurred between 2008 and 2009. Moreover, the urban population increased to 2.23×10^5 in 2014, with the proportion increasing from 34.2% in 1990 to 42.3% in 2014. Consequently, the proportion of the rural population decreased by 8.1% during the same period, with the population in 2014 being 3.04×10^5.

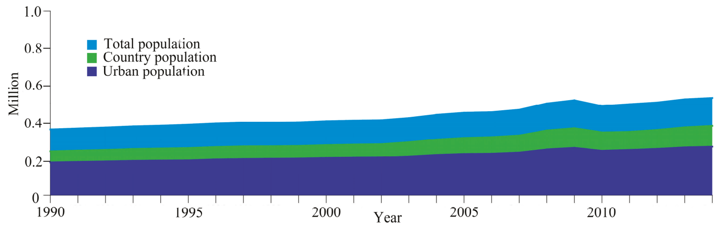

Figure 5. The total population, country population, and urban population from 1990 to 2010.

3.2.3. Government Investment

Along with the time series data, Figure 6 shows that both the budget in public and actual investment and new fixed assets showed increasing trends from 1990 to 2014. Through the budget spending of the public finance merely 1.69×10^4 million RMB in 2014, the actual investment reached 4.55×10^4 million RMB, exceeding 73.20% of the investment from government converted to new fixed assets in 2014. Thus, investment by government was preferred to infrastructure construction and public service. Moreover, the government increased investment after 2008, with slopes of 4.41×10^2 million/year ($y = 4.41x - 8778.4$) and 58.1×10^2 million/year ($y = 58.1x - 116{,}518.2$), respectively, before and after 2008. Meanwhile, high increasing speeds of direct budget subsides from the central government and fundraising by the local government were observed between 1990 and 2014 (Figure 6). Moreover, the proportion of state budget appropriation in actual investment accounted for 41.52%, with a value of 89.42 billion RMB from 1990 to 2014. Furthermore, Figure 6 also shows a series of policies and campaigns, including the "Lhasa City Master Plan 1980–2000" in 1983, the "Lhasa City Master Plan 1995–2015" in 1999, the "Development of the Western Region" in 2000, the Tibetan Railway, running in 2006, and the "Lhasa City Master Plan 2009–2020". The plough land protection policies of "Regulations on the Protection of Basic Farmland" and "The Arable Land Protection Redline of 12 million ha" are also presented.

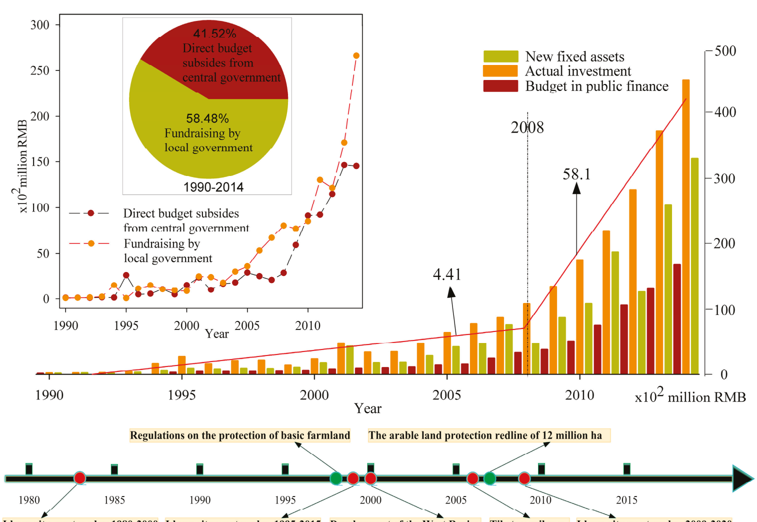

Figure 6. The actual investment of government, new fixed assets, and budget spending of public finance from 1990 to 2014, and the main policies on construction land and transportation land from the 1980s to the 2010s.

3.2.4. Tourism Development

The population of domestic tourists was the presentation of the economic development trait, and the tourist industry gradually became the dominant economy for tertiary industry in Lhasa (Figure 7). From 1990 to 2006, the population of foreign travelers and domestic tourists (slope = 3.5) did not show significant variation; hence, tourist income remained stable (slope = 0.4). Conversely, from 2006 to 2014, with a sharp increase of domestic tourists (slope = 97.4), the tourist income increased by 93.67 × 10^2 million RMB (slope = 11.0). Moreover, the proportion of tourist income in the tertiary industry economy has been growing continuously, increasing from 1.06% in 1990 to 54.01% in 2014.

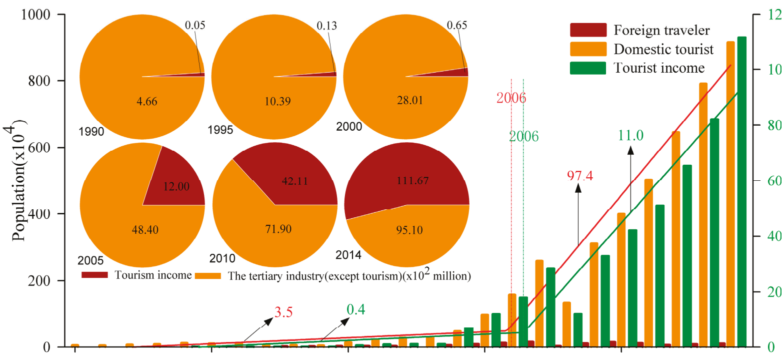

Figure 7. The population of foreign travelers and domestic tourists, as well as the tourist income and its dynamics in tertiary industries from 1990–2014.

3.3. Determinants of Urban Expansion in Lhasa

The relationships among the BA, greenbelt area (GBA) and determinants were examined at 0.05 level (Figure 8). All the selected determinants were observed significantly positively correlated with the BA, the whole of the correlation coefficients were greater than 0.85, except a relatively weak relationship between FT and BA. Moreover, remarkable relationships among the TP, GDP, TI, and AI were observed. However, fickle and lower values of correlation coefficients between the GBA and determinants were presented. Thus, to quantify the determinants for the urban expansion, we conduct a relative importance analysis between BA and TP, GDP, TI, and AI in the next section.

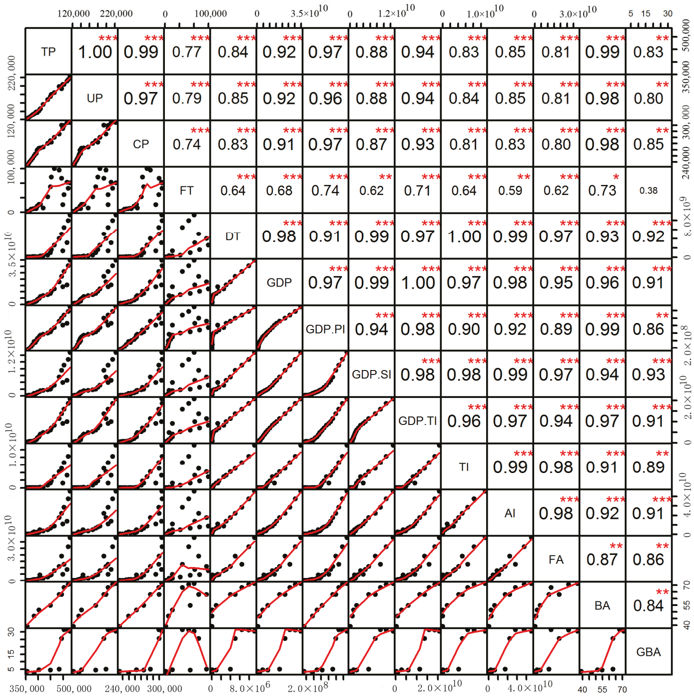

Figure 8. The relationships between the BA, GBA, and the determinants.

3.4. Relative Importance of the Identified Determinants

Based on the redundancy analysis, the relative importance of the main determinants for Lhasa's expansion was investigated (Figure 9). The results showed that the interactions of determinants (TP, GDP, AI, and TI) was the main driver of urban expansion in Lhasa, explaining 81.24% of the urban expansion. More specifically, the determinant TP had a relatively larger influence, explaining 99.38% of the urban expansion, followed by the GDP determinant, which explained 96.04% of the expansion, and AI and TI explained 86.96% and 84.97% of the expansion, respectively.

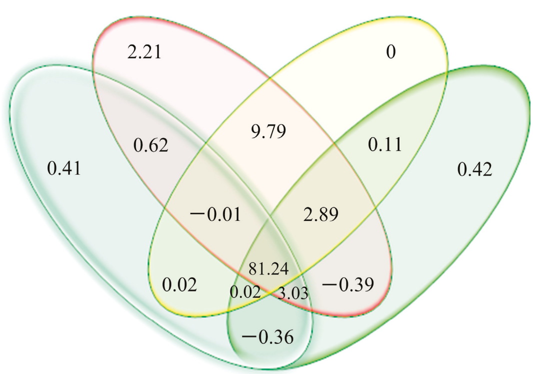

Figure 9. The contributions (%) of different categories' determinants to BA via redundancy analysis is presented in Venn diagrams.

4. Discussion

4.1. Determinants for Lhasa Expansion

The urban expansion of Lhasa is primarily explained by governmental policies and investment in the early stage (1990–2008); economic development, tourist growth, and increased government investment resulted in faster urban expansion from 2008 to 2015. The government's policies controlled and guided the macroscopic development of cities [69]; the development of cities is especially sensitive to administrative polices in China [74]. For historical reasons, urban planning in Lhasa has exhibited relative hysteresis. Until 1983, the local government promulgated and implemented the "Lhasa City Master Plan 1980–2000", which determined the basic pattern of Lhasa. Of note, most public infrastructures developed around the center of Lhasa during the 30th anniversary of the founding of the Tibet Autonomous Region (1985) and on the 40th anniversary of the peaceful liberation of the Tibet Autonomous Region (1991). Stimulated by the government investment, resulting in insufficient usable land for the development in the center of Lhasa. Specifically, urban expansion of Lhasa can be characterized as temperate sprawl between 1990 and 2001, with an annual average expansion area of 0.47 km^2, mainly around the "old center of Lhasa" (Downtown Chengguan, Figure 2A). Under these circumstances, the local government implemented the "Lhasa City Master Plan 1995–2015" in 1999, which not only confirmed the spatial layout of Lhasa as seven districts, but also determined the development of the south bank of Lhasa and selected LND, DCND, and DGND as the stand-by spare areas for future development of Lhasa. Moreover, in the national strategy "Development of the West Region", implemented in 2000, very large amounts of national capital continuously promoted urban and industrial expansion in the western provinces [4,21]. Against this backdrop, the area of construction land expanded by annual average of 1.36 km^2 from 2001 to 2008. With faster urban expansion outward, Lhasa's urban area started to grow past the fringe of the DCG. Thus, the LND in the southwest, the DCND in the east, and the DGND in the west of the DCG were formed gradually (Figure 2B), which was consistent with the connotations of the government policies.

Economic development is fundamental to urban expansion, because city expansion principally depends on the city's financial strength [69]. To further promote economic development, the government may attempt to enlarge investments in industrial parks and key infrastructures [48,60]. As more land is converted into construction land for industrial parks and scenic spots, this, in turn, promotes the growth of GDP [52]. Between 2007 and 2014, the GDP increased by 5.2 times, and the annual GDP was 4.52×10^3 million (1990–2007), which was much lower than the annual value level of 2.29×10^4 million from 2008 to 2014. Additionally, the GDP per capita increased from 1.96×10^4 RMB (2007) to 5.66×10^4 RMB (2014). The effect of rising GDP per capita and better services is to attract more rural people to migrate to the city, bringing more tourists and workers to Lhasa [29,31]. To simultaneously meet the economic development, population concentration, and old-city protection demands, the local government further implemented the "Lhasa City Master Plan 2009–2020" in 2009. This policy proposed the future expansion layouts of Lhasa: "East extension, westward and south pass, one city with two sides and three districts". Thus, a "tipping point" of government investment is observed after 2008, with governments expanding their public finances from 1.09×10^4 million RMB in 2008 to 4.55×10^4 million RMB in 2014, and 73.20% of the public finances were transformed into new fixed assets in 2014 (Figure 6). Meanwhile, Tibet has the highest proportion of state budget appropriation in fixed assets among western provinces (Appendix B). Consequently, Lhasa has been witnessing unimaginable growth of population and urban expansion: tourism increased by 7.91 million from 2008 to 2014, accompanied by urban expansion rates of 0.82 km^2/year and 5.43 km^2/year, respectively, before and after 2008, mainly occurring in LND, DGND and DCND (Figure 2C).

In particular, the "Pairing-up support" project also played an important role in the infrastructure expansion process, with assistance funds in Tibet being 14.1 billion RMB from 2011 to 2015 (Appendix C). Additionally, the running of the Tibetan Railway in 2006 accelerated the economic growth because of the "tipping point" found in GDP (Figure 5) and tourism income (Figure 8) was 2006. Overall, Lhasa transformed from a decentralized "old center of Lhasa" (DCG) to a new urban area with different functional zones in the south, west, and east during the study period.

However, with the growth of population and economy, the urban expansion in Lhasa is exactly a dilemma for the limited agriculture land and fragile ecosystem. Meanwhile, the inconvenient and unintelligent transportation hinders the economic development in Lhasa. In addition, education in Lhasa is faced with the challenges, such as the limitation of research teams and a shortage of education resources. It is difficult to evaluate the complete situation in Lhasa for the limited share database. In the future, the government should promote the progress of sustainable mobility payments and increase financial support [75], putting forth efforts to integrate the social-economic, democratic, technological, and sustainable aspects for the sustainable development in the mountain city of Lhasa [76].

4.2. Determinants of Urban Expansion in Different Regions in China

The interactions of GDP growth, population immigration from rural to urban areas, industrial development, and national regional strategies have been significantly positive factors for urban expansion in China [4,5,24,51,63,65]. However, the determinants of urban expansion have varied in different regions (Appendix D). For Eastern China, more international trade has been available for population growth, road construction, and service exports, resulting in economic growth [21,31,55,61]. This is particularly true for the cities in the pearl river delta and the Yangtze river delta, where favorable geographical conditions, accompanied by more government investment, have led to the development of many services, high-tech companies, and commercial centers [3,52,69,77]. Industrial direct investment by foreigners has been a positive determinant for urban expansion in Central China, where the large number of people working in coal enterprises has promoted the industrial output value [21,31,42,78,79]. Economic growth stimulated by industrialization has been considered as the main factor for urban expansion in Western China [24]. In general, the industrialization with population growth (mostly immigrants and workers) has played a critical role in urban expansion throughout China [49,52,80,81].

In contrast with other cities of China, the relatively weaker importance of secondary industries and immigration, and the development of tertiary industries, have contributed positively and significantly to urban expansion in Lhasa. Lhasa has served as the most dynamic potential core area for tourist aggregation in Tibet, which is famous for its unique plateau customs and religious culture and attracted more than 9.26 million tourists in 2014; this is about 17.56 times the TP in Lhasa in 2014. Thus, Lhasa experienced a drastic transformation of its economic structure because of the rapid development of tourism. Simultaneously, in terms of GDP, the proportion of the tourism revenues in Lhasa increased from 0.65% in 1990 to 32.14% in 2014, accounting for 54.01% of the GDP in tertiary industry. Obviously, the demands for residence, traffic, and tourism facilities resulted in rapid urban expansion from the urban areas to surrounding rural areas in Lhasa. With the accelerated social-economic growth, tertiary industries will further influence the urbanization process in Lhasa.

4.3. Suggestions and Implications

China became the world's second-largest economy in 2011. Simultaneously, the "National New-Style Urbanization Plan" and "China's 13th Five-Year Plan" were promulgated and implemented recently. So, how can eco-sustainable urban development be applied in Lhasa? To explore a "smart development model" suitable for Lhasa, it is essential to establish links between financial assistance and economic development to improve the self-sufficiency rate in Lhasa. For the central government, policies should be innovated and unified within the framework of the "Lhasa sustainable development model" for Lhasa's ecological economy. For local government, promoting scientific urban planning and increasing investment in human capital are decisive factors. Local government should implement preferential policies to attract medium and top talents to improve Lhasa's self-development capability. Simultaneously, investment in environmentally-friendly and sustainable economics of tertiary industries, especially tourism, should be increased. With financial assistance, further transforming and upgrading the industrial structure into a public service-type, developing ecological tourism and more specialized services, and improving access to international markets the rely on Lhasa's unique plateau custom and cultural advantages. Furthermore, full use should be made of the unique plateau's green resources, and technical innovations to avoid insufficient utilization of various resources, such as solar and water resources, should be applied. Lastly, the "Urban-Rural and Regional Integration Strategy" should be implemented to equalize urban–rural development. In practical terms, strategies should include promoting regional traffic and transport, extending specialized industries in villages, and elevating the self-supporting capability of natives through basic education and vocational training. We expect that the policy framework (Figure 10) can provide a few fresh insightful suggestions to policy-makers to establish a smart Lhasa development model for long-term stability and prosperity.

To realize the smart city in China, the coordination and communication between the administrative agencies are particularly important. Thus, contradictions exist between the administrative agencies: local government receives extra budgetary revenue by a land granting strategy [82], while the central government enacts regulations to re-control urban expansion [83]. However, the local government plays a proactive role [84]. In addition, intra-urban planning also touches off the chance to reexamine the distribution of infrastructure for intelligent transportation [85]. Attempts should be made to coordinate the increase of the population and built-up areas for a smart city. It was noticeable that the development of the economy would stimulate the growth of the population and the expansion of the city. The social-economic, population, and policies are spatially correlated and interaction has an effect radius. This implies it is essential to balance the demand for building in urban planning among these variational factors. Thus, a smart city can be realized.

Figure 10. The policy framework of the "Lhasa development model".

5. Conclusions

This study systematically revealed the mechanisms of urban expansion in the plateau city (Lhasa) during the past 25 years. Lhasa has experienced great expansion intensity, with the area of CL increasing by 52.7 km^2 between 1990 and 2015, and the areas of PL and GB transforming by 35.1 km^2 and 19.0 km^2, respectively, to CL at the same time. The faster urban expansion speed that was observed from 2008 to 2015 (5.4 km^2/year) mainly occurred in the east (DCND), south (LND), and west (DGND) of Lhasa.

In general, urban expansion in Lhasa is influenced by governmental investment, tourist population growth, and economic development. From 1990 to 2008, a series of governmental policies promoted the infrastructure construction process in the center of Lhasa. From 2008 to 2015, with a more rapid rate of increase of GDP increase, faster growth of the tourist population, and continuous government investment, there was an obvious high rate of urban expansion. In particular, the tourism industry apparently promoted economic development and urban expansion in recent years, and the running of Tibetan Railway accelerated the urbanization process in Lhasa.

In this paper, the spatial-temporal pattern of urban expansion and its determinants are performed for quantitative research to reveal the urban expansion mechanism in Lhasa, from which the integrative and proactive policy framework are put forward for smart city development in Lhasa. However, in this paper, the geographical factors (slope, temperature, precipitation, and so on) were neglected. Modeling the urban expansion under many factors (the socio-economic, policy, and geographical factors) will be a supplemental research agenda. To achieve a win-win situation in the dilemma of urban expansion and socio-economic development, and improve the self-sufficiency rate of Lhasa, the government policy must be innovated and unified, enhancing coordination and efficiency between administrative agencies and establishing links between financial assistance and economic development within the framework of the "Lhasa development model". In the future, to be a smart city, Lhasa should invest more money in transforming and upgrading industrial structures, especially in the environmentally-friendly and sustainable economic development of tertiary industries.

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

Appendix A

Table A1. Source of remote sensing data of Lhasa metropolitan area 1990–2015.

Data	Column/Row	Year	Spatial Resolution (m)
Spot1	5924/6000	March 1990	10
Spot4	5110/1768	November 2001	10
Spot5	18307/6258	December 2008	2.5
Word View	94420/31076	May 2015	0.5

Appendix B

Table A2. Sources of funds for investment in fixed assets in western provinces of China in 2014 (billion RMB).

	Qinghai	Gansu	Sichuan	Xinjiang	Ningxia	Chongqing	Guizhou	Inner Mongolia	Tibet
State budget appropriation	55.994	84.449	152.782	132.678	23.734	106.499	64.44	68.499	84.931
Self-raised funds	136.351	485.644	1688.449	610.044	162.486	835.35	570.403	941.733	38.12
Domestic loans	59.622	94.856	249.009	137.062	74.621	265.193	118.318	152.99	0.58
Foreign investment	0.422	3.448	9.507	0.325	0.285	28.269	2.776	1.02	0.14
Bonds	1.646	2.04	7.421	2.774	0	0.512	0	0	0
Others	28.532	77.054	442.192	96.514	37.764	315.732	239.596	68.637	6.36
Total investment in fixed assets	282.567	747.491	2549.36	979.397	298.89	1551.555	995.533	1232.879	130.131
The proportion of state budget appropriation in investment in fixed assets	19.82%	11.3%	5.99%	13.55%	7.94%	6.86%	6.47%	5.56%	65.27%

Appendix C

Table A3. The financial assistance budgets in "The Twelfth Five-year Plan" from 2011 to 2015.

Districts	Number of Projects	Total (Billion RMB)	2011 (Billion RMB)	2012 (Billion RMB)	2013 (Billion RMB)	2014 (Billion RMB)	2015 (Billion RMB)	Proportion
Lhasa	165	3.08	0.52	0.56	0.63	0.68	0.68	21.82%
Lhoka Prefecture	176	1.30	0.38	0.29	0.13	0.28	0.22	9.17%
Shigatse Prefecture	575	3.26	0.57	0.64	0.60	0.72	0.74	23.10%
Nyingchi Prefecture	361	2.66	0.51	0.52	0.44	0.57	0.62	18.80%
Chamdo Prefecture	132	0.75	0.14	0.15	0.15	0.18	0.14	5.28%
Nagqu prefecture	128	2.11	0.38	0.41	0.40	0.43	0.49	14.89%
Ngari Prefecture	73	0.98	0.17	0.19	0.20	0.21	0.22	6.94%
Total	1610	14.14	2.67	2.75	2.54	3.07	3.10	100%

Appendix D

Table A4. The determinants of urban expansion in different regions.

	Period	Regions	Determinants	Literatures
China	2005–2008	China	Marketization, Globalization, Government	[49]
	1990–2010	China	Immigration rural-urban, Fixed-asset investments, GDP growth, National regional strategies	[4]
	1993–2012	China	Economic growth, Industrial development, Economic structural transformation	[5]
China	-	China	Institutional, cultural conditions, Economy and industry conditions	[65]
China	-	China	Globalization, Government	[63]
Eastern China	2000–2010	Eastern China	Service exports, International trade	[21]
Central China		Central China	Service exports, International trade, Foreign direct investment	
Northeastern		Northeastern	Service exports, International trade	

Table A4. *Cont.*

	Period	Regions	Determinants	Literatures
Eastern China	1990–2010	Eastern China	Population growth, Road construction	[31]
Middle China		Middle China	Secondary industry, Economic development	
Western China		Western China	Economic growth	
Provincial level	1992–2009	Provincial level	Economic factors	[24]
Prefectural level		Prefectural level	Economic, Demographic, and traffic factors	
County level		County level	Demographic factors	
Beijing	1972–2010	Beijing	Physical, Socioeconomic, Neighborhood factors	[61]
Xiamen Island	1908–2007	Xiamen Island	Natural and socio-economic factors	[55]
The pearl river delta	1979–2002	Guangzhou	GDP, Total population, Urban resident income, Urban traffic	[69]
	1990–2008	Shenzhen	Technology, Government policy, Geographical factor, GDP	[52]
The Yangtze river delta	1985–2013	Nanjing	Non-agricultural population, Foreign direct investment, Tertiary sector	[3]
	1995–2013	Nanjing	Infrastructure, Commercial, Industrial sub-centers, Government policies	[77]
	1985–2006	Shanghai	Industrial structure improvement, Government policy	[70]
Central China	1986–2013	Shuozhou City	Non-agricultural population, Coalindustry	[42]
	1980–2010	Wuhan	Industrialization, Urban population growth, Government policies	[78]
	1949–2004	Changsha	Population, Economic, Transportation infrastructure, Strategic instruction	[67]

References

1. Angel, S.; Parent, J.; Civco, D.L.; Blei, A.; Potere, D. The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. *Prog. Plan.* **2011**, *75*, 53–107. [CrossRef]
2. Seto, K.C.; Fragkias, M.; Guneralp, B.; Reilly, M.K. A Meta-Analysis of Global Urban Land Expansion. *PLoS ONE* **2011**, *6*, e23777. [CrossRef] [PubMed]
3. Chen, J.L.; Gao, J.L.; Chen, W. Urban land expansion and the transitional mechanisms in Nanjing, China. *Habitat Int.* **2016**, *53*, 274–283. [CrossRef]
4. Kuang, W.H.; Liu, J.Y.; Dong, J.W.; Chi, W.F.; Zhang, C. The rapid and massive urban and industrial land expansions in China between 1990 and 2010: A CLUD-based analysis of their trajectories, patterns, and drivers. *Landsc. Urban Plan.* **2016**, *145*, 21–33. [CrossRef]
5. Zhang, Q.W.; Su, S.L. Determinants of urban expansion and their relative importance: A comparative analysis of 30 major metropolitans in China. *Habitat Int.* **2016**, *58*, 89–107. [CrossRef]
6. Sakata, Y.; Yamasaki, M.; Ohgushi, T. Urban landscape and forest vegetation regulate the range expansion of an exotic lace bug Corythucha marmorata (Hemiptera: Tingidae). *Entomol. Sci.* **2016**, *19*, 315–318. [CrossRef]
7. He, C.Y.; Liu, Z.F.; Tian, J.; Ma, Q. Urban expansion dynamics and natural habitat loss in China: A multiscale landscape perspective. *Glob. Chang. Biol.* **2014**, *20*, 2886–2902. [CrossRef] [PubMed]
8. Lin, T.; Xue, X.Z.; Shi, L.Y.; Gao, L.J. Urban spatial expansion and its impacts on island ecosystem services and landscape pattern: A case study of the island city of Xiamen, Southeast China. *Ocean Coast. Manag.* **2013**, *81*, 90–96. [CrossRef]
9. Batisani, N.; Yarnal, B. Urban expansion in Centre County, Pennsylvania: Spatial dynamics and landscape transformations. *Appl. Geogr.* **2009**, *29*, 235–249. [CrossRef]
10. Agegnehu, S.K.; Fuchs, H.; Navratil, G.; Stokowski, P.; Vuolo, F.; Mansberger, R. Spatial Urban Expansion and Land Tenure Security in Ethiopia: Case Studies from Bahir Dar and Debre Markos Peri-Urban Areas. *Soc. Nat. Resour.* **2016**, *29*, 311–328. [CrossRef]
11. Valerio, Q.; Anna, B.; Francesco, C.; Diego, G.; Dalila, R.; Piermaria, C. Monitoring land take by point sampling: Pace and dynamics of urban expansion in the Metropolitan City of Rome. *Landsc. Urban Plan.* **2015**, *143*, 126–133. [CrossRef]
12. Barragan, J.M.; de Andres, M. Urban expansion in the coastal areas of Latin America and Caribbean. *Rev. Geogr. Norte Gd.* **2016**, *64*, 129–149.

13. Leyva-Camacho, O.; Venegas-Cardoso, R.; Rojas-Caldelas, R.; Ranfla-Gonzalez, A.; Pena-Salmon, C. Urban expansion and change of land uses: City of Mexicali 1990–2005. *Wit Trans. Ecol. Environ.* **2010**, *129*, 547–558.
14. Kantakumar, L.N.; Kumar, S.; Schneider, K. Spatiotemporal urban expansion in Pune metropolis, India using remote sensing. *Habitat Int.* **2016**, *51*, 11–22. [CrossRef]
15. Gibson, J.; Boe-Gibson, G.; Stichbury, G. Urban land expansion in India 1992–2012. *Food Policy* **2015**, *56*, 100–113. [CrossRef]
16. Kumar, A.; Pandey, A.C.; Hoda, N.; Jeyaseelan, A.T. Evaluating the Long-term Urban Expansion of Ranchi Urban Agglomeration, India Using Geospatial Technology. *J. Indian Soc. Remote Sens.* **2011**, *39*, 213–224. [CrossRef]
17. Paulsen, K. Yet even more evidence on the spatial size of cities: Urban spatial expansion in the US, 1980–2000. *Reg. Sci. Urban Econ.* **2012**, *42*, 561–568. [CrossRef]
18. Tsutsumida, N.; Saizen, I.; Matsuoka, M.; Ishii, R. Addressing urban expansion using feature-oriented spatial data in a peripheral area of Ulaanbaatar, Mongolia. *Habitat Int.* **2015**, *47*, 196–204. [CrossRef]
19. Mansaray, L.R.; Huang, J.F.; Kamara, A.A. Mapping deforestation and urban expansion in Freetown, Sierra Leone, from pre- to post-war economic recovery. *Environ. Monit. Assess.* **2016**, *188*, 470. [CrossRef] [PubMed]
20. Zhang, Z.X.; Wen, Q.K.; Liu, F.; Zhao, X.L.; Liu, B.; Xu, J.Y.; Yi, L.; Hu, S.G.; Wang, X.; Zuo, L.J.; et al. Urban expansion in China and its effect on cultivated land before and after initiating "Reform and Open Policy". *Sci. China Earth Sci.* **2016**, *59*, 1930–1945. [CrossRef]
21. Shi, Y.; Yang, J.Y.; Hu, X.Y. How economic globalization affects urban expansion: An empirical analysis of 30 Chinese provinces for 2000–2010. *Qual. Quant.* **2016**, *50*, 1117–1133. [CrossRef]
22. Huang, X.M.; Schneider, A.; Friedl, M.A. Mapping sub-pixel urban expansion in China using MODIS and DMSP/OLS nighttime lights. *Remote Sens. Environ.* **2016**, *175*, 92–108. [CrossRef]
23. Wen, Q.K.; Zhang, Z.X.; Shi, L.F.; Zhao, X.L.; Liu, F.; Xu, J.Y.; Yi, L.; Liu, B.; Wang, X.; Zuo, L.J.; et al. Extraction of basic trends of urban expansion in China over past 40 years from satellite images. *Chin. Geogr. Sci.* **2016**, *26*, 129–142. [CrossRef]
24. Ma, Q.; He, C.Y.; Wu, J.G. Behind the rapid expansion of urban impervious surfaces in China: Major influencing factors revealed by a hierarchical multiscale analysis. *Land Use Policy* **2016**, *59*, 434–445. [CrossRef]
25. Liu, F.; Zhang, Z.X.; Wang, X. Forms of Urban Expansion of Chinese Municipalities and Provincial Capitals, 1970s-2013. *Remote Sens.* **2016**, *8*, 930. [CrossRef]
26. Liu, F.; Zhang, Z.X.; Shi, L.F.; Zhao, X.L.; Xu, J.Y.; Yi, L.; Liu, B.; Wen, Q.K.; Hu, S.G.; Wang, X.; et al. Urban expansion in China and its spatial-temporal differences over the past four decades. *J. Geogr. Sci.* **2016**, *26*, 1477–1496. [CrossRef]
27. Zhao, S.Q.; Zhou, D.C.; Zhu, C.; Sun, Y.; Wu, W.J.; Liu, S.G. Spatial and Temporal Dimensions of Urban Expansion in China. *Environ. Sci. Technol.* **2015**, *49*, 9600–9609. [CrossRef] [PubMed]
28. Zhao, S.Q.; Zhou, D.C.; Zhu, C.; Qu, W.Y.; Zhao, J.J.; Sun, Y.; Huang, D.; Wu, W.J.; Liu, S.G. Rates and patterns of urban expansion in China's 32 major cities over the past three decades. *Landsc. Ecol.* **2015**, *30*, 1541–1559. [CrossRef]
29. Gibson, J.; Li, C.; Boe-Gibson, G. Economic Growth and Expansion of China's Urban Land Area: Evidence from Administrative Data and Night Lights, 1993–2012. *Sustainability* **2014**, *6*, 7850–7865. [CrossRef]
30. Liu, J.Y.; Zhang, Q.; Hu, Y.F. Regional differences of China's urban expansion from late 20th to early 21st century based on remote sensing information. *Chin. Geogr. Sci.* **2012**, *22*, 1–14. [CrossRef]
31. Tian, G.J.; Xu, X.L.; Liu, X.J.; Kong, L.Q. The Comparison and Modeling of the Driving Factors of Urban Expansion for Thirty-Five Big Cities in the Three Regions in China. *Adv. Meteorol.* **2016**, *2016*. [CrossRef]
32. Wu, W.J.; Zhao, S.Q.; Zhu, C.; Jiang, J.L. A comparative study of urban expansion in Beijing, Tianjin and Shijiazhuang over the past three decades. *Landsc. Urban Plan.* **2015**, *134*, 93–106. [CrossRef]
33. Zhao, P.J. Sustainable urban expansion and transportation in a growing megacity: Consequences of urban sprawl for mobility on the urban fringe of Beijing. *Habitat Int.* **2010**, *34*, 236–243. [CrossRef]
34. Wu, Y.Y.; Li, S.Y.; Yu, S.X. Monitoring urban expansion and its effects on land use and land cover changes in Guangzhou city, China. *Environ. Monit. Assess.* **2016**, *188*, 54. [CrossRef] [PubMed]
35. Chen, J.L.; Gao, J.L.; Yuan, F. Growth Type and Functional Trajectories: An Empirical Study of Urban Expansion in Nanjing, China. *PLoS ONE* **2016**, *11*, e0148389. [CrossRef] [PubMed]
36. Li, H.; Wei, Y.H.D.; Huang, Z.J. Urban Land Expansion and Spatial Dynamics in Globalizing Shanghai. *Sustainability* **2014**, *6*, 8856–8875. [CrossRef]

37. Yin, J.; Yin, Z.E.; Zhong, H.D.; Xu, S.Y.; Hu, X.M.; Wang, J.; Wu, J.P. Monitoring urban expansion and land use/land cover changes of Shanghai metropolitan area during the transitional economy (1979–2009) in China. *Environ. Monit. Assess.* **2011**, *177*, 609–621. [CrossRef] [PubMed]
38. Tian, G.J.; Ma, B.R.; Xu, X.L.; Liu, X.P.; Xu, L.Y.; Liu, X.J.; Xiao, L.; Kong, L.Q. Simulation of urban expansion and encroachment using cellular automata and multi-agent system model-A case study of Tianjin metropolitan region, China. *Ecol. Indic.* **2016**, *70*, 439–450. [CrossRef]
39. Ma, X.Y.; Zhang, Y.C. Numerical study of the impacts of urban expansion on Meiyu precipitation over Eastern China. *J. Meteorol. Res.* **2015**, *29*, 237–256. [CrossRef]
40. Sun, Y.; Zhao, S.Q.; Qu, W.Y. Quantifying spatiotemporal patterns of urban expansion in three capital cities in Northeast China over the past three decades using satellite data sets. *Environ. Earth Sci.* **2015**, *73*, 7221–7235. [CrossRef]
41. Zeng, C.; Zhang, M.D.; Cui, J.X.; He, S.W. Monitoring and modeling urban expansion—A spatially explicit and multi-scale perspective. *Cities* **2015**, *43*, 92–103. [CrossRef]
42. Cao, Y.G.; Bai, Z.K.; Zhou, W.; Zhang, X.R. Analyses of traits and driving forces on urban land expansion in a typical coal-resource-based city in a loess area. *Environ. Earth Sci.* **2016**, *75*, 1191. [CrossRef]
43. Zhang, X.; Bai, Z.; Fan, X.; Lu, Y.; Cao, Y.; Zhao, Z.; Sun, Q.; Pan, J. Urban Expansion Process, Pattern, and Land Use Response in an Urban Mining Composited Zone from 1986 to 2013. *J. Urban Plan. Dev.* **2016**, *142*, 04016014. [CrossRef]
44. Jiang, L.; Zhang, Y.H. Modeling Urban Expansion and Agricultural Land Conversion in Henan Province, China: An Integration of Land Use and Socioeconomic Data. *Sustainability* **2016**, *8*, 920. [CrossRef]
45. Peng, W.F.; Wang, G.J.; Zhou, J.M.; Zhao, J.F.; Yang, C.J. Studies on the temporal and spatial variations of urban expansion in Chengdu, western China, from 1978 to 2010. *Sustain. Cities Soc.* **2015**, *17*, 141–150. [CrossRef]
46. Liu, Y.X.; Zhang, X.L.; Lei, J.; Zhu, L. Urban expansion of oasis cities between 1990 and 2007 in Xinjiang, China. *Int. J. Sustain. Dev. World. Ecol.* **2010**, *17*, 253–262. [CrossRef]
47. Cao, Y.G.; Bai, Z.K.; Zhou, W.; Ai, G. Gradient Analysis of Urban Construction Land Expansion in the Chongqing Urban Area of China. *J. Urban Plan. Dev.* **2015**, *141*. [CrossRef]
48. Shu, B.R.; Zhang, H.H.; Li, Y.L.; Qu, Y.; Chen, L.H. Spatiotemporal variation analysis of driving forces of urban land spatial expansion using logistic regression: A case study of port towns in Taicang City, China. *Habitat Int.* **2014**, *43*, 181–190. [CrossRef]
49. Deng, X.Z.; Huang, J.K.; Rozelle, S.; Uchida, E. Growth, population and industrialization, and urban land expansion of China. *J. Urban Econ.* **2008**, *63*, 96–115. [CrossRef]
50. Fahmi, F.Z.; Hudalah, D.; Rahayu, P.; Woltjer, J. Extended urbanization in small and medium-sized cities: The case of Cirebon, Indonesia. *Habitat Int.* **2014**, *42*, 1–10. [CrossRef]
51. Huang, Z.J.; Wei, Y.D.; He, C.F.; Li, H. Urban land expansion under economic transition in China: A multilevel modeling analysis. *Habitat Int.* **2015**, *47*, 69–82. [CrossRef]
52. Chen, J.F.; Chang, K.T.; Karacsonyi, D.; Zhang, X.L. Comparing urban land expansion and its driving factors in Shenzhen and Dongguan, China. *Habitat Int.* **2014**, *43*, 61–71. [CrossRef]
53. Quan, B.; Bai, Y.J.; Romkens, M.J.M.; Chang, K.T.; Song, H.; Guo, T.; Lei, S. Urban land expansion in Quanzhou City, China, 1995–2010. *Habitat Int.* **2015**, *48*, 131–139. [CrossRef]
54. Li, Y.; Ye, J.H.; Chen, X.H.; Abdel-Aty, P.E.M.A.; Cen, M. Transportation Characteristics Change under Rapid Urban Expansion: A Case Study of Shanghai. *Chin. Geogr. Sci.* **2010**, *20*, 554–561. [CrossRef]
55. Li, X.H.; Lin, T.; Zhang, G.Q.; Xiao, L.S.; Zhao, Q.J.; Cui, S.H. Dynamic analysis of urban spatial expansion and its determinants in Xiamen Island. *J. Geogr. Sci.* **2011**, *21*, 503–520. [CrossRef]
56. Long, H.; Wu, X.; Wang, W.; Dong, G. Analysis of Urban-Rural Land-Use Change during 1995–2006 and Its Policy Dimensional Driving Forces in Chongqing, China. *Sensors* **2008**, *8*, 681–699. [CrossRef] [PubMed]
57. Vannier, C.; Jérémie, L.; Pierre-Yves, L.; Sandra, L. Patterns of landscape change in a rapidly urbanizing mountain region. *Cybergeo* **2016**. [CrossRef]
58. Haller, A. Vivid valleys, pallid peaks? Hypsometric variations and rural-urban land change in the Central Peruvian Andes. *Appl. Geogr.* **2012**, *35*, 439–447. [CrossRef] [PubMed]
59. Walcott, S.M. Thimphu. *Cities* **2009**, *26*, 158–170. [CrossRef]

60. Cai, Y.B.; Zhang, H.; Pan, W.B.; Chen, Y.H.; Wang, X.R. Urban expansion and its influencing factors in Natural Wetland Distribution Area in Fuzhou City, China. *Chin. Geogr. Sci.* **2012**, *22*, 568–577. [CrossRef]
61. Li, Z.; Gu, X.; Wang, L.; Li, D.; Xie, Y.; Li, K.; Dubovik, O.; Schuster, G.; Goloub, P.; Zhang, Y.; et al. Aerosol physical and chemical properties retrieved from ground-based remote sensing measurements during heavy haze days in Beijing winter. *Atmos. Chem. Phys.* **2013**, *13*, 10171–10183. [CrossRef]
62. Qian, J.; Peng, Y.F.; Luo, C.; Wu, C.; Du, Q.Y. Urban Land Expansion and Sustainable Land Use Policy in Shenzhen: A Case Study of China's Rapid Urbanization. *Sustainability* **2016**, *8*, 16. [CrossRef]
63. Lu, D.; Tian, Y.; Liu, V.; Zhang, Y. The Performance of the Smart Cities in China—A Comparative Study by Means of Self-Organizing Maps and Social Networks Analysis. *Sustainability* **2015**, *7*, 7604–7621. [CrossRef]
64. Zhou, R.; Zhang, H.; Ye, X.-Y.; Wang, X.-J.; Su, H.-L. The Delimitation of Urban Growth Boundaries Using the CLUE-S Land-Use Change Model: Study on Xinzhuang Town, Changshu City, China. *Sustainability* **2016**, *8*, 1182. [CrossRef]
65. Pang, B.; Fang, C.; Liu, H. Quantitative Study on the Dynamic Mechanism of Smart Low-Carbon City Development in China. *Sustainability* **2016**, *8*, 507. [CrossRef]
66. Sun, J.; Wang, X.; Cheng, G.; Wu, J.; Hong, J.; Niu, S. Effects of grazing regimes on plant traits and soil nutrients in an alpine steppe, Northern Tibetan Plateau. *PLoS ONE* **2014**, *9*, e108821. [CrossRef] [PubMed]
67. Li, C.; Zhao, J.; Xu, Y. Examining spatiotemporally varying effects of urban expansion and the underlying driving factors. *Sustain. Cities Soc.* **2017**, *28*, 307–320. [CrossRef]
68. Choudhary, K.; Boori, M.S.; Kupriyanov, A.; Kovelskiy, V. Analysis of urban spatio-temporal land use/cover change and expansion with their driving force through remote sensing and GIS in Samara city, Russia. *Adv. Mater. Mech. Struct. Eng.* **2016**. [CrossRef]
69. Ma, Y.L.; Xu, R.S. Remote sensing monitoring and driving force analysis of urban expansion in Guangzhou City, China. *Habitat Int.* **2010**, *34*, 228–235. [CrossRef]
70. Shi, L.Y.; Shao, G.F.; Cui, S.H.; Li, X.Q.; Lin, T.; Yin, K.; Zhao, J.Z. Urban three-dimensional expansion and its driving forces—A case study of Shanghai, China. *Chin. Geogr. Sci.* **2009**, *19*, 291–298. [CrossRef]
71. Almadani, S.; Ibrahim, E.; Abdelrahman, K.; Al-Bassam, A.; Al-Shmrani, A. Magnetic and seismic refraction survey for site investigation of an urban expansion site in Abha District, Southwest Saudi Arabia. *Arab. J. Geosci.* **2015**, *8*, 2299–2312. [CrossRef]
72. Webster, R.D.J. Haze Measurement. *J. Inst. Brew.* **1983**, *89*, 143.
73. Chen, Y.-L.; Ding, J.-Z.; Peng, Y.-F.; Li, F.; Yang, G.-B.; Liu, L.; Qin, S.-Q.; Fang, K.; Yang, Y.-H. Patterns and drivers of soil microbial communities in Tibetan alpine and global terrestrial ecosystems. *J. Biogeogr.* **2016**, *43*, 2027–2039. [CrossRef]
74. Gao, J.L.; Wei, Y.D.; Chen, W.; Yenneti, K. Urban Land Expansion and Structural Change in the Yangtze River Delta, China. *Sustainability* **2015**, *7*, 10281–10307. [CrossRef]
75. Pinna, F.; Masala, F.; Garau, C. Urban Policies and Mobility Trends in Italian Smart Cities. *Sustainability* **2017**, *9*, 494. [CrossRef]
76. Anttiroiko, A.V. Urban Planning 2.0. *Int. J. E Plan. Res.* **2012**, *1*, 16–30. [CrossRef]
77. Chen, J.L.; Gao, J.L.; Yuan, F.; Wei, Y.D. Spatial Determinants of Urban Land Expansion in Globalizing Nanjing, China. *Sustainability* **2016**, *8*, 868. [CrossRef]
78. Lu, S.S.; Guan, X.L.; He, C.; Zhang, J.L. Spatio-Temporal Patterns and Policy Implications of Urban Land Expansion in Metropolitan Areas: A Case Study of Wuhan Urban Agglomeration, Central China. *Sustainability* **2014**, *6*, 4723–4748. [CrossRef]
79. Zhou, G.H.; He, Y.H. The influencing factors of urban land expansion in Changsha. *J. Geogr. Sci.* **2007**, *17*, 487–499. [CrossRef]
80. Xiao, J.; Shen, Y.; Ge, J.; Tateishi, R.; Tang, C.; Liang, Y.; Huang, Z. Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing. *Landsc. Urban Plan.* **2006**, *75*, 69–80. [CrossRef]
81. Li, T. Land use dynamics driven by rural industrialization and land finance in the peri-urban areas of China: "The examples of Jiangyin and Shunde". *Land Use Policy* **2015**, *45*, 117–127.
82. Gao, J.L.; Wei, Y.D.; Chen, W.; Chen, J.L. Economic transition and urban land expansion in Provincial China. *Habitat Int.* **2014**, *44*, 461–473. [CrossRef]
83. Feng, J.; Lichtenberg, E.; Ding, C.R. Balancing act: Economic incentives, administrative restrictions, and urban land expansion in China. *China Econ. Rev.* **2015**, *36*, 184–197. [CrossRef]

84. Li, H.; Wei, Y.D.; Liao, F.H.; Huang, Z.J. Administrative hierarchy and urban land expansion in transitional China. *Appl. Geogr.* **2015**, *56*, 177–186. [CrossRef]
85. Balasubramaniam, A.; Paul, A.; Hong, W.-H.; Seo, H.; Kim, J. Comparative Analysis of Intelligent Transportation Systems for Sustainable Environment in Smart Cities. *Sustainability* **2017**, *9*, 1120. [CrossRef]

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Review

Investigating the Role of Virtual Reality in Planning for Sustainable Smart Cities

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Abstract: With rapid population growth, urban designers face tremendous challenges to accommodate the increasing size of the population in urban areas while simultaneously considering future environmental, social, and economic impacts. A "smart city" is an urban development vision that integrates multiple information and communication technologies to manage the assets of a city, including its information systems, transportation systems, power plants, water supply networks, waste management systems, and other community services provided by a local department. The goal of creating a smart city is to improve the quality of life of citizens by using technology and by addressing the environmental, social, cultural, and physical needs of a society. Data modeling and data visualization are integral parts of planning a smart city, and planning professionals currently seek new methods for real-time simulations. The impact analysis of "what-if scenarios" frequently takes a significant amount of time and resources, and virtual reality (VR) is a potential tool for addressing these challenges. VR is a computer technology that replicates an environment, whether real or imagined, and simulates the physical presence and environment of a user to allow for user interaction. This paper presents a review of the capacity of VR to address current challenges in creating, modeling, and visualizing smart cities through material modeling and light simulation in a VR environment. This study can assist urban planners, stakeholders, and communities to further understand the roles of planning policies in creating a smart city, particularly in the early design stages. The significant roles of technologies, such as VR, in targeting real-time simulations and visualization requirements for smart cities are emphasized.

Keywords: smart city; virtual reality; urban planning; data visualization

1. Introduction

The extent of metropolitan areas has significantly increased over the past decades [1]. According to United Nations the world population will increase to 9.3 billion by 2050, and among which, 6.3 billion people will dwell in urban areas.

As a result of rapid urban growth and the establishment of megacities, new sets of challenges have developed in urban areas. These challenges include, but are not limited to, environmental issues, air pollution, the heat island effect, the lack of natural resources, and deteriorating infrastructure. The implementation of effective policies and strategies for a smarter urban growth has received further interest under such scenario. The increasing population requires governments to determine ways to create future spaces for citizens. They base their economic development policies on building advanced infrastructure to keep up with international competition.

At present, information and communication technology (ICT) changes the manner in which cities perform and affects the policies formulated for future growth. Smart cities base their strategy on the use of ICT in several fields, such as economy, environment, mobility, and governance, to transform city infrastructure and services with the least adverse impact on the environment.

The smart city concept has recently received significant attention from policy-makers. However, a clear and consistent understanding of this new phenomenon has yet to be fully gained. Smart cities, as effective strategies for addressing urbanization challenges, have attracted considerable interest from governments and policy developers worldwide.

Although no single description exists for smart cities, they are briefly defined as "those cities that utilize information and communication technologies with the aim to increase the quality of life of their dwellers, while providing sustainable development." The management of resources will be sustainable as a result of implementing these technologies in urban services and infrastructure. Other scholars have perceived smart cities in a different manner.

For example, Albino believes that six main criteria lead to the creation of a smart city: smart economy, smart environment, smart mobility, smart people, smart living, and smart governance. Some scholars have envisioned a smart city as a combination of sensor networks [2]. Others have portrayed a smart city as an improvement in the quality of social operation [3].

In the context of sustainable urban growth, a smart city is a concept that is developed based on three major pillars: establishing economic growth, addressing environmental issues, and incorporating social equity. In the context of geomatics, a smart city is the integration of a digital city, the Internet of Things, and cloud computing technology.

A digital city creates a 3D spatial framework for a city. The Internet of Things conducts real-time sensing, measurement, and data transmission of moving objects. The function of cloud computing is similar to that of a human brain. It is responsible for complicated calculations, data analyses, and pattern recognition; it also provides remote monitoring, control, and feedback. The link among different components of a smart city is shown in an integrative framework in Figure 1.

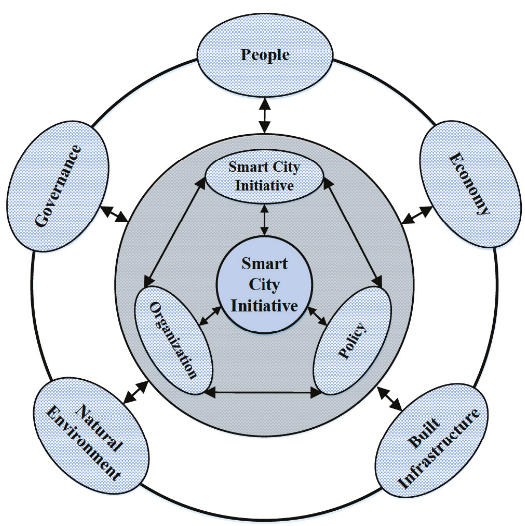


Figure 1. Smart city initiative framework.

Smart city design is largely influenced by the development and advances in digital technology and visualization of smart city is identified as the most important part of the design process. Nowadays, a wider range of digital tools and visualization techniques assist the planning and designing of smart cities which consists of data storage and retrieval. Visualization techniques aim to analyze and inform the design process and provide sophisticated communication strategies between the final users (i.e., communities, public) and decision-makers (i.e., governments, policy makers). This paper presents an overview of the challenges in creating smart cities and discusses the use of virtual reality (VR) in data visualization. This paper presents an overview of the challenges in creating smart cities and discusses the use of virtual reality (VR) in data visualization.

2. Literature Review

2.1. Smart, Sustainable Cities, and VR

A smart city is defined according to a model which was initially employed as a classification system-and established on six main pillars; intelligent mobility system, smart environment, smart lifestyle, smart urban citizens, smart economy, and smart governance—against which smart cities can be assessed [4]. The concept of smart city can be also defined as an urban development technique to highlight the growing role of ICT infrastructure in improving the triple bottom lines in urban sustainability. Sustainability, on the other hand deals with the complex interactions between environmental, social, economic, and physical subsystems of an urban environment [5].

Smart city design often consists of formal sequence of different formal stages and has a cyclic process in which expertise and professionals get together and come up with innovative solutions. These stages should be communicated to numerous decision-makers. The design process should be communicated during and before the design process, particularly if the design teams consist of professionals with diverse backgrounds. The most important factor in designing smart cities is clear communication between the clients, designers, political decision-makers, and communities. The urban design solutions and master plans are basically visual in nature. Therefore, the most effective method to communicate these solutions is visual as well. This method involves functional, economic, social, and aesthetical aspects of design.

The emergence of virtual reality and ICT assist urban planners to effectively overcome these complexities through visualizing the big data [6]. In fact, visualization through virtual reality has made it possible to approach a range of issues around the sustainable development from a new perspective.

Furthermore, virtual reality as an interactive platform enable smart and sustainable cities to identify their potentials by getting smarter and by improving their contribution to sustainability and increasing rate of urbanization. The lost connection between smart and sustainable cities and virtual reality is the main factor in the emergence of smart city which also highlights the important role of urban management system [7]. Therefore, recent research projects have started to look at the methods to improve smart and sustainable city approaches and smarten the sustainability in the urban environments [8,9]. Web-based visualization technologies, such as VR, present a dynamic virtual environment. Urban simulation is carried out to provide further dynamic virtual process with which a user can interact. These tools enable the designers to produce a sophisticated, yet real, world.

VR is one step higher than 3D visualization. VR is explained as a, computer-generated environment that provides a user with the sense of being surrounded by a real world. The emergence of VR in in the late 1980s opened numerous opportunities for architects, professional animation, 3D makers and also held a promise for public participation planning.

The first step is creating a 3D environment in VR, in which the user would be able to easily navigate inside this virtual world. VR is capable of creating very detailed virtual environments that are highly complex. For instance in a VR project conducted by the Divisions group in Japan, users were able to explore and navigate inside the room of each house, using a headset and a three-dimensional mouse. The user's hand appears on the screen and the user can use this hand to open the doors or drawers, push or pool the doors, turn on or turn off the lights, run the water in the bathroom, and change the interior design. Although architects claim that this program does not provide a satisfactory level of detail, its effectiveness in participatory planning has been evident, since it enables the user to see and assess the development scenarios before it is constructed.

The application of VR in promoting participatory planning is in its experimental and infant stage. However, this application provides a best communication tool for individuals with diverse background to talk in a same language. For instance, a modeled and visualized neighborhood in VR enables public and communities to walk through the virtual environments and experience the proposed design scenarios.

Currently there are a limited number of VR related applications available specifically for use in designing or simulating smart cities. This is likely to change with the rapid increase in the need to provide clients and government parties with BIM (building information modelling), GIS (geographic information system), and LIDAR (light detection and ranging) data that can be used to create 3D virtual environments. Navisworks, an Autodesk application, is commonly used in the construction industry to navigate and annotate 3D models and provide limited VR support such as stereo real-time rendering and VR stereo 360-degree image rendering. It is possible to extend this capability with plugins which can support different VR hardware, such as a VR CAVE. However, due to the rapid developments in the field, the technology has to be updated accordingly.

Revizto [10] is an application developed to support a range of BIM and CAD applications to present interactive 3D virtual presentations, typically walkthroughs, and has recently added support for Oculus RFT and HTC Vive VR hardware. While Revizto provides a great solution for viewing the virtual models, the level of interactions in the buildings or cities using VR hardware is limited. For instance, one of the challenges is to select individual objects or layers using tracked hand controllers.

Nowadays, the ideal approach to take full advantage of current VR hardware and the latest VR features is developing smart city applications within a game engine such as Unity [11] or Unreal. This will provide a great opportunity to employ advanced VR interaction features, such as hand and gesture based tracking. While this approach requires extra time and expertise in optimizing the models or programming interactions, but it gives developers the freedom of implementing a range of supported VR interaction techniques available in the selected game engine. Although VR is still in its infant stages, using a VR supported game engine is a good approach to experiment with VR interactions required for smart city applications. As the deployment of VR technology progress, it is expected that interactions will be considered important for smart city design and will likely lead to specific smart city design applications that support the required VR interactions natively.

2.2. Development of VR

Visualization refers to a process of transforming data into visual representations, which are intended to develop effective and efficient cognitive processes to gain insight into those data [12].

Virtual technology is not a new concept, and it has evolved from other technologies. The actual roots of VR date back to 1962 with the ill-fated "sensorama" of Morton Heiligs and the development of teleoperation displays by using head-mounted, closed-circuit television systems.

The use of VR in modeling, communication, and visualization has received increasing interest. One of the main reasons why VR has attracted considerable attention is that it offers benefits to a wide range of users (e.g., scientific visualization, operations in hazardous or remote areas), particularly in visualizing, planning, and designing ideas in a built environment before they are established.

VR is the capability to simulate the physical presence of a user within a VE by stimulating senses, usually sight, sound, and touch, and by providing an intuitive interaction. VR is a reemerging technology that exhibited promise in the late 1990s, but lacked the hardware capability and processing requirements to become a fully mature technology at that time.

Computing power has progressed in recent years to a point that VR is currently a commonly accessible technology, and several VR hardware and software solutions have been rapidly released. The VE presented to a user can either be fictional or can simulate a real-world environment depending on its design. User immersion is achieved using a range of different VR hardware solutions, such as stereoscopic displays, tracking systems, sound systems, and haptic devices.

VR comprises two main types based on the degree of immersion and interface in a synthetic environment: immersive and non-immersive VR systems. Immersive VR is an application in terms of quasi-physical experience. In such an experience, a fuller contact occurs between the user and the virtual environment. These types of VR can be obtained by using data gloves and multimedia head-mounted display (HMD) devices. Non-immersive VR uses a screen interface and enables users to feel the modeled environment through devices, such as eyeglasses. These types of VR, which are also called desktop VR or screen-based VR, include "division" and "superscape" software.

In another classification, VR systems are divided into HMDs and cave automatic virtual environments (CAVEs). HMDs, such as Oculus Rift, HTC Vive, Gear VR, and Google Cardboard, provide a low-cost VR solution by using a stereoscopic display mounted on the head of a user. They provide users with rotational head tracking that allows them to look in any given direction within the VE from a fixed point. The more sophisticated tracking systems allow users to walk around a given area and may also support hand tracking to provide natural interaction with virtual objects.

A challenge in HMDs is the loss of the proprioceptive of users because their physical body cannot be observed while wearing an HMD. By contrast, CAVEs are commonly constructed with three to six walls in a cube shape using stereoscopic projectors. A user typically wears stereoscopic glasses and interactive markers to provide a fully immersive experience within a given workspace that they can physically navigate. Unlike in HMDs, user vision is not obstructed from their physical surroundings. Figure 2 shows a four-sided CAVE.

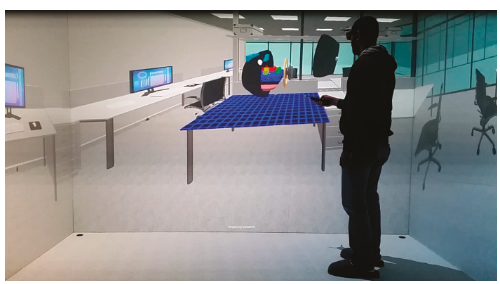


Figure 2. Interactive CAD demo deployed within a four-wall CAVE located at the Center for Advanced Design in Engineering VR Lab, Deakin University.

Online multi-user VR is an emerging field within VR allowing multiple users to connect using either local networks or the Internet. This alters the VR experience from an isolated experience to a platform ion which multiple users can interact within the same virtual environment. An emerging standard for VR format on the web is WebVR [13], which provides a format for describing 3D interactive virtual environments on the web. This VR format currently supports a wide range of VR hardware including Oculus Rift, HTC Vive, and Google Cardboard that can be used to view a VR website.

2.3. VR and Planning Smart Cities

Urban planning is a complex process that encompasses different aspects in social, economic, physical, and spatial sciences. These aspects are dependent, and they interact with one another within an urban system. Therefore, the decision-making process relies equally on all these aspects.

Neighborhoods, cities, and precincts are complex structures, and the way urban designers and planners perceive the challenges and identify the opportunities is strongly visual.

A significant challenge in modeling cities, particularly smart cities, is data visualization, which is mainly due to the various data generated from numerous processes, such as traffic, human movement, environmental pollutions, energy resources, and water supplies. This information will provide the data to determine how a city will look and what is happening in the city.

Communication is another challenge between planning authorities and designers, which frequently leads to uncertainties in decisions and the lack of consistency among stakeholders. Therefore, discussions, formal meetings, and the presentation of informative and accessible data that can also exhibit the complex interactions of multiple variables in urban environments are integral parts of any decision-making process.

Providing an effective visualization tool to evaluate and forecast the environmental and social consequences of creating a city is the key to achieving a sustainable and resilient urban design. Considerable research has focused on different visualization techniques including heat maps [14], glyph annotated maps [15] and tradition 2D graphs [16], but studies on the effectiveness of VR in modeling the future of smart cities and on demonstrating the impacts of "what-if" scenarios to policy-makers and communities is lacking.

Visualization in urban planning and urban design provides three main benefits [16]: (1) it assists in understanding the consequences of design schemes from multiple perspectives; (2) it helps understand the different layers of information about urban planning and urban design; and (3) it offers an effective platform for communicating with others.

The traditional approach in visualization is to demonstrate information and data within a 2D framework. The 2D layers are complex, and only planning professionals can fully manipulate information. Consequently, the potential use of 3D VR systems has been explored in depth to overcome the limitations of 2D systems.

Planners can evaluate the impacts of new developments in relation to transportation patterns, environmental consequences, and access to landmarks, infrastructure, and other amenities, by using VR. Planners can also map and assess the social, cultural, and behavioral responses to the built environment. VR creates environments that can be entered into and interacted with directly, thereby considerably facilitating the visualization, communication, and evaluation of new design schemes.

The successful application of VR to urban design is assessed in two ways: (1) the capability of the 3D VR system to convince clients (i.e., the public, authorities, lobby groups) to address urban design guidelines and planning policies; and (2) the capability to provide an accurate and exact visualization that is realistic and is a validated benchmark for further design alternatives. Both ways contribute to the concept of "participatory planning," which presents the process in which all the stakeholders and urban dwellers actively involved in the planning and policy processes and play a significant role in defining the directions, visions, and initiatives of urban growth and development.

In fact, engaging different sectors in the decision-making process is a key step in designing a smart and resilient city, and this practice will lead to a good balance among different levels of power, interests, and resources. Moreover, such an approach will create a platform for further interaction and communication on an equitable basis, thereby allowing participants to be part of the final planning outcomes and empowering individuals to address issues and set priorities.

Participatory planning enables communities to engage in the different aspects and scales of the planning process and changes a top-down hierarchy into a joint and elaborate experience which, in turn, will lead to a creative and informed outcome [17].

VR, as an emerging discipline in the area of information technology (IT) and ICT, can significantly contribute to creating a platform for such an interaction, supporting mutual learning and transparency in planning policies, and establishing strong partnerships among different parties and disciplines. In fact, VR helps establish participatory planning among different parties, which varies from a conventional problem-solving approach. Figure 3 illustrates the key elements of participatory planning.

As Figure 3 demonstrates, participatory planning brings up a novel political approach to planning, within which decision-making and policy-making occur on shared issues via the active interaction between various parties including urban planners, citizens, stakeholders, scientists, and policy-makers.

Therefore, instead of only focusing on problem solving, participatory planning mainly consists of an interaction platform which supports the mutual learning, the establishment of partnerships and the empowerment of stakeholders. It also constitutes a process of collective analysis, learning, and policy action, where the decision-making is highlighted more than the sketch of the final planning outcome [18].

Data visualization via VR provides adequate information on different opinions, insights, visions, fears, desires, and empirical knowledge for communities, planners, and stakeholders, which subsequently defines the type of planning decisions that best fit the specific need of a certain community (Figure 4). Data visualization via VR involves sharing responsibilities for the decision-making process, in which local planners, community, and stakeholders will benefit.

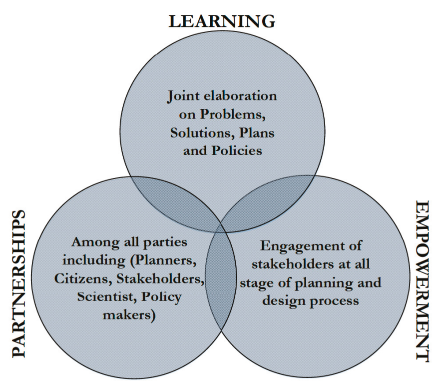


Figure 3. Key dimensions of participatory planning [1].

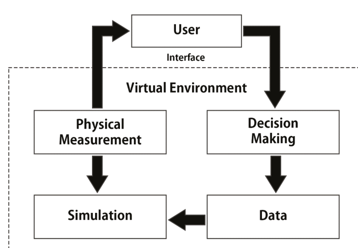


Figure 4. Diagram of the proposed VR (virtual reality) participatory planning system.

2.4. VR and Real-Time Simulation

Recent advancements in VR have changed the way in which research is conducted and have provided alternative solutions to traditional educational methods. The design and simulation of smart cities using VR technology can also benefit from the increased level of immersion in and natural interaction with virtual environments that current VR technology affords. Game engines, such as Unity and Unreal, provide a high level of realism using physically-based rendering (PBR) materials [19] and create realistic visual effects that closely represent real physical interaction with light. They are combined with built-in physics engines, such as NVidia's PhysX [20], which enable investors and developers to create interactive VEs that provide a good representation of the real world.

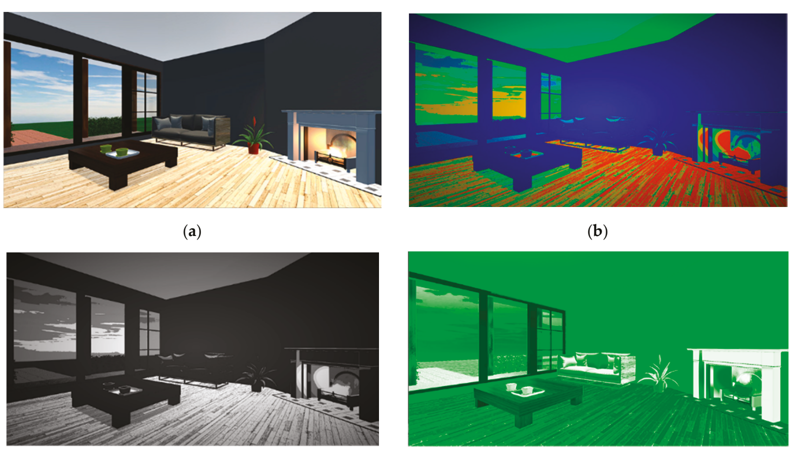
The deployment of "serious games" has rapidly grown in the last few decades. "Serious games" refer to a term coined for VEs used in research, education, and industry for real-world applications other than edutainment that are currently being deployed using the latest VR hardware.

Conventional methods for modeling and data visualization create confusion in understanding design concepts, particularly for nonprofessional cohorts who lack the required skillsets to interpret 2D data, such as tables, graphs, and diagrams. Simulations for smart cities also frequently lack real-time data visualization which, in turn, contributes to difficulties in effective communication among different stakeholders.

Smart cities represent an ideal candidate to deploy a VR solution for design and simulation phases. Planning and designing smart cities include analyzing and synthesizing different layers of information and data, particularly when considered over specific time intervals.

The use of modern game engines and interactive VR hardware enables researchers to apply the information obtained from traditional simulation techniques and to provide real-time, naturally interactive, and fully immersive VEs that lead to good visualization of vast amounts of smart city data. A given city can be modeled or scanned using modern techniques that provide a 3D visual reference that closely replicates an actual city. Specific layers of data important to smart city design, such as services, traffic, pollution, and thermal comfort, can be requested through handheld controllers or gesture-based commands while navigating important areas of interest. Designers and planners can alter design and planning parameters (e.g., the location and size of green and gray infrastructure), provide real-time simulations, and illustrate the environmental, social, and economic impacts of each design/planning scenario.

In graphic design, the term "rendering" refers to the calculation of computer visuals based on a modeled scene using certain physical characteristics, such as light, shadow, and reflection. A shader provides information on how a modeled scene will be rendered and is frequently used to provide special effects, such as chroma keying, bump-mapping posterization, and distortion. For visualizing different layers of data in smart cities, the use of infrared, thermal, and night vision shaders can provide real-time camera views (Figure 5) by adopting a simple user interaction. Consequently, users can visually switch among important physical information, such as heat and light in real-time while virtually navigating a city to gain a good understanding of the changes they make during the design or simulation process.



(**a**) (**b**) (**c**) (**d**)

Figure 5. Normal (**a**), thermal (**b**), infrared (**c**), and night vision (**d**) shaders used in a virtual architecture scene in the Unity game engine, enable the users to visually switch among important physical information, such as heat and light in real-time.

Planning for future urban development is a visionary "debate and decide" process, not a "predict and provide", computer-driven process. Therefore, to create a smart sustainable city all the decisions should be sustainability-based, integrating social, economic, environmental, and cultural considerations. Such decision-making processes are inclusive and require a thorough analysis of big data. Virtual reality as an emerging field provides a platform to visualize the impact of future urban development scenarios prior any implementation stage, and thereby leads to a significant reduction in the cost, drastic improvement in the environment of the cities (pedestrian thermal comfort/air temperature, transportation) and, finally, further socio-cultural and psychological awareness among urban dwellers. Therefore, this paper focuses on the role of VR in creating smart, sustainable cities through investigating different aspects of sustainability in urban environments and by exploring the (1) potential of VR in visualizing pedestrian thermal comfort in cities (environmental aspect); (2) potential of VR in visualizing smart transportation for a city (environmental aspect); (3) potential of VR in data management and planning of the cities (economical and physical aspects); and, finally, (4) the potential of VR in visualizing the cognitive behavior of urban dwellers (socio-cultural aspects).

3. Using VR in Designing/Planning Smarter Cities

3.1. Potential of VR in Visualizing Pedestrian Thermal Comfort in Cities

An example of VR urban models was created for an environmental planning study for a future development in Melbourne. The study examined the thermal consequence of implementing "Plan Melbourne" at the pedestrian level at a neighborhood scale [21].

In May 2014, "Plan Melbourne" was launched by the Victorian government to outline the vision for the growth of Melbourne until the year 2050. The draft of the municipal strategic statement of the City of Melbourne identified "City North" as a great urban renewal area that could accommodate a significant part of the growth. Structural plans provided guidance to the community, planners, businesses, government, and developers about the appropriate directions and opportunities for future changes in City North. This area would be developed according to the structural plans to provide a diverse mix of uses associated with denser urban environments.

Proposing a street hierarchy, increasing building heights, expanding urban forests by increasing tree canopy coverage, implementing green roofs, and overall transition from a low-rise to a medium-rise urban area were some of the strategies presented in the structural plans. The effects of future structural plans presented in "Plan Melbourne" on the microclimate and pedestrian thermal comfort in City North were modeled in three different stages using a 3D microclimatic modeling tool, namely, ENVI-met (Version 3.1).

The outcomes of this study contribute to the understanding of how altering urban morphology and landscape can modify the interaction among individual elements in a built environment, microclimatic processes, and human-energy balance across urban developments within the Melbourne metropolitan region. This study also helps urban planners develop policies that will include urban climatic considerations in future planning schemes. These climatic considerations can improve the climate of Melbourne and avoid adverse consequences on public health arising from future development and renewal projects.

As shown in Figures 6 and 7, implementing "Plan Melbourne" strategies will slightly improve thermal comfort at the pedestrian level. The spatial distribution of PET is shown for the existing (2015) and future (2050) scenarios in Figure 7.

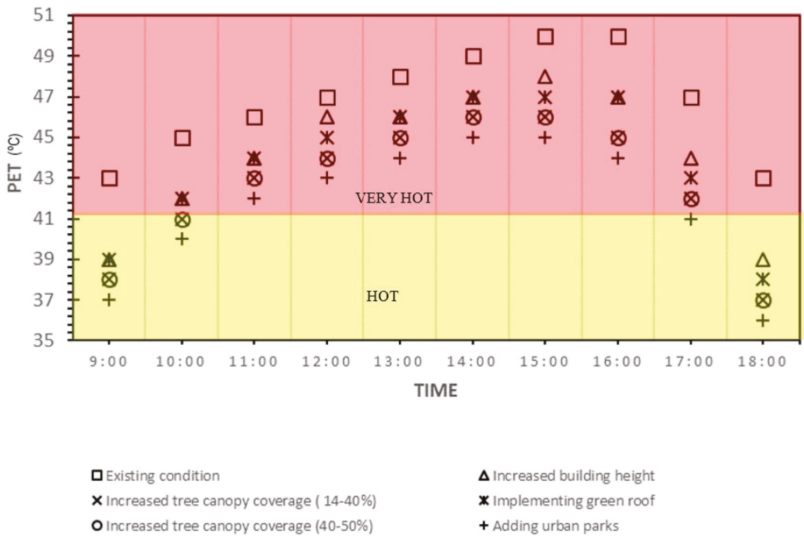
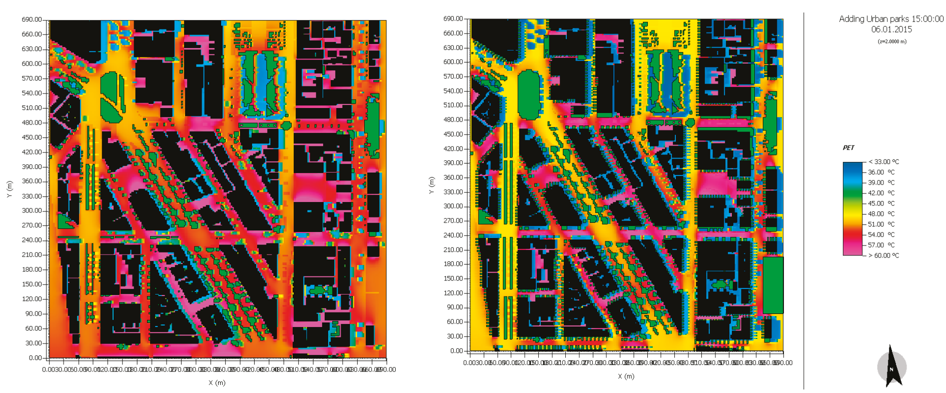


Figure 6. Thermal comfort (PET) condition in the existing, future, and proposed scenarios.



(a) (b)

Figure 7. Spatial distribution of thermal comfort (PET) across the study area in the existing (**a**) and proposed (**b**) scenarios.

The final outcomes of the study can lead to urban planning recommendations for municipalities and urban planners. This work demonstrates that establishing a continuous dialogue between urban planners and researchers can address changes and adapt to interventions in urban planning recommendations. Developing adaptation and mitigation actions to improve the quality and livability of urban spaces and human thermal comfort within them will only be possible by increasing interaction and cooperation between municipal actors and researchers. The outcomes obtained in this work demonstrate a need for communication among municipal decision-makers, academic researchers, and communities, particularly during early urban design phases.

Visualizing the outcome of this study by using VR will not only result in an increased level of awareness among stakeholders, urban planners, and community developers on the impacts of their decision-making, but will also develop high trust among different parties. For example, in this specific case study, data visualization via VR and the addition of thermal sensors to the final outcome would help communities further understand the impact of "Plan Melbourne" on the environment of their cities, and the findings would not always remain as raw materials on papers. Communities will feel highly engaged in the policy-making process, and lost trust on city councils and state governments will return among communities. Furthermore, planners and stakeholders will have a clear vision on the environmental, social, and economic benefits of every "what-if" scenario, which in turn, will lead to the creation of not only a smart city (integration with IT and ICT), but also a sustainable and resilient city wherein a triple bottom line is completely respected.

3.2. Potential of VR in Visualizing Smart Transportation for a City

Traffic and effective transportation are important topics in smart sustainable cities. There are different methods to collect the traffic and transport data, such as smartcards used mainly in smart public transportation, car navigators, smart camera systems for traffic control, and smart pedestrian sensors. These technologies require data to effectively manage the transportation in urban environments. Data derived from GPSs, GIS-generated data, POI data, and space syntax data are the most important data sources for smart transportation systems.

Urban scholars employ different ranges of data sources and data analysis methods to understand and analyse the urban data and to better manage the traffic condition and thereby providing navigation, traffic control and recommendations for the traffic condition.

Some studies aim to investigate the perception rate and conduct analysis on the traffic condition in the urban environments. These studies often collect the data from the traffic conditions in different parts of the city, analyse the traffic behaviour statistics and create algorithms and planning frameworks.

Some studies used real-time traffic data that is generated via monitored urban data [22].

Other studies, which contributed to a significant improvement in the traffic control, focused on the identification of unique road sections [23], assessment of the commuting time between defined destinations [24], exploring the pattern of traffic condition in a city, and thereby assess and forecast the traffic patterns [25].

Other studies on the smart traffic systems for smart cities have focused on specific traffic services, such as GPS-oriented systems. A high-quality navigation system is often generated through a digital map in addition to a real-time traffic data and analyses [26]. Human movement is tracked using GPS, which optimizes the selected route by the driver [27].

Some studies analysed the behaviour and patterns of taxis and passenger's movements and the connection which exists among them. For instance, in a study conducted by Li [28], the effectiveness of different passenger searching techniques for five thousands taxis was explored. In a similar study, the methods to increase taxi driver incomes were evaluated by ameliorating the passenger search techniques [29].

One of the most important strategies in optimizing the public transportation system is the assessment of urban traffic data. In a study in London, the passenger congestion patterns was analysed and a technical solution was proposed to tackle the underground traffic issue [30]. In a similar study to effectively decrease the traffic load, a planning model for the ride-sharing system was proposed [31], using a historic passenger origin-destnation information.

One of the examples of implementing VR in smart cities is through real-time transportation systems and smart transportation corridors. This implementation consists of creating a linkage among all the neighborhoods, applying crime prevention strategies to design safer streets, constant supervision on the provision of high-quality, affordable, and accessible transportation systems, and finally decreasing the CO_2 emissions via effective retrofication methods.

To address these objectives, virtual reality can help provide real-time data on traffic, pedestrian and parking conditions and diverse available transportation systems to reduce the traffic issues and the incidence of major accidents. VR can also help in visualizing future smart corridors which increase the efficiency of transportation systems. This visualization uses the traffic data and electronic street signs to warn the possibility of incidents and provides diverse detours options. In this regard, VR creates an enterprise data management ecosystem, which is a system that incorporates data to demonstrate a real-time image of traveling in a city (e.g., people movement and travelling pattern).

3.3. Potential of VR in Data Management

The data-centric smart city concept consists of the combination of data sources and computation techniques to identify and assess the diverse urban features and to better inform the future urban developments. One of the examples is the land use data. The urban areas often consist of different land uses, such as commercial, residential, industrial, and administrative uses. The challenge in planning smart cities with diverse or mixed land uses is that different land uses exist in even a small piece of land and defining the function of each land use is a challenging task.

Additionally, the function and land use of urban areas depend on the semantic features. However, it is a very challenging task to simultaneously measure these characteristics and retrieve the urban design characteristics from the dynamic urban data.

In some studies only residential and non-residential areas are explored [32]. In others [33], only residential, industrial, and administrative areas are distinguished. Finally, in studies conducted by [34], four areas—commercial, industrial, service, and residential—are identified and facilitate the data collection for smart city planning. However, none of the above-mentioned studies fulfil the demand of megacities. Therefore, it is important to use finer scales in land use identification technologies and employ more innovative methods to address this challenge. The urban area is explored by division into residential, working, and other function areas in a study conducted by [35] and the diverse travelling systems and patterns were analysed via a linear combination between the coefficients, each presenting different characteristics of land use.

VR assists in several aspects of spatial information management and urban development, e.g., managing urbanization, three and four dimensional physical models, land use planning, spatial data infrastructure and, finally, web- and mobile-generated geographic information systems (GIS). VR can also effectively link the government to the society and enable planning professionals to take appropriate decisions during the approval process. For example, in managing urbanization, the database of a city model can be displayed in VR. The deletion of one element (e.g., tree, building, or pole) in an urban area will remove the icon from the visualization.

Another application of VR in relation to 3D/4D models involves visualizing these models before and after planning schemes. Large GIS data from multiple sources can be demonstrated in real-time through VR. Spatial data infrastructure, along with the environmental and visual impact assessments of building/tree shadows, precipitation, fog, air flow, and light, demonstrate the connection between the education centers and transport systems. The links among different transport corridors, future development scenarios, and the existing infrastructure can also be illustrated via VR.

3.4. Potential of VR in Visualizing the Cognitive Behavior of Urban Dwellers

The design and analysis of cognitive behavior of people in urban/public spaces often require a great contribution from a number of disciplines; such as architects, psychologists, IT specialists, and data analysts.

Citizen cognitive behavior is a study of people behavior via employing statistical analysis. This science aims to mix the data and information on pedestrian movement with urban design strategies and psychology to analyze and identify the human behavior and solve the urban issues. Nowadays, studies of human behavior using big data are becoming more on-demand, particularly with respect to the concept of smart, sustainable city design.

One of the data sources used to investigate the temporal-spatial pattern of human activities in public spaces is mobile phone data. Based on the data obtained from SMS records, it was found that human behavior follows a power law distribution with a power exponent between 1.2 and 1.7 [36]. In a similar study 1.5 million SMS records from 140 thousand users were analyzed to demonstrate that these records follow a two-mode distribution, starting with a power law distribution and ending with an exponential distribution [37].

The spatial features of human cognitive behavior and its movement were analyzed via mobile phone records obtained from 100,000 people and the findings showed that that the journey distance for each user is calculated using the power law with a caudal index [38]. In a similar study, the activity pattern and movement of human were assessed via analyzing the mobile records. The findings of this study showed that there is 93% chance to predict the spatial activity pattern and this percentage is independent from the selection of the case studies and each individual.

GPS data is another important urban data source that can be used to analyze the human behavior. In a study conducted in Sweden, the GPS data in four cities was analyzed to explore taxi passengers' travel statistics and the findings showed that the travelling distance for each passenger is a variable of a two-mode power law distribution [39]. To predict the possibility of the locations where people check in through social networks urban GPS data was used in [40].

VR is one of the best tools for analyzing and simulating people's interaction with their surrounding environments by connecting the urban design features of cities to the user behavior. VR acts as a complementary link among space syntax, navigation, and pedestrian cognitive behavior in urban areas.

The connection between pedestrian movement and syntactic representation has a cognitive meaning [41]. Several studies have supported this hypothesis on real-world navigation via eye-tracking data. The cognitive behavior in an urban environment is also believed to be contributed to the mental representations and symbolic icons in the urban environment [42,43]. In a study conducted by Turner, the syntactic representation of numerous urban streets was simulated, and it was found that the users prefer continuous paths for walking [44].

VR creates a link between theoretical and practical frameworks by employing the cognitive psychology in architectural design, as well as urban design. VR can be also used as the basis for the cognitive movement in cities. In a study conducted by Ozbil, the extent to which street network configuration is associated with path selection by pedestrians was evaluated. The findings of this study showed that spatial configuration has a strong impact on pedestrian route choices. The study also proposed the optimal street design, pedestrian walkway, landscape design and preferred spots for the urban infrastructures [45]. In another study, several types of visibility patterns during random walks were investigated. The study showed a strong link between local and global visibility properties during a random walk, which is a main component for designing smart, sustainable public spaces and street networks [46].

One of the major challenges in the studies related to the cognitive behavior and urban design is the translation of research findings into design interventions. This gap can be filled by conducting a direct analysis of user experience. In the past, this problem was solved only through observation and the use of mobile technologies, such as eye tracking and recording of biometric data. At present, the rapid advances in virtual world modeling allow the testing of urban design scenarios in a controlled setup.

4. Conclusions

The notion of smart cities has gained considerable traction in recent years as a vision for stimulating and supporting innovation and economic growth and for providing sustainable and efficient urban management and development. Significant aspects of the smart city concept are data visualization and forecasting. VR enables researchers to perform a real-time analysis of different "what-if" scenarios and helps governments, stakeholders, and communities to be aware of the environmental and social impacts of their decisions.

VR exerts tremendous impacts on the future of urban design, particularly smart city design. The use of Internet-based VR enhances public participation in planning and design. It also provides a platform for designers to contribute to a project regardless of their location.

This paper discusses the possible benefits of VR for efficiently visualizing smart city design and simulations. Important point includes the capability to be fully immersed into a VE that closely represents real-world environments using PBR materials. This feature allows natural interaction methods to rapidly access required data layers while navigating VEs, view previously obtained simulation data in real-time for specific periods, and access different camera views using custom shaders, such as thermal and infrared information.

Key benefits of using VR in designing smarter cities include the following:

- Capability to assess design ideas in real time and within a 3D space during the design and planning phase;
- Effective communication among different stakeholders, academics, planning professionals, and communities;
- Saving of a significant amount of time by excluding guesswork in design;
- Integration of all aspects in the design and, thus, achieving a resilient sustainable city design with the least amount of time/funds; and
- Promotion of participatory planning.

A key challenge in implementing VR in urban planning is cost. The use of VR has been limited to only private companies, high-end workstations, and educational institutions. The visualization and simulation of urban built environments require the extensive use of integrated software to include GIS, digital drawings (computer-aided designs), multimedia data, and World Wide Web-based VR techniques. Future works are necessary to determine how urban designers who work in small companies will benefit from VR systems in their urban design or planning practices.

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References

1. Gartland, L.M. *Heat Islands: Understanding and Mitigating Heat in Urban Areas*; Routledge: Oxford, UK, 2012.
2. Stewart, I.; Oke, T. Classifying urban climate field sites by "local climate zones": The case of Nagano, Japan. In Proceedings of the Seventh International Conference on Urban Climate, Yokohama, Japan, 29 June–3 July 2009; Volume 29.
3. Johansson, E.; Emmanuel, R. The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka. *Int. J. Biometeorol.* **2006**, *51*, 119–133. [CrossRef] [PubMed]
4. Bibri, S.E.; Krogstie, J. Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustain. Cities Soc.* **2017**, *31*, 183–212. [CrossRef]
5. Yin, C.; Xiong, Z.; Chen, H.; Wang, J.; Cooper, D.; David, B. A literature survey on smart cities. *Sci. China Inf. Sci.* **2015**, *58*, 1–18. [CrossRef]
6. Shahrokni, H.; Årman, L.; Lazarevic, D.; Nilsson, A.; Brandt, N. Implementing smart urban metabolism in the Stockholm Royal Seaport: Smart city SRS. *J. Ind. Ecol.* **2015**, *19*, 917–929. [CrossRef]
7. Kramers, A.; Höjer, M.; Lövehagen, N.; Wangel, J. Smart sustainable cities–Exploring ICT solutions for reduced energy use in cities. *Environ. Model. Softw.* **2014**, *56*, 52–62. [CrossRef]
8. Batty, M.; Axhausen, K.W.; Giannotti, F.; Pozdnoukhov, A.; Bazzani, A.; Wachowicz, M.; Portugali, Y. Smart cities of the future. *Eur. Phys. J. Spec. Top.* **2012**, *214*, 481–518. [CrossRef]
9. Bibri, S.E.; Krogstie, J. On the social shaping dimensions of smart sustainable cities: A study in science, technology, and society. *Sustain. Cities Soc.* **2017**, *29*, 219–246. [CrossRef]
10. Ewart, I.; Harty, C. Creating a Virtual Museum. *Work. Pap. Commun. Cult. Netw.* **2016**, *7*, 11–14.
11. Sun, Q.; Wan, W.; Yu, X. The simulation of building escape system based on Unity3D. In Proceedings of the IEEE International Conference on Audio, Language and Image Processing (ICALIP), Shanghai, China, 11–12 July 2016; pp. 156–160.
12. Mantho, R. *The Urban Section: An Analytical Tool for Cities and Streets*; Routledge: Oxford, UK, 2014.

13. Lv, Z.; Yin, T.; Han, Y.; Chen, Y.; Chen, G. WebVR—Web virtual reality engine based on P2P network. *J. Netw.* **2011**, *6*, 990–998. [CrossRef]
14. Vakali, A.; Anthopoulos, L.; Krco, S. Smart Cities Data Streams Integration: Experimenting with Internet of Things and social data flows. In Proceedings of the 4th International Conference on Web Intelligence, Mining and Semantics (WIMS14), Thessaloniki, Greece, 2–4 June 2014; p. 60.
15. Villanueva, F.J.; Aguirre, C.; Villa, D.; Santofimia, M.J.; López, J.C. Smart City data stream visualization using Glyphs. In Proceedings of the IEEE Eighth International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), Birmingham, UK, 2–4 July 2014; pp. 399–403.
16. Hudson-Smith, A.; Dodge, M.; Doyle, S. *Visual Communication in Urban Planning and Urban Design*; Centre for Advanced Spatial Analysis (CASA): London, UK, 1998.
17. Braem, B.; Latre, S.; Leroux, P.; Demeester, P.; Coenen, T.; Ballon, P. Designing a smart city playground: Real-time air quality measurements and visualization in the City of Things testbed. In Proceedings of the IEEE International Smart Cities Conference (ISC2), Trento, Italy, 12–15 September 2016; pp. 1–2.
18. Algeciras, J.A.R.; Consuegra, L.G.; Matzarakis, A. Spatial-temporal study on the effects of urban street configurations on human thermal comfort in the world heritage city of Camagüey-Cuba. *Build. Environ.* **2016**, *101*, 85–101. [CrossRef]
19. Karis, B. Real Shading in Unreal Engine 4, Part of ACM SIGGRAPH 2013 Courses. 2013. Available online: https://cdn2.unrealengine.com/Resources/files/2013SiggraphPresentationsNotes-26915738.pdf (accessed on 4 September 2013).
20. Xu, Z.; Lu, X.; Guan, H.; Han, B.; Ren, A. Seismic damage simulation in urban areas based on a high-fidelity structural model and a physics engine. *Nat. Hazards* **2014**, *71*, 1679–1693. [CrossRef]
21. Jamei, E.; Rajagopalan, P. Urban development and pedestrian thermal comfort in Melbourne. *Sol. Energy* **2017**, *144*, 681–698. [CrossRef]
22. Gühnemann, A.; Schäfer, R.-P.; Thiessenhusen, K.-U.; Wagner, P. *Monitoring Traffic and Emissions by Floating Car Data*; Working Paper; ARRB Group Limited: Melbourne, Australia, 2004.
23. Kanoulas, E.; Du, Y.; Xia, T.; Zhang, D. Finding fastest paths on a road network with speed patterns. In Proceedings of the IEEE 22nd International Conference on Data Engineering, Atlanta, GA, USA, 3–7 April 2006; p. 10.
24. Pfoser, D.; Brakatsoulas, S.; Brosch, P.; Umlauft, M.; Tryfona, N.; Tsironis, G. Dynamic travel time provision for road networks. In Proceedings of the 16th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems, Irvine, CA, USA, 5–7 November 2008; p. 68.
25. Castro, P.; Zhang, D.; Li, S. Urban traffic modelling and prediction using large scale taxi GPS traces. In Proceedings of the 10th International Conference Pervasive Computing, Newcastle, UK, 18–22 June 2012; pp. 57–72.
26. Gonzalez, H.; Han, J.; Li, X.; Myslinska, M.; Sondag, J.P. Adaptive fastest path computation on a road network: A traffic mining approach. In Proceedings of the 33rd International Conference on Very Large Data Bases, Vienna, Austria, 23–27 September 2007; pp. 794–805.
27. Ziebart, B.D.; Maas, A.L.; Dey, A.K.; Bagnell, J.A. Navigate like a cabbie: Probabilistic reasoning from observed context-aware behavior. In Proceedings of the ACM 10th International Conference on Ubiquitous Computing, Seoul, Korea, 21–24 September 2008; pp. 322–331.
28. Li, B.; Zhang, D.; Sun, L.; Chen, C.; Li, S.; Qi, G.; Yang, Q. Hunting or waiting? Discovering passenger-finding strategies from a large-scale real-world taxi dataset. In Proceedings of the IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops), Seattle, WA, USA, 21–25 March 2011; pp. 63–68.
29. Sun, L.; Zhang, D.; Chen, C.; Castro, P.S.; Li, S.; Wang, Z. Real time anomalous trajectory detection and analysis. *Mob. Netw. Appl.* **2013**, *18*, 341–356. [CrossRef]
30. Ceapa, I.; Smith, C.; Capra, L. Avoiding the crowds: Understanding tube station congestion patterns from trip data. In Proceedings of the ACM SIGKDD International Workshop on Urban Computing, Beijing, China, 12 August 2012; pp. 134–141.
31. Yousaf, J.; Li, J.; Chen, L.; Tang, J.; Dai, X. Generalized multipath planning model for ride-sharing systems. *Front. Comput. Sci.* **2014**, *8*, 100–118. [CrossRef]
32. Puissant, A.; Hirsch, J.; Weber, C. The utility of texture analysis to improve per-pixel classification for high to very high spatial resolution imagery. *Int. J. Remote Sens.* **2005**, *26*, 733–745. [CrossRef]

33. Herold, M.; Liu, X.; Clarke, K.C. Spatial metrics and image texture for mapping urban land use. *Photogramm. Eng. Remote Sens.* **2003**, *69*, 991–1001. [CrossRef]
34. Van de Voorde, T.; Jacquet, W.; Canters, F. Mapping form and function in urban areas: An approach based on urban metrics and continuous impervious surface data. *Landsc. Urban Plan.* **2011**, *102*, 143–155. [CrossRef]
35. Peng, C.; Jin, X.; Wong, K.-C.; Shi, M.; Liò, P. Collective human mobility pattern from taxi trips in urban area. *PLoS ONE* **2012**, *7*, e34487. [CrossRef]
36. Wei, H.; Xiao-Pu, H.; Tao, Z.; Bing-Hong, W. Heavy-tailed statistics in short-message communication. *Chin. Phys. Lett.* **2009**, *26*, 028902. [CrossRef]
37. Wu, Y.; Zhou, C.; Xiao, J.; Kurths, J.; Schellnhuber, H.J. Evidence for a bimodal distribution in human communication. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 18803–18808. [CrossRef] [PubMed]
38. Gonzalez, M.C.; Hidalgo, C.A.; Barabasi, A.-L. Understanding individual human mobility patterns. *Nature* **2008**, *453*, 779–782. [CrossRef] [PubMed]
39. Liang, X.; Zheng, X.; Lv, W.; Zhu, T.; Xu, K. The scaling of human mobility by taxis is exponential. *Phys. A Stat. Mech. Appl.* **2012**, *391*, 2135–2144. [CrossRef]
40. Li, R.-H.; Liu, J.; Yu, J.X.; Chen, H.; Kitagawa, H. Co-occurrence prediction in a large location-based social network. *Front. Comput. Sci.* **2013**, *7*, 185–194. [CrossRef]
41. Dalton, R.C.; Hölscher, C.; Turner, A. Space syntax and spatial cognition. *World Arch.* **2005**, *11*, 41–45.
42. Haq, S. Investigating the syntax line: Configurational properties and cognitive correlates. *Environ. Plan. B Plan. Des.* **2003**, *30*, 841–863. [CrossRef]
43. Kim, Y.O.; Penn, A. Linking the spatial syntax of cognitive maps to the spatial syntax of the environment. *Environ. Behav.* **2004**, *36*, 483–504. [CrossRef]
44. Dalton, A.T.N.; Turner, A. A Simplified Route Choice Model Using the Shortest Angular Path Assumption. In Proceedings of the 8th International Conference on GeoComputation, Ann Arbor, MI, USA, 31 July–3 August 2005.
45. Ozbil, A.; Argin, G.; Yesiltepe, D. Pedestrian route choice by elementary school students: The role of street network configuration and pedestrian quality attributes in walking to school. *Int. J. Des. Creat. Innov.* **2016**, *4*, 67–84. [CrossRef]
46. Natapov, A.; Czamanski, D.; Fisher-Gewirtzman, D. Visuospatial search in urban environment simulated by random walks. *Int. J. Des. Creat. Innov.* **2016**, *4*, 85–104. [CrossRef]

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Article

Assessing the Value of Housing Schemes through Sustainable Return on Investment: A Path towards Sustainability-Led Evaluations?

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Abstract: The 2016 United Nations (UN) New Urban Agenda clearly reaffirms the concept that sustainable cities require intertwined environmental and social sustainability. The United Nations Sustainable Development Goal (SDG) 11—"Make cities inclusive, safe, resilient, and sustainable"—sets (as a primary target) the provision of sufficient affordable housing. Despite the central role that housing plays in ensuring sustainability and the importance of both environmental and social pillars in ensuring sustainable development, current evaluative methods that support decision making on social housing interventions fail to capture all of the socio-environmental value contained in the UN SDG 11. This paper addresses the issue by demonstrating how Sustainable Return on Investment can successfully describe and analyse a range of externalities related to the sustainable value generated by social housing regeneration schemes. To achieve this goal, a single case study strategy has been chosen. Two extant projects—a high-rise housing scheme and an environmental-led program developed by City West Housing Trust (a nonprofit housing association based in the Manchester area)—have been assessed in order to monetise their social and environmental value through different methods. The findings show that, historically, the environmental and social value of regeneration schemes have been largely disregarded because of a gap in the evaluation methods, and that there is room for significant improvement for future evaluation exercises.

Keywords: housing associations; sustainable return on investment; housing-led urban regeneration; social and environmental value

1. Introduction

The concept of sustainable development has been recently re-contextualised by the United Nations (UN) Conference on Housing and Sustainable Urban Development (Habitat III)—held from 17–20 October 2016 in Quito—thanks to the adoption of the New Urban Agenda. The concept of sustainably developing urban areas is clearly related to central social issues, including poverty, health, and housing. Previously, the General Assembly of the United Nations had asserted in the resolution "Transforming our world: the 2030 Agenda for Sustainable Development", which was adopted on 25 September 2015, that among the 17 Sustainable Development Goals (SDGs), Goal 11—"Make cities inclusive, safe, resilient and sustainable"—sets as its primary target the provision of sufficient affordable housing. Despite the central role played by housing in ensuring sustainability, and the importance of both environmental and social factors in ensuring sustainable development, current evaluative methods that support decision making on social housing interventions fail to capture all of the socio-environmental value generated by these schemes. This shows a misalignment with the internationally recognised sustainability goal UN SDG 11. While consensus exists on the concept of sustainability and its theoretical background, at the operational level, decision makers still struggle with inadequate implementation methods and tools that are incapable of turning policy commitments into real benefits for stakeholders. This paper aims at filling this gap by demonstrating how far a more comprehensive assessment methodology, Sustainable Return On Investment (henceforth: SuROI), allows for a more consistent alignment between the establishment of regeneration schemes and the current concept of urban sustainable development.

The paper firstly discusses the limitations of the most commonly applied assessment methods, and then introduces SuROI in order to pave the way for the calculation of the overall benefits of two case studies. Both case studies are approached with two alternative methods that show how SuROI allows the unveiling of benefits that are related to the wider concept of sustainability. The contribution that the application of the SuROI methodology to the housing sector can bring to the achievement of the SDG mainly relies on quantifying the hidden benefits of housing interventions on stakeholders. As stated by the UN, "common urban challenges include (. . .) lack of funds to provide basic services, a shortage of adequate housing, and declining infrastructure". A thorough understanding of the mutual interconnections provided by good housing and its related impacts may influence the willingness to fill some of the current gaps in resources for housing provision. SuROI is therefore suitable not only as a decision-making support tool, but also as a means for facilitating better governance.

Although the evaluation of regeneration schemes has been referred to as a "vital task", there does not appear to be an agreed consensus on how this should be done. It has been argued that although there is a need to monitor and evaluate regeneration initiatives, there has been "scant regard" paid to this area [1,2], and any evaluations carried out have not had any real effect on wider progress within the field of urban regeneration. Over the years, various authors and scholars have published a variety of methods, models, frameworks, and metrics for evaluating the impacts and results of regeneration. While these reflect different visions of successful urban regeneration, they are not necessarily related to the concept of sustainability. For example, the importance of physical or aesthetic redevelopment has been highlighted [3], whilst economic redevelopment is emphasised [4] and social impact is also referred to [5]. It has been asserted that sustainability appraisal frameworks used in the built environment must address economic, environmental, and social impacts in order to ensure continued sustainable development after regeneration [6]. However, there are gaps in sustainability frameworks in practice [7], and it has been argued that many frameworks sacrifice social and economic factors at the expense of the environment [8]. Some assessment methods have been described as either too diverse from other methods [9], inadequate [10], lacking in important elements [11] or even concerning [12].

Within the housing sector, the Homes and Communities Agency has demanded "robust assessments" of assets [13]. It has also been argued that schemes' value to society need to be clear in today's challenging economic environment [14]. Although the need to take both quantitative and more qualitative or intangible impacts into account has been clarified [15–18], measuring their impacts has remained under theorised [19].

2. Materials and Methods

2.1. Evaluation Methods for the Housing Sector in the UK: Setting the Context

In the United Kingdom (UK), the assessment of urban regeneration strategies has been typically performed through a variety of assessment methods, which have been commonly used to assess the impacts of investment in housing in different programs or initiatives. The following methods, which are mainly related to governmental schemes, will be reviewed: (1) Evaluation Group on Regional and Urban Programmes (EGRUP) Guidance, (2) City Challenge, (3) Single Regeneration Budget, (4) New Deal for Communities, (5) Urban Development Corporations, and (6) Enterprise Zones. These methods will be complemented by the following models: (7) the Hemphill framework and (8) the Sustainable Urban Renewal Project Assessment Model. The purpose of this discussion is to understand how far each method is able to provide enough understanding of the sustainability goals within the housing-led regeneration scheme, in order to guide the selection of two possible methods to compare.

2.1.1. Evaluation Group on Regional and Urban Programmes (EGRUP) Guidance

The Evaluation Group on Regional and Urban Programmes (EGRUP) guidance uses a framework for the ex-post evaluation of expenditure and regeneration schemes and improves the comparability of information on the value for money of regeneration programmes [20]. This framework reinforced Government emphasis at the time on value for money and the public purse [21]. It measures cost effectiveness via a basic cost-benefit account for each regeneration measure concerned. EGRUP uses four proformas within its guidance, which involve general management information about a scheme, quantifiable outputs and their costs, other relevant outputs and their costs, and a measurement of additionality. It focuses on economic efficiency and outlines the inputs, outputs, and outcomes of an urban regeneration scheme. The guidance refers to the importance of using indicators relating to government expenditure, but concedes in Section 3 of the guidance that although all costs can be quantified, some "important" or intangible benefits cannot. Some benefits, such as social benefits for example, are simply listed, rather than being assigned a monetary and quantifiable value. This translates to such impacts not being recorded. In addition, attention is drawn to the users of the guidance that there are issues with "outputs that are essentially unquantifiable" [20]. Environmental benefits were measured quantitatively, but by using a Likert scale. The guidance itself states that there is "clearly a need for a more rigorous approach, which would involve assigning monetary values to the environmental improvements" [20].

2.1.2. City Challenge (CC)

The City Challenge (CC) [22] was commissioned by the Department for the Environment, Transport and the Regions (DETR), and aimed to regenerate 31 areas through regeneration partnerships. It ran in deprived urban areas between 1991 and 1998, and aimed to improve specific rundown inner city areas and the quality of life of local residents in particular [23]. In terms of the evaluation of this scheme, one negative was that there was no one method or framework in place to cover the multitude of partnerships, which makes consistency of evaluation very difficult. The "Final Evaluation of CC" [24] found that there was an enormous diversity of local evaluations, which translated to an insufficient level of consistency to make meaningful comparisons across all areas. A more standardised methodological approach was considered to have been of wider value [23]. Additionally, the evaluations undertaken or commissioned by the partnerships themselves varied significantly in quality, content, and approach. Some chose to assess the effectiveness, efficiency, and impact of a programme, while others concentrated on updating baseline indicators [23]. A key aspect of the schemes supported through the CC programme was their integrated nature. For example, traditional housing improvements were complemented by other regeneration projects concerned with job creation, training, and crime and community safety. However, no method was set up to capture any of this information in a numerical and quantifiable format. The DETR [23] touched on the notion of sustainable development, including a statement that if a regeneration programme was to be regarded as successful, the outcomes it generated must be sustainable in some form. However, it did not mention any method of measuring such aspects of sustainability. Along the same lines, concern was also expressed within the CC Final Evaluation on the lack of monitoring requirements for the quality of outputs or outcomes. Both CC reports focussed on outputs (rather than outcomes or impact) and expenditure in relation to annual targets [25]. Impact indicators formed an integral part of the evaluation approach, but the DoE chose the indicators, rather than stakeholders involved in the scheme in question [26]. Further to this, it has also been cited that although some indicators appear to be covering outcomes, but are actually again measurements of outputs [27]. The focus of the Government at the time was rather a case of what had been done, rather than the impact it had on local communities, meaning that CC was in fact output oriented [26]. This emphasis is shown in the listings of such items as the amount of jobs created, the amount of business and commercial floorspace built or the amount of dwellings improved [23]. The indicators used within the evaluation were only available for specifically quantified aspects. Within the qualitative and more intangible areas, such as the quality of life category, the report stated that there is no standard indicator. In addition, within the unit cost per output statistics [24], values pertaining to health and community and social were simply listed without any figures as "not applicable", and impacts were simply not measured within the summary cost benefit account [24]. It is additionally admitted within the official final evaluation that "more emphasis should be given to assessing outcomes" [24].

2.1.3. The Single Regeneration Budget (SRB)

The Single Regeneration Budget (SRB) [28] used a cost–benefit, inputs versus outputs approach within the study. Outcomes were measured in terms of indicators in such areas as jobs created or safeguarded, enhanced pupil attainment, the personal development of young people, and community safety initiatives [29]. There were three levels of outcomes involved within the evaluation that cut across the distinction between social, economic, and environmental goals. These were termed delivery (the level of outputs), impact (the level of outcomes), and sustainability, defined as the longer term social, economic and environmental impact over the life of a given partnership. Indicators were used to gauge economic benefits, housing benefits, social benefits, environmental benefits, and community benefits [30], whilst an extensive baseline was also used [31]. Social surveys and structured interviews were used to gauge the opinions of key stakeholders within the SRB partnerships, in combination with an in-depth case study approach [31]. The methodology looked to cite overall net additional achievements; however, it was not able to numerically quantify the holistic sustainable impact of the programme in terms of all three aspects of the triple bottom line. In addition, it is stated that there are problems of comparability in the way the SRB is evaluated [28]. Perceptions about physical and environmental quality and amenity were assessed through resident and visitor surveys according to the methodology of Glennerster and Turner [32] where scores were derived from direct observation [28]. In addition, in terms of the measurement of social aspects such as quality of life, quantified outputs in this area simply enumerate the numbers of new health, sports, and cultural facilities, and the numbers of local people given access to them. It is also stated that it is not thought generally possible to quantify all social effects [28].

2.1.4. New Deal for Communities (NDC)

Each New Deal for Communities (NDC) programme was expected to achieve positive change in relation to six outcomes. Three of the outcomes were intended to improve 39 places: crime, the local community, and housing and the physical environment. Three were intended to improve outcomes for people: education, health, and worklessness [33]. A number of data collation and analysis tasks were central to the national evaluation, the most important of which was the biennial household survey. In 2002, a baseline was established across all 39 NDC areas using a survey questionnaire. This addressed socio-demographic status and attitudinal considerations across all outcome areas. It was based on a random-sample survey design, and used 3, 4, or 5-point Likert scales to quantify the responses [34]. Any change in NDC areas was benchmarked against other deprived, comparator areas. No previous evaluation of any English Area Based Initiative (ABI) at that time had been able to explore questions of net change across all relevant regeneration areas and their residents, for all outcomes, from a common baseline [33]. The NDC programme used shadow-pricing methods to determine value for money, which was the first time that this had ever been done [34].

2.1.5. Urban Development Corporations (UDCs)

According to Imrie and Thomas [35], Urban Development Corporation (UDC) evaluations are performance-related measurements with a limited range of criteria, such as "jobs created and safe-guarded, hectares reclaimed, and quantities of constructed roadway". The emphasis in UDC evaluations is on value for money, with many commentators asserting that a greater range of non-quantifiable variables should have been accounted for within the scope of the evaluation [36]. Oatley [37] states that performance indicators [were] mainly input, and output measures and "did not provide a complete basis for assessment of how effectively the corporations have achieved their regeneration objective". A list of such indicators can be seen on page 10 of Oatley [37] showing that social and environmental outcomes are not taken into account via a quantified methodology.

2.1.6. Enterprise Zones (EZs)

The final evaluation of the original enterprise zones (EZs) was carried out in 1995 [38] and assessed the extent to which EZs had generated both additional economic activity and physical regeneration [39]. The evaluation methodology covered an analysis of data, which included annual monitoring data provided by the Department of the Environment, in combination with further data collected by consultants to quantify the additional economic activity generated. Main factors analysed included employment characteristics, the number of firms established, industrial compositions of the firms within the zones, environmental improvements, and the impact on the local property markets [38]. The amount of jobs and costs per job created were highlighted, but the evaluation made a limited assessment of any inward investment into the zones [39]. Interviewers and postal surveys were sent out to local companies to gauge company perceptions of EZ benefits. Lastly, studies were carried out to assess the effects of EZ policy on local property markets, the creation of new economic activity, and the physical environment. There is simply no mention at all within archived governmental documentation of the social and environmental impacts of enterprise zones being quantified.

2.1.7. Hemphill Framework

Hemphill et al. [40] measured sustainability by allocating a points score to indicators within five areas, including: economy and work, resource use, buildings and land use, transport and mobility, and community benefits. Residents and other users within a regeneration area were consulted through questionnaires and structured interviews, and results contributed directly to a points scoring system. Points are allocated to each involved indicator and to each indicator set. Indicators are used to measure the performance of the regeneration scheme against sustainability criteria. However, the authors added that "although it is possible to set indicator parameters for certain regeneration outputs (number of jobs created; amount of private sector investment levered), it is difficult to extend the same rationale to more specific and intangible sustainability criteria (quality of life, community enterprise, and the social economy)" [40].

2.1.8. The Sustainable Urban Renewal Project Assessment Model (SURPAM) Model

The Sustainable Urban Renewal Project Assessment Model (SURPAM) model uses weighted indicators and data from survey and questionnaires. Subsequent factor analysis and analytic hierarchy processes are carried out. All of the indicators fall under the triple bottom line. The model requires input from stakeholders, and can be used to properly plan a prospective urban regeneration scheme. Citizens are able to express opinions on the design of a particular proposal before it becomes a reality, with scores being expressed through the multiplication of the weight of a design criterion by the score indicating the performance of a scheme with respect to an individual criterion. However, the authors cited that the model struggles to measure subjective topics such 'sense of community', as it "was impossible to develop relevant quantitative indicators". As a best fit, the authors solve this issue by using both cardinal and ordinal scales as well as Likert scales [16].

2.2. *Assessing the Value of Regeneration Schemes through the SuROI*

Sustainable Return on Investment incorporates such frameworks as Social Return on Investment (SROI) or ecosystem services analysis (ESA) [41], and places a numerical value on the social and environmental components of the triple bottom line. These aspects are normally difficult to compare against more easily measured economic impacts [42]. Other authors describe the difficulty of measuring the social 'pillar' due to its abstract nature, and warn that it could be overshadowed by the economic and environmental domains [43–45]. Xing et al. [46] state that one of the main challenges can be a difficulty in the measurement of what they term "apples and pears", which is to compare the measurement of costs and values that are expressed in different units. The SuROI method solves this issue. Recent guidance from the Royal Institution of Chartered Surveyors [47] recognises the need to include a wider range of factors that can influence the value of built environment projects, and asserts that sustainability considerations are now considered important when undertaking valuations [41]. In the UK, the Public Services (Social Value Act) 2012 additionally requires that economic, environmental, and social benefits are taken into consideration as part of any procurement processes, showing that the focus on sustainability is perhaps starting to change and become more important at a national level.

There are five stages involved in a SuROI calculation. Four stages can be seen within the parameter of the impact map (see Figure 1 below), in spreadsheet format, while the final stage involves the calculation of the return on investment ratio. Stage one of the process involves the establishment of a project's scope. This includes making the aims and objectives of a project explicit, including "features of the scheme that it is appropriate to measure" [48], and intended/unintended changes arising from a project [49]. The identification of relevant and affected stakeholders who influence a project and/or who are affected by it is additionally carried out. Nicholls et al. [49] and Bichard [41] cite the importance of involving stakeholders at this stage. Once stage one is complete, stage two of the impact map involves the identification of impacts, the valuing of inputs, and the clarification and description of outputs involved. Nicholls et al. [49] explain that understanding the cost of the scheme (inputs) leads to directly to both the number (outputs) and nature (outcomes) of the resulting impacts on stakeholders.

Stage three involves gathering evidence of what changes. This stage involves fieldwork and desk-based research to better understand the type and magnitude of the outcomes and their relevant monetary values [50]. At this stage, interviews, focus groups, questionnaires, or workshops can be held with stakeholders who are materially affected. Outcomes are then determined and their effects quantified using verifiable monetary values attached to each outcome. The monetary values (proxies) can be gleaned from primary data; academic, public or social enterprise literatures [48] or existing social value assessments or datasets such as the Housing Associations Charitable Trust (HACT) database of well-being valuation [51] or the Global Value Exchange [52]. The "total incidence of impact multiplied by the proxy determines the value created by each outcome for a specific user group in a single year" [48]. The duration of an impact is also highlighted within this stage.

Stage four involves adjustments to the gross social value sum by considering counterfactuals such as deadweight, displacement, and attribution. The figure is then adjusted for inflation if the impact takes place over a period longer than one year [49]. This enhances the validity of the calculations and impact [41] and "allows adjustments to be made to the initial valuation, ensuring it provides a reasonable representation of new impact" [48]. Stage five involves the calculation of the SuROI by dividing the net present value by the value of inputs. The ratio does not express financial value, but is instead a comprehensive way of expressing the "currency" of social value [53].

Sensitivity testing at the end of the process guards against any possibility of over claiming [49]. The sensitivity analysis is used to ensure the validity of findings. Royal Institution of Chartered Surveyors (RICS) guidance recommends that financial appraisals have a full sensitivity analysis carried out prior to reporting and that any counterfactuals are examined to ensure validity.

Stage 1		Stage 2			
Stakeholders	**Intended/unintended changes**	**Inputs**		**Outputs**	**The Outcomes (what cha**
Who do we have an effect on? Who has an effect on us?	What do you think will change for them?	What do they invest?	Value £	Summary of activity in numbers	Description How would you describe the change?

Stage 3							Stage 4					
anges)							**Dead-weight %**	**Displace-ment %**	**Attribu-tion %**	**Drop Off %**	**Impact**	**Action Plan**
Indicator	Source	Quantity	Duration	Financial proxy	Value £	Source	What would have happened without the activity?	What activity did you displace?	Who else contibuted to the change?	Does the outcome drop off in future years?	Quantity times financial proxy, less deadweight, displacement, and attribution.	What needs to be done
How would you measure it?	Where did you get the information from?	How much change was there?	How long does it last?	What proxy would you use to value the change?	What is the value of the change?	Where did you get the information from?						

Figure 1. Sustainable Return On Investment (SuROI) impact map, which uses the Social Value United Kingdom (UK) Social Return on Investment (SROI) impact map as its framework.

3. Results

3.1. A Comparison across Different Methods in the Light of the Sustainability Principles

The review of assessment methods and tools discussed in the previous section allows the assertion that, despite there being previous tools within the field of urban regeneration which have evaluated urban regeneration schemes, there appear to be none that fully take into consideration the hidden social and environmental benefits of a scheme. SuROI aims to allow the environmental and social value of a project, programme, or policy in the built environment to be made explicit through evidence, and be added to capital costs to give an overall sustainable value [41]. SROI compares the prospective social benefits of a particular scheme against its costs, and ESA takes the costs and benefits of the environment into consideration. ESA covers both the natural and built environment, including architectural aspects, within its definition [54]. SuROI is heavily influenced by SROI (Social Return on Investment), and incorporates the Social Value UK impact map as its framework [41]. Although SROI takes only social value into account, amendments to SROI [41] outline that environmental value can also be taken into account, and such quantifiable impact can be input into the impact map framework format, thus providing a more sustainable impact calculation than SROI otherwise would. The impact map requires inputting details and figures into its spreadsheet format to ultimately arrive at the final quantitative impact ratio of a project. Such details include the establishment of stakeholders (those who influence the project), inputs (costs of the project), outputs (number of units of delivery), and outcomes (predicted/stakeholder change) [48]. The approach attributes financial value to inputs and outcomes [53]. Financial proxies are used to estimate the value of non-traded and non-market goods. Figure 2 draws from the discussion of the assessment methods commonly used to assess regeneration schemes in the UK so far, in order to check their capability of addressing the different aspects of sustainability. The analysis clearly shows how the SuROI is the only method that explicitly allows encompassing both the social and environmental outcomes of a given scheme, which are equally considered in terms of quantifiable impacts. With respect to SDG11, it therefore allows contributing to meet in full the aspiration to "make cities inclusive, safe, resilient, and sustainable". This objective is embedded into a holistic vision of sustainability encompassing economic, environmental, and social issues (the first criterion in Figure 2), and complemented with a systematic appreciation of all the values considered in the process (following criteria in Figure 2).

Evaluation method	Holistic (focus on economy, environment, social issues)	Measures inputs of a project	Measures outputs of a project	Measures outcomes of a project	Measures outcomes quantitatively	Measures social impact quantitatively	Measures environmental impact quantitatively
SuROI	✓	✓	✓	✓	✓	✓	✓
EGRUP	✗	✓	✓	✓	✗	✗	✗
CC	✓	✓	✓	✗	✗	✗	✗
SRB	✓	✓	✓	✓	✗	✗	✗
NDFC	✓	✓	✓	✓	✓	✓	✗
UDCs	✓	✓	✓	✗	✗	✗	✗
EZs	✗	✓	✓	✗	✗	✗	✗
Hemphill et al	✓	✗	✓	✓	✓	✗	✗
SURPAM	✓	✗	✓	✓	✓	✗	✗

Figure 2. Criteria for assessment of SuROI against other, more traditional approaches.

3.2. Quantifying the Sustainability Gap: A Comparison of SuROI and SRB

Figure 2 shows a comparison between each of the reviewed assessment methods. While they share some of the criteria, only SuROI contains all of the factors mentioned by the authors. Particular attention should be paid to the comparison between SuROI and the Single Regeneration Budget (SRB). The choice of the Single Regeneration Budget (SRB) as comparator is motivated by a variety of reasons. SRB projects were subject to a considerable amount of monitoring and evaluation [55]. SRB has been responsible for a huge amount of expenditure across the UK (£26 billion in the 1990s) [56], it is holistic in approach [57], and the review of the SRB conducted from the Department of Land Economy at Cambridge University [31] had been referred to as the most extensive piece of evaluation work on the impact of urban regeneration interventions [31] with a substantial evaluation framework [28]. Indeed, the SRB application spans over quite a long period, running from 1994 until 2004 as part of a package of measures to make Government activity more responsible to local needs and priorities in England. There was also an encouragement of mainstream service deliverers to focus more resources on deprived areas. Additionally, it was more flexible than previous Government-led initiatives, in that it could vary according to size and geography. A hands-off management approach was also a common feature, with local partnerships being responsible for the management of their own regeneration schemes [31]. There is a great deal of information available regarding the evaluation of the many SRB schemes carried out, including many reports, case studies, and annexes.

In order to more comprehensively compare SuROI and SRB, both methods have been applied to two extant housing-led regeneration schemes, which were selected from the portfolio of a housing association based in northwest England. The City West Housing Trust (CWHT) is a not-for-profit housing association based in West Salford that owns and manages over 14,600 homes in northwest England. It launched in October 2008 following a stock transfer from Salford City Council. Almost £250 million has already been invested in homes and neighbourhoods, and further major projects are underway. However, these projects work against a backdrop of difficult economic times. The two sub-case studies to be covered within this paper have been chosen due to the range of housing types on offer, the amount of community engagement carried out with stakeholders by the CWHT, and the potential for future research. Both cases have been investigated by analysing internal reports and documents, and by interviewing selected key informants from the CWHT.

The first case study is a high-rise scheme. The CWHT has invested £43.2M to improve 666 high-rise flats across nine blocks in Eccles, Salford. Improvements include thermal cladding, enclosed conservatory balconies, self-cleaning windows, and new lifts, whilst internal improvements include remodelling to provide an open plan living spaces as well as new kitchens, bathrooms, security doors, and heating and ventilation systems. Figures 3 and 4 show before and after photos of the high-rise blocks.

Figure 3. City West Housing Trust high-rise blocks before works.

Figure 4. City West Housing Trust high-rise blocks after works.

The second case study is an environmental scheme. During 2014/15, the CWHT delivered high-specification environmental improvements to 476 customer homes. These improved the physical appearance of neighbourhoods, enhanced property security, and provided off-street parking. Figures 5 and 6 show photos of before and after the works.

Figure 5. City West Housing Trust "environmental" scheme before works.

Figure 6. City West Housing Trust "environmental" scheme after works.

As anticipated, both schemes have been assessed twice, by adopting the SRB and the SuROI methods, thus allowing a comparison of the numerical values. The SRB overall impact of the projects has been assessed through the following steps: (1) Obtain information on the activities and gross outputs associated with the SRB projects and the expenditure incurred disaggregated by key funding source; (2) Assess the additionality of SRB projects using five categories: negligible, low, medium, high, and very high additionality; (3) Assemble other information for the relevant projects relating to intended beneficiaries, displacement, substitution, and leakage effects. Meanwhile, the SuROI was calculated by applying the scheme in Figure 1.

The tables in Appendix A show: (1) the calculation of the benefits from the environmental scheme and from the high-rise scheme investments following the SRB approach; (2) the spreadsheet for the environmental scheme investment following the SuROI (split into stages due to the size of the calculation spreadsheet); and (3) the spreadsheet for the high-rise scheme investment following the SuROI (split into stages due to the size of the calculation spreadsheet). The results of the comparison show that while the SuROI valuation for the projects came to £25,776,603.30 + £43,362,504 = £69,139,107; while the SRB valuation came to £4,255,000 + £10,150,912 = £14,405,912. This suggests that the SRB approach undervalued the benefits of the same regeneration schemes by almost £55M compared with the SuROI method.

4. Discussion

The evaluation of both the environmental and high-rise schemes cited, using the SuROI approach as compared with the SRB approach, highlights how different conclusions on respective impacts of schemes can be gleaned simply by using two different evaluation approaches. It would have been ideal to carry out a direct comparison of the two evaluation approaches on each of the two schemes as part of an analysis. However, this simply cannot be done, because the traditional SRB method of evaluation simply does not pick up on the social and environmental impacts that the SuROI approach does. In addition, each method of evaluation does not follow the same structure or methodology. Consequently, in order to show a comparison between the two approaches, it was felt that the most comprehensive way of going about this would be to list the benefits of both approaches (SuROI against SRB), thus showing the gaps in the SRB and quantifying the differences by considering those items that appear only in the SuROI impacts, and not in the SRB approach.

Whereas items such as "intended beneficiaries" or "activities" are listed within the SRB evaluation, they are left out and not compared with the SuROI approach. The central argument and defence of this stance centres on the notion that if you cannot quantify something, you cannot measure it. This is the same stance we have taken elsewhere within the paper. Since our focussed evaluation approach of SuROI is a method that by its very essence quantifies, thus subsequently enabling comparisons between items that were previously difficult to compare, it was felt that in order to ensure consistency in approach, we should use the same stance to gauge the difference in impact between the two evaluation approaches. Consequently, any aspect of the SRB approach that could not be quantified was left out, and this resulted in the direct and quantifiable comparisons between the two evaluation approaches on each scheme, as seen in the tables in Appendix A.

In terms of the quantifiable outputs, the difference in value recorded for the environmental scheme was £6.06 for every £1 invested, and that the ratio was £0.23 for every £1 invested. These figures are significant, and are increasingly significant the more money is invested in a scheme. In terms of the types of data analysed: scheme expenditure and the details of quantities of works carried out were recorded, staff salaries and officer time were factored in terms of scheme inputs; customer surveys were used for primary data that assessed impact, the detail of which could be used within both the SRB and SuROI approaches; lastly, monetary values were used based on a suitable financial proxy [49] from a variety of respected statistical sources, including the Global Value Exchange (GVE), the HACT database, and a wide variety of City West Housing Trust company statistics. Such statistics included investment scheme costs, fuel bill amounts saved by tenants, and the amount of rent received as income by City West Housing Trust. Some observations can be gleaned from the comparison between the SRB evaluation and the SuROI approach. Within the SRB, there appears to be a lot less information on hand from which make strategic decisions or conclusions on the level of impact of a given scheme. In comparison, because the SuROI method in effect "makes the invisible visible", previously intangible areas become tangible, meaning that more information is readily available to decision makers, which in theory will increase the accuracy of decision making in the field of housing-led urban regeneration. Additionally, not all of the impacts of a scheme are going to be quantitative. The SRB-led methodology quantifies qualitative values in terms of the change in numbers of respondents or the percentage change of the response. This provides accurate information from directly involved stakeholders, but this perhaps does not bring enough supporting data into play. By utilising the SuROI method, further indicator sets and proxies brought about by tapping into sometimes thousands of responses again provide much more information, which in theory increases the accuracy of the impact and the accuracy of any subsequent strategic decision making.

5. Conclusions

In conclusion, the SuROI approach allows conclusively measuring the clear-cut, holistic, and sustainable impact of a scheme. There is no clear-cut, quantifiable, and easy-to-understand ratio depiction of the impact or change promoted by a scheme within the SROI approach, whereas within SuROI, this is a fundamental part of the conclusion to the process. The SuROI approach can use many different tools within its framework to gauge the various impacts, from social benefits to well-being to environmental benefits. This makes SuROI a highly flexible and integrated approach. This level of flexibility and integration does not appear within the traditional evaluation. To ensure consistency in approach, SuROI's following of the Social Value SROI guidance principles brings a level of discipline to an evaluation that does not appear to be present with the traditional evaluation approach involved with the SRB method. Lastly, with the SRB methodology, it would not be possible to predict the effects of a housing-led urban regeneration scheme that is planned for the future. With the SuROI approach, because of the amount of data the method taps into, an accurate assessment could be gauged to again help strategic decision making.

The case study allowed identifying the gap that exists in terms of current evaluation methodology in the light of the sustainable development goals and how far an alternative innovative method, the SuROI, can support overcoming it. While environmental and social spillovers are largely disregarded because of a gap in the evaluation tools, implementing a more holistic and comprehensive methodology such as SuROI to the housing sector [58] can be extremely beneficial in regard to being able to capture those hidden benefits and emphasising the targets achieved on the sustainable development goals.

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Author Contributions: Erik Bichard conceived the SUROI methodology, hypothised its importance to the social housing sector; he revised the paper and the conclusions; Claudia Trillo provided the conceptual framework to link the SuROI to the Habitat III framework and to assess the different evaluative tools; she wrote the abstract and part of the introduction; Kevin Dean contextualized the concepts in the case studies, collected and analysed the data; he wrote the Sections 2–5 of the paper and part of the introduction. Both the paper rationale and the revisions following the reviewers' comments were discussed jointly by the three authors.

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Appendix A

Table A1. Comparison between SRB and SuROI in the City West Housing Trust (CWHT) high-rise scheme.

SRB	Values	SuROI	Values
Expenditure	£43,362,504	Inputs	£43,362,504
Activities and outputs	666 high-rise flats refurbished and 36 h per week worked per staff member as a minimum	Outputs	666 high rise flats refurbished and 36 h per week worked per staff member as a minimum
Key outcome indicators and related baseline	Physical/aesthetic improvement: Customer rating on appearance of blocks after works: 85% (increase of 74 responses)	Outcomes, Indicators, proxies and source	Physical/aesthetic improvement: Customer rating on appearance of blocks after works: 85% (increase of 74 responses)
			Living space improvement: Customer rating on quality of living space: 86% (increase of 49 responses)
			Improve security: Customer rating on quality of security: 81% (increase of 52 responses)
			Improve community pride: Customer rating regarding feelings of pride amongst customers: 85% (increase of 36 responses)
			Ensure that customers have decent homes with affordable warmth: 93% now consider flat to be affordable (increase of 75 responses)
			Average annual fuel saving bill due to affordable warmth improvements (£460 per property)
			Customer rating of heating as being affordable or flat requiring little or no heat 93% (112 responses out of 121)
			"Average annual spend on repairs and maintenance of a home (per household)" (£187,146)
			"Not worried about crime for individuals" (£638,271.40)
			"Good neighbourhood" (£129,278)
			"Quality of life for health services (the state) (per person)" (£980,000)
			"Feeling part of the community" (£487,200)
			Active in tenants group (conservative estimate of 10%) (£56,812)
			Well-being value for improved neighbourhood (£199,610)
			Well-being value for improved health (£479,712)
	Living space improvement: Customer rating on quality of living space: 86% (increase of 49 responses)		Cost to CWHT per ASB case (£629)

Table A1. *Cont.*

SRB	Values	SuROI	Values
Key outcome indicators and related baseline	Improve security: Customer rating on quality of security: 81% (increase of 52 responses)	Outcomes, Indicators, proxies and source	Housing, fuel, and power expenditure per household (£6,764.80)
	Improve community pride: Customer rating regarding feelings of pride amongst customers: 85% (increase of 36 responses)		Financial comfort (£62,419)
	Ensure that customers have decent homes with affordable warmth: 93% now consider flat to be affordable (increase of 75 responses)		Regeneration improvement to local area (per person) (£4,329,000)
	Average annual fuel saving bill due to affordable warmth improvements (£460 per property)		Rent figure per year (£2,546,784)
	Customer rating of heating as being affordable or flat requiring little or no heat 93% (112 responses out of 121)		Cyclical costs (£47,286)
		Value in currency—quantifies with common unit	£52,426,585.34
		Deadweight	0
		Displacement	0
		Attribution	0
		Drop off	0
		Impact	1:1.21
		Difference in value between SuROI and SRB	−£43,362,504 − £10,150,912.20 = £33,211,592

Table A2. Comparison between SRB and SuROI in the City West Housing Trust (CWHT) environmental scheme.

SRB	Values	SuROI	Values
Expenditure	£4,255,000	Inputs	£4,255,000
Activities and outputs	476 customer homes refurbished; 300 dropped kerbs to access driveways; 476 plans drawn up for scheme; salaries of 14 CWHT officers	Outputs	476 customer homes refurbished; 300 dropped kerbs to access driveways; 476 plans drawn up for scheme; salaries of 14 CWHT officers
Key outcome indicators and related baseline		Outcomes, Indicators, proxies and source	Customers happy with neighbourhood appearance-percentage increased of 60% (CWHT customer surveys)
			Security rated as good or excellent - increased by 23% (CWHT customer surveys)
			Vandalism and damage an issue -decreased by 10% (CWHT customer surveys)
			Works made a difference to 74% of customers (CWHT customer surveys)
			Amount of cars taken off the road (300)
			Well being values from less graffiti and damage (£83,384)
			£71 per year in cyclical costs per property (£2,130)
			Relet costs of £987 per property (£469,812)
			"Killed or seriously injured in road traffic accidents" (£4,590,000)
			"Good neighbourhood" (£3,563,880)
			"Life satisfaction" (£7,131,146.40 + £1,243,456.20)
			CWHT cost of ASB case (£6,919)
			Not worried about crime for individuals (£319,135.70)
			"Living in a safe area" (£309,400)
			Costs of crime averaged for cost of vehicles and burglary (£1,561,500)
	Customers happy with neighbourhood appearance-percentage increased of 60%		Talks to neighbours regularly (£6,495,840)
	Security rated as good or excellent - increased by 23%		
	Vandalism and damage an issue -decreased by 10%		
	Works made a difference to 74% of customers		
	300 cars off the road		

Table A2. *Cont.*

SRB	Values	SuROI	Values
		Value in currency—quantifies with common unit	£26,788,353.30 is the grand total of all values
		Deadweight	0
		Displacement	0
		Attribution	0
		Drop off	0
		Impact	1:26.25
		Difference in value between SuROI and SRB	£25,776,603 − 4,255,000 = £21,521,603

References

1. Bowey, R. *Literature Review on Urban Renewal*; South Australian Department of Human Services: Adelaide, Australia, 1997.
2. Roberts, P.; Sykes, H. *Urban Regeneration: A Handbook*; Sage: London, UK, 2000.
3. Jeffrey, P.; Pounder, J. Physical and Environmental Aspects. In *Urban Regeneration: A Handbook*; Roberts, P., Sykes, H., Eds.; Sage: London, UK, 2000; pp. 86–108.
4. McGregor, A.; McConnachie, M. Social exclusion, urban regeneration and economic re-integration. *Urban Stud.* **1995**, *32*, 1587–1600. [CrossRef]
5. Colantonio, A.; Dixon, T. *Urban Regeneration and Social Sustainability: Best Practice from European Cities*; Wiley: Oxford, UK, 2010.
6. Brandon, P.S.; Lombardi, P. *Evaluating Sustainable Development in the Built Environment*; Wiley-Blackwell: Oxford, UK, 2011.
7. Clapham, D. *Regeneration and Poverty in Wales: Evidence and Policy Review*; Centre for Regional Economic and Social Research, Sheffield Hallam University: Sheffield, UK, 2014.
8. Carter, K.; Fortune, C. Sustainable development policy perceptions and practice in the UK social housing sector. *Constr. Manag. Econ.* **2007**, *25*, 399–408. [CrossRef]
9. Russell, G.; Johnston, T.; Pritchard, J. *Final Evaluation of City Challenge*; KPMG Consulting Commissioned by Department of the Environment Transport and the Regions: London, UK, 2000.
10. Smith, R. Housing Stock Transfer: Investing in Renewal as a Tool for Sustainable Regeneration. *Hous. Stud.* **2006**, *21*, 269–282. [CrossRef]
11. Madlener, R.; Robledo, C.; Muys, B.; Hektor, B.; Domac, J. *A Sustainability Framework for Enhancing the Long-Term Success of LULUCF Projects*; Springer: Berlin, Germany, 2003.
12. Diamond, J.; Liddle, J.; Southern, A.; Townsend, A. *Managing the City*; Routledge: London, UK, 2006.
13. Homes and Communities Agency (HCA). *The Regulatory Framework for Social Housing in England from April 2012*; HCA: London, UK, 2012.
14. Tyler, P.; Warnock, C.; Provins, A.; Lanz, B. Valuing the Benefits of Urban Regeneration. *Urban Stud.* **2013**, *50*, 169–190. [CrossRef]
15. Church, C.; Young, S. The United Kingdom: Mainstreaming, mutating or expiring? In *Sustainable Communities in Europe*; Lafferty, W.M., Ed.; Earthscan Publications Ltd.: London, UK, 2001.
16. Lee, G.; Chan, E. Indicators for evaluating environmental performance of the Hong Kong urban renewal projects. *Facilities* **2008**, *27*, 515–530. [CrossRef]
17. Communities and Local Government (CLG). *Transforming Places; Changing Lives—A Framework for Regeneration: Summary of Consultation Responses*; CLG: London, UK, 2009.
18. McQuaid, R.W.; Greig, M.; Lindsay, C. *Approaches to Evaluation in Community Regeneration: A Report to Communities Scotland*; Employment Research Institute, Napier University: Edinburgh, UK, 2006.
19. Ebrahim, A.; Rangan, V.K. *The Limits of Nonprofit Impact: A Contingency Framework for Measuring Social Performance*; Harvard Business School: Boston, MA, USA, 2010.
20. Treasury, H.M. *A Framework for the Evaluation of Regeneration Projects and Programmes*; HMSO: London, UK, 1995.
21. Gregory, D.; Martin, S. Issues in the evaluation of inner city programmes. *Local Econ.* **1988**, *2*, 2. [CrossRef]
22. Russell, H.; Dawson, J.; Garside, P.; Parkinson, M. *City Challenge: Interim National Evaluation*; The Stationery Office: London, UK, 1996.
23. Department of the Environment, Transport and the Regions. *Planning for Sustainable Development: Towards Better Practice*; HMSO: London, UK, 1998.
24. Dean, K.; Trillo, C. Assessing sustainability in housing led urban regeneration: Insights from a housing association in Northern England. In *AMPS, Living and Sustainability: An Environmental Critique of Design and Building Practices, Locally and Globally*; London South Bank University: London, UK, 2017.
25. OECD. *Local Economic and Employment Development: How to Assess What Works among Programmes and Policies*; OECD Publications: Paris, France, 2004.
26. Ho, S.Y. *Evaluating British Urban Policy: Ideology, Conflict and Compromise*; Ashgate: Farnham, UK, 2003.
27. Robson, B.; Bradford, M.; Parkinson, M. *Assessing the Impact of Urban Policy*; HMSO: London, UK, 1994.

28. Department of the Environment. *The SRB Evaluation Framework*; Discussion Article 83; Department of Land Economy, University of Cambridge: Cambridge, UK, 1997.
29. Zuberi, D.; Taylor, A. Urban Renewal in Vancouver, Canada. In *The Routledge Companion to Urban Regeneration (Routledge Companions)*; Leary, M.E., McCarthy, J., Eds.; Routledge: London, UK; Taylor & Francis Group: New York, NY, USA, 2013.
30. Brennan, A.; Rhodes, J.; Tyler, P. The Distribution of SRB Challenge Fund Expenditure in Relation to Local-area Need in England. *Urban Stud.* **1999**, *36*, 2069–2084. [CrossRef]
31. Rhodes, J.; Tyler, P.; Brennan, A. *Evaluation of the Single Regeneration Budget: Final Evaluation*; Department of Land Economy, University of Cambridge: Cambridge, UK, 2007.
32. Glennerster, H.; Turner, T. *Estate Based Housing Management: An Evaluation*; Her Majesty's Stationery Office: London, UK, 1993.
33. Lawless, P. Understanding the Scale and Nature of Outcome Change in Area-Regeneration Programmes: Evidence from the New Deal for Communities Programme in England. *Environ. Plan. C* **2011**, *29*, 520–532. [CrossRef]
34. Lawless, P.; Pearson, S.; Wilson, I.; Batty, E.; Beatty, C.; Foden, M. *The New Deal for Communities Experience: A Final Assessment*; DCLG: London, UK, 2010.
35. Imrie, R.; Thomas, H. *British Urban Policy: An Evaluation of the Urban Development Corporations*; Sage: London, UK, 1999.
36. Hambleton, R.; Thomas, H. (Eds.) *Urban Policy Evaluation: Challenge and Change*; Paul Chapman Publishing: London, UK, 1995.
37. Oatley, N. Evaluation and urban development corporations. *Plan. Pract. Res.* **1989**, *4*, 6–12. [CrossRef]
38. Her Majesty's Stationery Office (HMSO). *A Further Assessment of the Enterprise Zone Policy*; HMSO: London, UK, 1995.
39. Potter, J.; Moore, B. UK Enterprise Zones and the attraction of inward investment. *Urban Stud.* **2000**, *37*, 1279–1311. [CrossRef]
40. Hemphill, L.; Berry, J.; McGreal, S. An indicator-based approach to measuring sustainable urban regeneration performance: Conceptual foundations and methodological framework. *Urban Stud.* **2004**, *41*, 725–772. [CrossRef]
41. Bichard, E. *Developing an Approach to Sustainable Return on Investment in the UK, Brazil and the USA*; Royal Institution of Chartered Surveyors Research Trust: London, UK, 2015.
42. Conejos, S.; Langston, C.; Smith, J. AdaptSTAR Model: A Climate-Friendly Strategy to Promote Built Environment Sustainability. *Habitat Int.* **2013**, *37*, 95–103. [CrossRef]
43. Lehtonen, M. The environmental-socio interface of sustainable development: Capabilities, social capital, institutions. *Ecol. Econ.* **2004**, *49*, 199–214. [CrossRef]
44. Davidson, M. Social Sustainability: A potential for politics? *Local Environ.* **2009**, *14*, 607–619. [CrossRef]
45. Littig, B.; Griessler, E. Social sustainability: A catchword between political pragmatism and social theory. *Int. J. Sustain. Dev.* **2005**, *8*, 65–79. [CrossRef]
46. Xing, Y.; Horner, R.; El-Haram, M.; Bebbington, J. A framework model for assessing sustainability impacts of urban development. *Account. Forum* **2009**, *33*, 209–224. [CrossRef]
47. Royal Institution of Chartered Surveyors (RICS). *RICS Valuation—Professional Standards*; Royal Institution of Chartered Surveyors: London, UK, 2014.
48. Higham, A.; Barlow, C.; Bichard, E.; Richards, A. Valuing sustainable change in the built environment: Using SuROI to appraise built environment projects. *J. Facil. Manag.* **2017**, in press.
49. Nicholls, J.; Lawlor, E.; Neizert, E.; Goodspeed, T. *A Guide to Social Return on Investment*; SROI Network: Liverpool, UK, 2012.
50. Watson, K.J.; Whitley, T. Applying Social Return on Investment (SROI) to the Built Environment. Building Research and Information. Available online: http://www.tandfonline.com/doi/full/10.1080/09613218.2016.1223486 (accessed on 5 November 2017).
51. Trotter, L.; Vine, J.; Leach, M.; Fujiwara, D. *Measuring the Social Impact of Community Investment: A Guide to Using the Wellbeing Valuation Approach*; HACT: London, UK, 2014.
52. GVE 2.0. 2017. Available online: http://www.globalvaluexchange.org/ (accessed on 5 November 2017).
53. Arvidson, M.; Lyon, F.; McKay, S.; Moro, D. Valuing the social? The nature and controversies of measuring social return on investment. *Volunt. Sect. Rev.* **2013**, *4*, 3–18. [CrossRef]

54. Department for Environment, Food and Rural Affairs. *An Introductory Guide to Valuing Ecosystem Services*; Department for Environment, Food and Rural Affairs (DEFRA): London, UK, 2007.
55. Robinson, F.; Blackman, T.; Stephens, C. *Monitoring and Evaluating City Challenge*; Research for Policy; Local Authorities Research and Intelligence Association: Newcastle, UK, 1995; pp. 135–145.
56. Rhodes, J.; Tyler, P.; Brennan, A. New Developments in Area Based Initiatives in England: The Experience of the Single Regeneration Budget. *Urban Stud.* **2003**, *40*, 1399–1426. [CrossRef]
57. Communities and Local Government (CLG). The Single Regeneration Budget: Final Evaluation. In *Urban Research Summary*; CLG: London, UK, 2007.
58. Dean, K.; Trillo, C. *Housing and Urban Regeneration: Honing an Existing Assessment Method through the Design Science Methodology*; University of Salford: Salford, UK, 2017.

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Land Valuation Sustainable Model of Urban Planning Development: A Case Study in Badajoz, Spain

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Abstract: The urban planning development process in urban territories has multiple consequences, not only in spatial structure but also in land valuation patterns. The economic value of land encompassed in municipal planning—which is associated with a certain urbanized use—increases as the planning processes evolve over these lands. For economic land valuation to comply with the required parameters of urban and territorial sustainable development, it is pivotal that in the determination of land value there are no expectations of difficult or impossible realizations, in order to eliminate any speculative element from the valuation. The land valuation model presented in the current study complies with this premise, proposing a sustainable land valuation model based on the evolution of urban planning development, achieving maximum value when it is fully urbanized. The main objective of the present work is to analyze how land value increases as municipal planning develops and to suggest a sustainable valuation model for land with urban use. Contextually, through a case study analysis, the development of municipal planning has been divided over time into four urban states: (i) land without detailed planning; (ii) land with detailed planning; (iii) land with re-parceling; and (iv) urbanized land. In this regard, the gradual evolution of land value which has reached different states over time has been determined, as has scenarios where the value has increased up to the value of urbanized land.

Keywords: free cash flow (FCF); land value; land uses; Sustainable Planning; Valuating Models

1. Introduction

One of the keys to achieving prosperity in urban agglomerations is sustainable urban and territorial development. A desired sustainable development implies relations between human communities in the environment to occur not by physical environment quantitative or uncontrolled growth but through qualitative improvements favoring development over growth. Here lays the difference between growth and development: there can be no undefined and continuous urban growth, but development can be continuous, and this would be a territorial and sustainable urban development [1]. In a development with minimal physical growth, it is possible to avoid compromising resources of future generations. The Sustainable Urban and Territorial Development (SUTD) implies abandoning the idea of unlimited urban growth in favor of a concept of urban regeneration, in such a way that new urban developments will be well justified. Nevertheless, to achieve SUTD, its inspiring principles need to be embodied in the instruments of territorial and urban planning with a strong commitment by all the involved actors [2–4].

Also, the concept of the Circular Green Economy is gaining attention in the field of sustainable planning. The main goal of a circular green economy is to achieve environmental sustainability, which, at a local level, is performed through the transition to more sustainable cities. Therefore, the SUTD model should involve sustainable urban planning and limit the effects and impacts that urban planning can represent over the environment. This would be the contribution that can achieve urban circular economy towards sustainability [5]. In this sense, one of the essential requirements to achieve more sustainable, inclusive, and equitable cities would have to go through a proper allocation of land use and adopting innovative and flexible approaches leading to adequate services to the inhabitants [6].

Thus, one of the principles of the SUTD is to present public policies related to the established legislation of land use regulation [7] (Figure 1). Sustainability, as a global concept, will depend on the sustainability of cities and other factors [8]. In this regard, it is widely accepted that the incorporation into the city of newly urbanized lands will have an impact in the economic sustainability of municipalities and their local finances, in terms of both expenses incurred since the start of the new developments, and expected taxation that local councils may apply on increasing local property. Contextually, to achieve economic sustainability in the long term, there must be a balance between expenditures that should consider the effect of councils and incomes. These will be based on the value that the administration grants to specific land, so it is critical to set a fair contribution system according to its real value [9], particularly in times of economic crisis and/or recession periods.

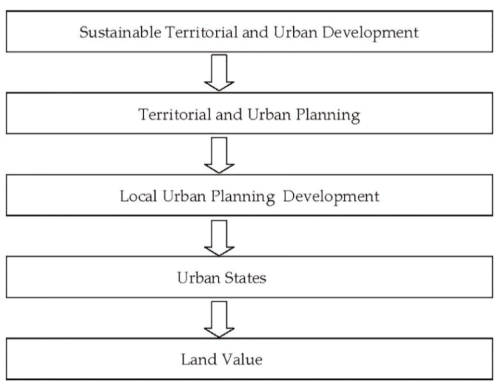

Figure 1. SUTD linking to land value. Source: Own elaboration.

The development of municipal planning must ensure the economic sustainability of municipalities, and therefore be referred and considered in the documents that comprise it. The costs of infrastructure and non-residential equipment required by a sustainable city must be identified and considered in new urban developments; determining the long-term economic sustainability for municipal treasuries and public services is pivotal to meet a guaranteed urban growth [10–12].

Soil is a scarce, limited, and non-renewable natural resource [13,14], and is central to territorial and urban planning instruments to manage land use, which should be developed according to sustainable principles to reach integrated planning. Within the process of urban planning, the establishment of land values both by assigning its applications and building intensities, implies the attribution of economic value to land through planning objects, and therefore providing those lands with certain capital gains.

Consequentially, the generation of capital gains is carried out in a reciprocal manner, since when administrations promote infrastructure and community facilities, there is also an increase in value of surrounding lands [15]. However, in some exceptions (e.g., the core of the economic crisis of 2008), such land valuation did not occur until the area and their surroundings developed considerably. Such a scenario is due to the land value being deeply connected to the final real estate product value. In those cases, the scarcity of sales, along with low real estate values, can have a direct influence on the value of undeveloped land.

On the other hand, there is also public participation in generated capital incomes, the necessary support for effective financing instruments, strengthening municipal finance and local tax systems through fair taxes over the capital gains [16,17] aimed at returning the land value to the benefit of the community, and allowing economic development of the environment through the improvement of facilities and infrastructures. For the determination of these gains, it is essential to perform a correct economic valuation of land with urban development features. Actual assessment that is made over a piece of land is carried out based on the economic benefit coming from the adoption of sustainable land use management and compared with the costs that will be generated [18].

In fact, there are models that value the land through sustainability indicators [19], on explanatory theories of the space formation of land valuation, and depending on accessibility, space qualification or space social hierarchy [20,21]. However, the fact remains that to determine land valuation with urban development, it must be performed using models that quantify economically its real and reasonable value, which will depend on the realization of land use rights [22–27].

The methods for land valuation must be rigorous and prudent, preventing its results from causing tensions in the market, i.e., a new housing crisis affecting banks, in the long run, and eventually extending into the economy [28]. Therefore, it would be desirable that bullish cycles in the real estate market are contained and balanced [29]. Therefore, the criteria applied in valuation methods must be guided to prevent results rising to speculative practices. The value of soil has an influence in central elements of municipal funding [30], either through obtaining part of the generated capital gains [15], or through real estate taxes, or even through tax figures on vacant ground [31]. Therefore, valuation methods should be vested with transparency and objectivity that make them easily understood by the taxpayer [32].

In this regard, there are studies on the change which occurs in land value with urbanizing features, unfolding from the land without urban developing power until it is fully built, with repercussions that land value has on the final real estate product [7,33,34]. However, these changes in land values only occur once it has finished construction, independent of urban development, ending when the land is already urbanized; in fact, they are actually linked to the evolution of the real estate market.

The novelty of this work consists in the presentation of the analysis of impact that different stages of urban planning development [35] have on the gradual increase in land value, depending on the different states of urbanization that are acquired as land develops. In this regard, the impact of already developed land is not considered, once the changes in value that may occur in it are produced by the change in the value of the complete real estate product, due to market fluctuations, but not due to a change in urban planning, which would be fully developed in the stage of urbanized land. The study has been carried out on the change in value of specific land based on data collected by urban planning tools. To calculate the land value at each state of urbanization, the free cash flow discount model has been used, which is one of the most widely used methods (across different countries) to value investment projects [36,37].

The land value in the initial state corresponds to the delimited developable land, without any detailed planning. The following state corresponds to the land on which a detailed arrangement is established; the third is related to an action unit with approved re-parceling, and lastly, the value is calculated in the final state, corresponding to fully urbanized land. With these results, the calculated values are compared, in the different states, to the value corresponding to the land in the final state.

The relevance of this study lies in establishing changes in relative value that are produced at each stage (state) of urban development, comparing them with value acquired by the land when fully developed, and enabling the extrapolation of value to any land in the nearby environment, where the urban features and conditions are manifestly similar. The present study hopes to be a useful tool to perform massive assessments, in which it might be necessary to provide valuation to land that is not urbanized or in which it is necessary to carry out urbanization actions—when they are not yet fully urbanized or are developing or unconsolidated—based on the value impact of urbanized land.

2. Materials and Methods

2.1. Study Area

The proposed methodology has been applied in the valuation of a specific land endowed with urban use. The area is in a region of southern Europe—the EUROACE is a Euro-Region located in the Iberian Peninsula that comprises the Portuguese regions of *Alentejo* and Centro and the Spanish region of Extremadura—and inserted in a Euro-City, the Euro-City Elvas-Badajoz-Campo-Maior (Figure 2) [38]. The chosen area for the study is in the municipality of Badajoz (Spain), within Zone 6, Sector SUB-CC-6.1-3, according to the Municipal General Plan (PGM) (Figure 3). Badajoz is a city located in the southwest Spain and is also the capital of its province, the Autonomous Community of Extremadura. It has 150,000 inhabitants, and is the most populated city of Extremadura. Badajoz is crossed by one of the most relevant water resources of the Iberian Peninsula, the Guadiana river. The proximity of Badajoz to the border with Portugal is relevant. Badajoz is inserted in a Cross-Border Cooperation project with the Portuguese cities of Elvas and Campo-Maior, the Euro-city Elvas-Badajoz-Campo-Maior.

Figure 2. Location of Badajoz, in Spain. Source: Authors.

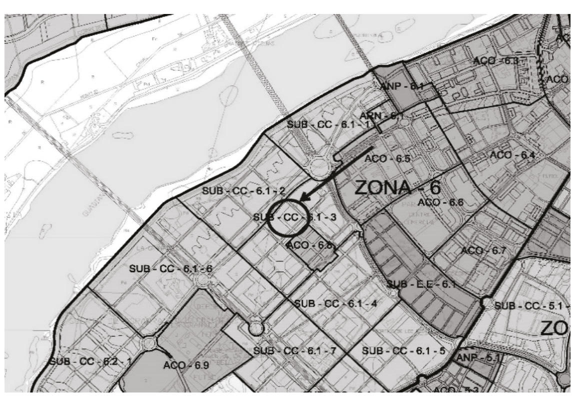

Figure 3. Location of the study area. Source: Badajoz City-council.

At the time of this research, Badajoz has urban developable land classification, but is, however, located in a sector without development. It has not established its detailed ordering or drafted the corresponding partial plan. Its global use is residential [39].

The planning development that affects the study area has been divided into four urban states: the first level is the current state—state E1—which corresponds to the classified land and delimited in sectors in the general plan, with no management detailed; the second level—state E2—corresponds to the land of the sector developed through a partial plan and in which its detailed arrangement is already reflected; the third level—state E3—corresponds to the action units with approved re-parceled project, its goal being the distribution among the owners of the urban development granted by the planning, proportional to the area of land that each one has, with a distribution equitable of charges and benefits. In fact, at this level, the city blocks and plots are already reflected with their respective parameters of detailed uses, buildings and building typologies, but the land is not yet urbanized. The fourth level—state E4—corresponds to the final urbanized land, ready to be built.

2.2. Methodology Fundamentals

The selected methodology for land valuation in the different urban states was the discount model of the Free Cash Flow (FCF). This methodology is based on the economic analysis of a virtual real estate investment project, to be developed on the land subject to valuation, following the greater-and-better-use principle. This process does not take place at a specific time or in a single moment; however, the collections flow and the consequent payments occur over a time horizon, a circumstance that is decisive for the final result [40,41].

One of the main principles of corporate finance establishes that the value of an investment project can be expressed as the updated value of the FCF expected by that asset. The FCF discount model is one of the most widely used internationally to value investment projects [42–47]. FCF represents the excess liquidity or the money that remains available to attend, on the one hand, the sharing of profits among the investors and on the other, the payment of the debt to the creditors. The FCF is the flow of funds generated by the operations, without taking into account the indebtedness, after taxes. In fact, it is the money that would be available in the investment project assuming there is no debt. In short, it is the flow generated by the project regardless of how it is financed [48,49].

As these flows are expected over a certain time horizon, to update them, they will have to be discounted at a specific discount rate. The general formulation of the model to determine the Net Present Value (NPV) of the investment, using the FCF will be:

$$NPV = -A + \sum_{J=1}^{n} \frac{FCF_j}{(1+k)^j} \tag{1}$$

where:

A = initial disbursement of the project, equivalent to the land value; $FCFj$ = the expected free cash flow of each considered period; j = each period of the time horizon in which the flows occur; k = discount rate; and n = number of considered periods for the project's time horizon.

To determine the total value of the investment project, the appropriate flows considered are the FCF and the appropriate discount tax is the weighted average capital cost (WACC) [50,51]; therefore, k = WACC.

If we consider NPV = 0, thus, would be at the threshold of minimum profitability required by the project, and therefore this discount rate (WACC) is equivalent to the Internal Return Rate (IRR) of the project. The initial outlay, "A", would be the land value (A = VS), which represents the maximum amount that could be paid for it to make the project profitable. If NPV = 0, the discount rate, WACC = IRR. The expression to obtain the value of the soil would be:

$$VS = \sum_{j=1}^{n} \frac{FCF_j}{(1 + WACC)^j} \quad (2)$$

2.3. Stablishing of Free Cash Flow (FCF)

The general formulation for the calculation of the *FCF* is given by the following expression [44,45,52,53]:

$$FCF = \ [EBIT] \times (1 - T)] + Dep - FCInv - WCInv \quad (3)$$

where:

EBIT = Earnings before interest and taxes; *T* = Tax rate; *Dep* = Depreciations; *FCInv* = Fixed Capital Investment (capital expenditure); *WCInv* = Working Capital Investment.

In the analyzed case study, it has been considered that the project will be developed through a real estate development—where the initial capitals contribute—without investments in amortizable assets or cash investments or fixed assets. Therefore, the FCF of the real estate investment project will be given by the following expression:

$$FCF = [EBIT \ \times \ (1 - T)] \quad (4)$$

The FCF of each period is a parameter that will depend on many variables [54,55], thus, they will influence, both in the sales collection of the real estate units and in the payments made for the expenses that are generated along the time horizon.

The inflows include all incomes obtained from the sales of real estate units. To calculate the inflows, the valuation criterion has been followed by use units (u.u.), with the corresponding application of the homogenization coefficients by uses, established in the initially collected data in the granted conditions by the planning [39]. Therefore, it has been considered that this criterion is acceptable and prudent since these data are supported in the initial documentary information, and calculated according to the legal possibilities that the land has, relating to uses and building intensities [56].

The outflows comprise the following elements: Management and Urban Development expenses (MUD); Urbanization Costs (CU); Construction Costs (CC); Necessary Promotion Expenses (NPE); and Marketing Expenses (ME).

The estimated time horizon to develop the investment project, until finalizing the sales for the real estate units, considering each one of the states' (S) are as follows: S1 14 years; S2 11 years; S3 8 years; and S4 4 years. The outflows dispersion in the time horizon, of each one of the urbanistic states, have been estimated as follows: for S1 and S2, where the lands are undeveloped, have been considering payment typologies as MUD, CU, CC, NPE and ME; for S3, where the land is already in (re)parceling have been considered CU, CC, NPE and ME; and for S4, where the land is urbanized, have been considered CC, NPE and ME.

The MDU includes the following expenses: expenses associated with land sales; creation of the compensation board; urban interest group; topographic survey and demarcation; professional fees for drafting the execution program; development planning; re-parceling the project; notary fees and registration of the resulting parcels; environment effect investigation; technical fees for urbanization works (project, facultative direction, security and health); real estate property tax; municipal taxes for urbanization works; and other management and urban development expenses. The CU include the costs of contract execution of the urbanization works and topographic surveys. The CCs include contract execution costs of the construction works of the real estate units; construction waste management costs according to current legislation; geotechnical study; and quality control standards. The NPE includes the following expenses: technical-facultative fees (projects, work management, security); municipal taxes levied on urbanization and construction; compulsory insurance of the promoter; management expenses of the promotion (salaries, social security, labor management, fiscal); notary, registration, and taxes not recoverable by the deeds of new work and horizontal division; property tax of real estate units until sale; and other necessary expenses. The CCs include the following expenses: commissions for sales of real estate agents; and advertising and marketing expenses. It should be highlighted that, in the calculation of the FCF, the financial expenses generated by the financing of the investment project with foreign capital are not considered, once the FCF is the operating cash flow; that is, the cash flow generated by the operations of the project activity, without taking into account the indebtedness, after taxes. The debt is not considered to prevent the indebtedness chosen by the project managers (degree of financial leverage) from conditioning the value of such project. Therefore, this analysis is performed without considering the debt taken to develop the project [42,44].

2.4. Defining the Discount Rate: The WACC Model

2.4.1. Formulation

A major issue that must be noted, before defining the discount rate, is that there is no discount rate that is objective and indisputable, because it is a value that is calculated based on the risk perceived by the assessor (who provides valuation) in the investment project, depending on whether there is a greater or lesser risk in the production of project flows [57].

In the valuation of investment projects for the discount of free cash flow, the appropriate discount rate to consider is the WACC model [58–60]. The WACC is the cost of financing the project as a whole and, therefore, given that the capital costs differ from each financial source, depending on whether it is equity capital or debt, we will have to calculate the weighted average cost according to the different funding sources from which the virtual project feeds. The weightings reflect individual weights that each of the sources has in the whole project, and in short, they reflect the proportion of the capital structure of the investment project. Conceptually, WACC provides an estimate of the average opportunity cost of capital providers to an investment project. The WACC model is based on the theory that capital costs are different depending on the financing source on which the company feeds, i.e. if a company is financed on the one hand through its own capital and on the other through debt, each of these two sources of financing will have a determined cost of capital that will be different from one another. As each resource (debt and equity capital-equity) represents a certain weight in the total capital of the project, we will have to weigh each type of resource according to the weight that each of them has in the total capital [44,45].

According to the WACC definition, it is obtained by the following formulation [61]:

$$WACC = \frac{E\,k_e}{E+D} + \frac{D\,k_d(1-T)}{E+D} \tag{5}$$

where:

k_e, the cost of the project's own capital (equity); k_d, the cost of project debt; E, the total value of the project equity; D, the total value of the project debt; T, the legal tax rate at the time of valuation.

Thus, to calculate the WACC, the following steps (3) must be followed:

1. Calculate the cost of each funding source—k_e and k_d.
2. Calculate the values of E and D according to the financial leverage considered
3. Formula application [4]

2.4.2. The Equity Cost, k_e

The equity costs of an investment project represent the opportunity cost of the project, reflecting the return that an investor requires to their own resources, when investing in said project, including a premium for the risk assumed when making the investment. It is equivalent to the minimum profitability demanded by the investors of the project because of them investing in it. Of all the financing costs, that of the own capital is the one with the highest risk associated [62]. The expected return of a physical asset, i.e., land with urban development or financial assets, is obtained by adding a risk premium to the profitability offered by an asset without risk. The investor will demand his own capital invested in a project, an opportunity cost that will be determined by the addition of a differential or compensation for risk to an asset free of any risk [63,64]. The cost of equity will be given by the following expression: *i* = *io* + differential (compensation) for risk, where *io* is the free rate of all risks. This differential will be the project's risk premium. Therefore, the mathematical expression for the equity costs of an investment project will be given by the following formula:

$$k_e = r_f + PR \tag{6}$$

where:

k_e, the equity capital costs of an investment project; r_f, the risk-free rate; PR, the risk premium of the investment project

The risk-free rate (r_f) is the rate of return of an asset whose profitability is always known and equal to that expected within its investment horizon and known with complete accuracy and certainty the maturity at a certain moment [65]. For the case study, the Debt of the Spanish State has been estimated as a risk-free asset, with a single payment at maturity and the most recent issuance possible for the valuation of the investment. Given that it is an investment project in Spanish territory, the choice of the Spanish State Debt is justifiable since it is considered to have sufficient liquidity. In this regard, it is not necessary to add the country risk premium to a risk-free rate of the debt issued by another country with lower risk than Spain, such as that of Germany or the United States. Therefore, the calculation of this parameter has been obtained through the arithmetic mean of the marginal interest rates of the 10-year Obligations auctions issued by the Spanish Government.

Therefore, the risk-free rate is an element that is possible to obtain through the publications put forward by the government's economic departments; nevertheless, the risk premium is a feature that depends on the market or the investment project and is, thus, is not sustainable in historical data to calculate the risk premium [37,42] once it is an element with direct dependent on the project risk [36,41]. There is, thus, difficulty in obtaining the data related to the risk premiums of another project. This is due to the reluctance that originates in the promoters themselves to provide this information, and also the existing reservation from data protection policies. Such circumstances arise that the assessor does not have enough data to calculate the risk premium with a minimum of scientific rigor [24,26,28]. The calculation of the project risk premium (RP) was made based on the factors that influence the risk of the project, considering the following variables: the type of real estate asset to be built, the location of the real estate project, the liquidity of the investment, the time horizon of the project, the volume of investment necessary to perform it, access to the credit of the potential buyers of the real estate units, the level of indebtedness of the project, and the interest rates offered by banks in the market of mortgage loans and inflation [66]. The methodology for determining the risk premium of the project was based on the Analytical Hierarchical Process (AHP). AHP is an alternative selection method that considers variables that influences the final outcomes. It consists in the weighting of the criteria and alternatives through the so-called paired comparison matrix, which is a judgments matrix that is released by previously selected experts [67–69]. This method is widely used for the evaluation of all types of projects in numerous fields and disciplines [70–72].

Thus, it should be taken into account that the same discount rate cannot be used in the four land development states once the assessment of each state has been evaluated as different investment projects with different time horizons; in short, they have different levels of risk [73]. The time horizon is an explanatory variable for the determination of the risk premium of the project and is different for each state of urbanization; therefore, there will also be a different risk premium for each state. In the same way, different risk-free rates could have been used according to the different debt issuance state periods, but still, given the low variation and the low interest rates offered by Spanish public debt, it has finally been estimated according to the state obligations with a 10-year maturity (Table 4). Furthermore, those issues are the most representative of the auctions carried out by the Spanish government and as used as a reference to establish the differential of the risk premium regarding a German bond.

2.4.3. The Debt Costs, k_d

Debt costs, kd, is another component of WACC. It will be estimated from the information on the existing interest rates in the mortgage market. The cost of the debt is the profitability required to meet the payment of this. Therefore, to obtain it, an analysis of the current economic situation has been carried out [74,75]. Once the data was collected, a prudent estimate was made of the non-preferential interest rates offered by the financial entities that operate in the sector.

2.4.4. The Level of Financial Leverage: Determination of E and D

It is usual for companies in the real estate sector, both in Spain and abroad, to have high levels of leverage, although in recent years this level has been in decline [76]. The level of leverage is a factor that must be estimated prudently since a high level of indebtedness for the project directly influences an increase in the investment risk [77]. The capital structure of the project is determined by the contribution of own capital (equity) and third parties (debt). The term E is the percentage that represents the equity in the total investment, and the term D is the percentage that represents the debt in the total investment, in such a way that: E + D = 100 [78].

Contextually, to calculate these parameters, other information must be inserted into the data regarding the financial leverage ratio of companies in the real estate development sector [79,80]. From this ratio it has been possible to obtain the leverage degree that transport it directly to the WACC formula; the degree of financial leverage is given by the expression: NAF = D/(E + D), therefore: E/(E + D) + NAF = 1.

2.5. The Time Horizon for the Evaluation of the Investment Project

In the valuation model of investment projects by discounting flows, the time horizon is the period during which the different flows, positive and negative, will occur. It is one of the factors that most influence the value of the project [81] since it is necessary to estimate the specific moments in which both the inflow and the outflow will occur. The time horizon is a parameter that also influences the determination of the discount rate of the project, increasing it as that parameter increases [82]. In the case of the valuation of land by the flow discount model, this horizon is related to the global term of management, development, and completion of the virtual real estate development that is considered to be developed on land. It will cover the global timeframe, considering the totality of flows that may occur during the development of the real estate investment project, from the creation of the company to carry out the virtual project until its dissolution. It is a parameter that requires good coordination among principles of management, development, urbanization, construction process and marketing promotion, especially when the land is in the phase of urban development, as there are deadlines that do not depend on the direction of the project but do depend on the time that the administration delays in approving definitively the different instruments of planning and urban development [83]. On the other hand, there are authors establishing that the maximum time horizon to apply the discount model of flows can be simply considered to be fifteen years [52,84].

2.6. Data Collection

The inflows have been calculated based on the urban development conditions established by the Badajoz' City Master Plan for the specific sector where the land is located (Table 1). The criteria for evaluating the subjective average use of the distribution area—where the study land lies—has been followed, based on the units of use, coefficients of homogenization and use features established by the municipal planning [39]. The conversion of the use of monetary flows has been made based on an analysis of previous publications on the sale price of the residential characteristic use established for the sector [85].

Table 1. Features of urban development attributed to the sector. Source: Badajoz Urban Planning.

Average utilization of the distribution area	0.5647	u.u.
Average sector use	0.5845	u.u.
Subjective use of the distribution area	0.5082	u.u.
Proposed net of constructability coefficient	0.7687	
Minimum net of constructability coefficient	0.7302	
Maximum net of constructability coefficient	0.8071	
Proposed gross of constructability coefficient	0.7277	
Constructability in residential	132,806	m^2
Constructability in premises ground floor	5312	m^2
Buildings exclusive buildings constructability	3961	m^2
Total provision of minimum commercial equipment	3.00	%

The outflows corresponding to the costs of urbanization and construction have been calculated from the data provided by specialized publications [86,87]. An inter-annual inflation rate of 1.5% has been considered.

The risk-free rate was obtained from the data published by the treasury for the marginal interest rates of the 10-year obligations issued by the Government of Spain [88]. A risk-free rate of 1.70% has been estimated.

The risk premium of the investment project has been calculated by applying the AHP multi-criteria model [67]. The expert panel was made up of academics and professionals with considerable experience in urban planning and real estate valuation processes. It was composed of a total of 10 experts: a Ph.D. expert in environmental sciences, 2 environmental engineers, 2 architects, 2 civil engineers and 3 real estate appraisers. Thus, the following criteria and variables have been selected: V1, the type of real estate asset; V2, the location; V3, the liquidity of the investment; V4, the time horizon; V5, the volume of investment; V6, access to the credit of the potential buyers of the real estate units; V7, the financial leverage level; V8, the interest rates; and V9, the inflation rate. The set of experts has also selected the following alternatives or risk levels: level 1, very low; level 2, low; level 3, medium; level 4, high; and level 5, very high. Thus, the consistency and the own vector (OV) of the comparison matrix, as well as the variable paired comparison (VPC), with a size of 9×9 was calculated. The OV enable us to define the weight or importance of each variable with respect to the rest. On the other hand, the different paired comparison matrix of risk levels was obtained, for each variable (size 5×5), obtaining the OV of each one, once the consistency of each one was verified. Therefore, 9 OV were obtained. With these vectors it has been possible to obtain the matrix (OVM) (size 5x9). The result of the multiplication of the OVM by the column matrix OV offers us the weights of each risk level [66]. The overall result of the risk premium in each state of urbanization is shown in Table 4.

A different risk premium was calculated for each state, once, among the explanatory variables considered in the AHP model, considering the time horizon and the volume of investment needed, and parameters that are determined by the urban development of the land. The following values were obtained (Table 2).

Table 2. Assessed risk premiums according to the urban state of the land. Source: authors.

	Urban States	**Risk Premium**
S1	Land to develop without detailed planning	19.49%
S2	Land to develop with detailed planning	18.52%
S3	Land action unit with re-parceling	17.54%
S4	Final urbanized land	13.64%

The level of financial leverage has been obtained from the data published by the Bank of Spain on sectorial ratios of non-financial corporations [89]. A level of financial leverage of 30% was estimated.

The cost of the debt has been estimated at 4.75% and was acquired from surveys conducted on local banks on the interest rates of loans for real estate developments. The general rate of corporate income tax has been estimated at 25%, the current rate in Spain.

2.7. Formulating Land Values in Each Urban State

The main components of the formulation are: the annual free cash-flow updated (FCF), the discount rate (WACC) and the considered time horizon of the investment project, finalizing with the sales of the real estate units (HT). The FCF obtained over the years will be shown in Table 5. The WACC is presented in Table 4.

Contextually, the time horizons of the investment project, used for the calculation, to the end of the sales of real estate units were: for S1-14 years; for S2-11 years; for S3-8 years; and for S4-4 years (Table 3). Below are the applied formulas to obtain the land value for each urban state:

$$\text{For S1}: \ VS_1 = \sum_{j=1}^{14} \frac{FCF_j}{(1+0.1590)^j} \tag{7}$$

$$\text{For S2}: \ VS_2 = \sum_{j=1}^{11} \frac{FCF_j}{(1+0.1522)^j} \tag{8}$$

$$\text{For S3}: \ VS_3 = \sum_{j=1}^{8} \frac{FCF_j}{(1+0.1454)^j} \tag{9}$$

$$\text{For S4}: \ VS_4 = \sum_{j}^{4} \frac{FCF_j}{(1+0.1181)^j} \tag{10}$$

Table 3. Estimated times. Source: authors.

	Urban Stages	Time to Get the Stage TS (Years)	Time to Get Urbanized Land TU (Years)	Time Horizon Investment Project TH (Years)
S1	Land to develop without detailed planning	(Current Status) 0	10	14
S2	Land to develop with the detailed arrangement	3	7	11
S3	Land action unit with re-parceling	6	4	8
S4	Urbanized land	10	0	4

The *WACC* is presented in Table 4. The *FCF* obtained over the years will be shown in Table 5. To develop the inflows, the authors started from the collected data regarding the sales of real estate units carried out by real estate companies in the sector; thus, the time horizon, necessary to consider for the investment project analysis, goes from the considered state until the completion of the sales of the real estate units.

The S1 (state 1) corresponds to the current moment, therefore the obtained land value for this state does not need to be corrected; however, the land values in S2, S3 and S4 have been extrapolated under the current state hypothesis and must be corrected through capitalization at a future moment in which it is estimated that these states are achieved. The used time periods for the calculation are shown in Table 3. Through Figure 4 is possible to analyze the time sequence of the different urban states.

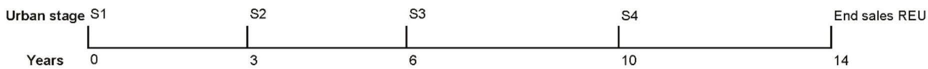

Figure 4. Linear time scheme until end sales of real estate units. Source: Authors.

Table 4. Actualized Free Cash-Flows. Source: authors.

Year	Urban Stage 1	Urban Stage 2	Urban Stage 3	Urban Stage 4
1	−183,906	−123,330	−1,240,642	3,577,392
2	−161,054	−108,644	−1,649,136	2,671,162
3	−94,028	−1,004,931	−3,112,028	3,873,889
4	−41,172	−1,233,299	−714,913	9,728,398
5	−36,056	−1,457,807	2,679,991	
6	−631,516	−1,284,221	1,904,193	
7	−553,045	−2,845,955	2,443,283	
8	−950,627	1,744,535	5,630,970	
9	−930,648	1,984,325		
10	−1,919,997	2,312,100		
11	1,117,632	3,748,553		
12	1,263,770			
13	1,463,856			
14	2,359,347			
∑ FCF Act (€)	702,558	1,731,326	5,941,719	19,850,842

Table 5. Discount rate for each state. Source: authors.

Parameters	E1	E2	E3	E4
Risk Free Rate (TLR) (%)	1.70%	1.70%	1.70%	1.70%
Project Risk Premium (PR)	19.49%	18.52%	17.54%	13.64%
Financial Leverage Level	30.00%	30.00%	30.00%	30.00%
Debt Cost (Kd) (%)	4.75%	4.75%	4.75%	4.75%
Corporation Tax Rate (T)	25.00%	25.00%	25.00%	25.00%
WACC	15.90%	15.22%	14.54%	11.81%

2.8. Capitalization of the Value at the Time of Each Urban State

Through the parameters described, it is possible to obtain the land value for each urban state—E1, E2, E3, and E4—on the current period. Therefore, only the value obtained for the state E1 will be real, since the states E2, E3, and E4 will be acquired in the future, throughout the development of the urban planning inherent processes. Thus, the values obtained for the states E2, E3 and E4 must be capitalized to obtain the value in future periods, when those urban states are acquired. For this, studies on the evolution of the real estate market have been considered [90,91]. The estimated time to obtain the corresponding urban states is presented in Table 3.

3. Results

Four urban states have been considered: E1, developable land without detailed planning; E2, developable land with detail arrangement; E3, action unit with approved re-parceled, without urbanization; and E4, final urbanized land.

In Table 4, it is possible to analyze the actualized FCF of the investment project, through the time horizon until the end of the real estate units' sales. For the calculation, a unit of 100,000 m^2 has been used, with urban development potential of 50,820 m^2t.

Through the starting data presented, a discount rate was obtained for each state, which is shown in Table 5.

With the data, the proposed methodology and the starting assumptions, the land value has been calculated in each state of urbanization, compared to the results with the land value in the E4 state completely urbanized. The results obtained are shown in the following (Table 6, Figure 5).

Table 6. Gradual evolution of land value according to planning development. Source: authors.

Urban Stages	Time to Get the Urban Stage (Years)	Repercussion Values (€/u.u.)	Gradual Evolution of Land Value
S1: without detailed arrangement	Current moment (0)	13.82	2.90%
S2: with detailed arrangement	3	35.62	7.48%
S3: with re-parceling	6	127.84	26.85%
S4: final urbanized land	10	476.15	100.00%

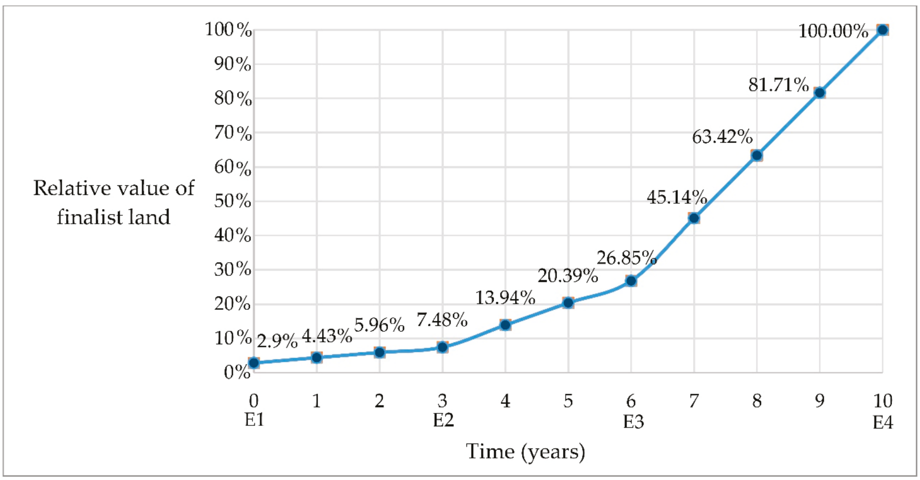

Figure 5. Gradual evolution of land value according to the development of urban planning. Source: authors.

Through the analysis of the graphic above, the land valuation in state E1 represents a low percentage of the completely urbanized land. Such percentage goes up steadily until state E3, which corresponds to the floor of the action unit with re-parceling. The transition from this state to the urbanized land is when the greatest jump in the land value takes place, until obtaining the value that the completely urbanized land has. With this figure, it is shown that the exposed valuation model does indeed work and is also compatible with a sustainable valuation of the land.

4. Discussion and Conclusions

Through the study, the evolution of land valuation has been determined, along with the planning processes developed, applying the principle of prudential value in the estimation of the fundamental parameters, flows, time horizon and risk premium, obtaining results far from all considerations of unattainable expectations and speculation, fundamental aspects in the sustainable valuation of the land use, and catalysts for future land values approaches in a more sustainable and realistic manner.

The main goal of a sustainable land valuation should be able to eliminate most speculative elements, strengthening the initial stages of the planning development process with adequate criteria, in a way that can be used to provide more accurate results in those initial states, which do not cause artificial growth in the final urbanized land value.

The establishment of classification and urban qualification of land in planning processes implies the allocation of uses and building intensities, determining their urban development and therefore its real value. However, this real value is not attributed to the land at the time of its expression in the planning documents. However, it increases as it develops and is managed until it reaches its maximum value when it is already completely urbanized land.

Also, through the literature review, several models have been identified, explaining the changes in the value of real estate property as urban planning is developed, from the drafting of municipal planning in which the land is classified, to the final real estate product, with the construction of buildings [7,33,34]. In these models, the obtained land value is represented according to the prices of the finalized or already existing building. Such models admit an increase in the land value after urbanization (when built). Nevertheless, the authors believe that such increase is not due to the development of urban planning itself, but instead it incorporates a certain post-value that would be motivated by the increase in the real estate prices and not by the development of urban planning. On the other hand, through the literature review, we have not found specific valuation methodology to obtain land valuation. In this regard, the present study summarizes two main differences related to it: (i) the impact of urban planning development is analyzed in the evolution of the increase of land value, motivated solely by its development over time, until it is fully urbanized, which does not consider the subsequent increase when the land is built on, produced by the movements that occur in the real estate market; (ii) a specific method of land valuation is established and specified, which is the discount model of the FCF, considering the virtual real estate investment project to be developed on the land to be valued. Effectively, this method is one of the most widely used internationally for the evaluation of investment projects [42–47]. The discount rate considered was the WACC (after taxes). For proper application, a different risk premium has been estimated depending on the urban development state of the land, resulting in different discount rates for each one of them.

The obtained results show that at the end of each state, different capital gains will be generated. Four levels of surplus value are obtained: (i) by delimitation; (ii) by ordination; (iii) by re-parceling; and (iv) by urbanization. These capital gains increase as the state moves closer to fully urbanized land, with the highest surplus value obtained with the passage from state E3 to E4—from re-parceled land to fully urbanized. The function of creating land value throughout the development of urban planning increases, as is the case of its slope as it approaches urbanized land.

To determine the gradual evolution of the land value as planning progresses, unitary values on gross soil surface should not be used, since the land surface in the initial stages—when there is no management—will not match the surface or with the geometry plots resulting from the re-parceling; but what will not vary are the units of subjective use established in the planning. Therefore, it is necessary to consider this parameter.

In the land value obtained, for each state, we have presented of major relevance not only the consideration of different time horizons, but also the application of different discount rates, considering a discount rate for each state, depending on the estimated risk for the investment project. By introducing the time horizon as an explanatory variable for the risk premium calculation of the project, discount rates are obtained that increase as the variable does too. In the general model formulation, the discount rate and the time horizon represent an exponential function, the base being the discount rate and the exponent the time horizon (Formula 2); This function causes the resulting values to decrease sharply as these two parameters also increase, especially for the time horizon variable.

In the present study, it is obvious that land values in the initial stages of urban development represent a fraction of the value in the final urbanized state, producing a steep rise when the land is urbanized and ready to be built. The highest rise occurs between the final states, E3 and E4. The unit values resulting from the application of the method by flow discount for the case study are valid for the time of writing; if absolute value is needed to be assessed, it must have updated in order to use the model for future scenarios and time periods; however, this has no significance in the study results, which represent the evolution of the land once we are given in relative values, as a percentage of the value of the final urbanized land. The low values obtained in the urban planning states of land without planning are very close to the initial value—which encompass their agricultural use—confirm that they have not considered expectations of difficult realization and therefore are far from any speculative practice. The maximum capital gains are obtained in the passage of re-parceled land to urbanized land, which promotes a sustainable land valuation, avoiding the creation of unrealized capital gains.

A major achievement of this methodology is its practical functionality to calculate the land value of the different urbanization states from the value of the fully urbanized land. Calculating only the value of this urbanized land, we have the value of the land in prior states to urbanization, by applying the different coefficient results for each state.

For final remarks, this research contributes directly to both making individualized land valuations and in making massive valuations, carried out by the administration for the liquidation of taxes on the land. Following this methodology, the land values without development or urbanization can be calculated, starting from the establishment of the hypothetical value of the fully urbanized land for the land that belongs to the same sector, always considering the same features of urban development established by the available planning tools.

Thus, the study has considered an estimate of the time horizons in the analysis of the investment project that involves land valuation in each urban state. Nevertheless, future research and study may be able to introduce variables of uncertainty and even consider other time horizons.

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References

1. Engelman, R. *Is Sustainability Still Possible?* Island Press: Washington, DC, USA; London, UK, 2013; Chapter 1; pp. 3–19.
2. Hildenbrand, A. La política de ordenación del territorio de las comunidades autónomas: Balance crítico y propuestas para la mejora de su eficacia. *Rev. Derecho Urban.* **2006**, *230*, 79–139.
3. Kaufmann, V.; Sager, F. The coordination of local policies for urban development and public transpotation in four swiss cities. *J. Urban Aff.* **2006**, *28*, 353–374. [CrossRef]
4. Elorrieta, B.; Olcina, J.; Sánchez, D. La sostenibilidad en la planificación territorial de escala regional en España: Estudio de casos. *Cuad. Geogr.* **2015**, *55*, 149–175.
5. Healey, P. The Treatment of Space and Place in the New Strategic Spatial Planning in Europe. *Int. J. Urban Reg. Res.* **2004**, *28*, 45–67. [CrossRef]
6. Beretic, N.; Djukanovic, Z.; Campus, G.; Kramers, M.; Kern, R. *The City We Need*; World Urban Campaign Secretariat, UN-Habitat: Nairobi, Kenya, 2016.
7. Williamson, I.; Enemark, S.; Wallace, J.; Rajabifard, A. *Land Administration for Sustainable Development*; Esri Press: Redlans, CA, USA, 2010.
8. Aherm, J. From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landsc. Urban Plan.* **2011**, *100*, 341–343. [CrossRef]
9. Bruce, J.W.; Renèe, G.; Rolfes, L., Jr.; Bledsoe, D.; Mitchell, R. *Land Law Reform. Achieving Development Policy Objetives*; The International Bank for Reconstuction and Development, The World Bank: Washington, DC, USA, 2006.
10. Rigamonti, L.; Sterpi, I.; Grosso, M. Integrated municipal wate management systems: An indicator to assess their enviromental and economic sustainability. *Ecol. Indic.* **2016**, *80*, 1–7. [CrossRef]
11. Herva, M.; Neto, B.; Roca, E. Envoromental assessment of the integrated municipal solid waste management system in Porto (Portugal). *J. Clean. Prod.* **2014**, *70*, 183–193. [CrossRef]
12. Epstein, M.J.; Buhovac, A.R. *Making Sustainability Work*; Berret-Koehler Publishers, Inc.: San Francisco, CA, USA, 2014.

13. Nooten, G.A. Sustainable development and Nonrenewable resources. A multirateral perspective. In *Proceedings, Workshop on Deposit Modeling, Mineral Resource Assessment and Sustainable Development*; USGS: Reston, VA, USA, 2007; pp. 35–40.
14. Berges, A.; Ontiveros, E. La nueva ley del suelo desde la perspectiva económica. Sostenibilidad y eficiencia en los mercados del suelo. *Ciudad Territ.* **2007**, *29*, 259–275.
15. Walters, L.C. *Land Value Capture in Policy and Practice*; World Bank Conference on Land and Poverty: Washington, DC, USA, 2012.
16. Smith, J.; Gihring, T.A. Financing Transit Systems through Value Capture: An Annotated Bibliography. *Am. J. Econ. Sociol.* **2006**, *65*, 751–786. [CrossRef]
17. Carrol, D.A. Tax Increment Financing and Property Value. An Examination of Business Property Using Panel Data. *Urbana Aff. Rev.* **2008**, *43*, 520–552. [CrossRef]
18. Stewart, N. *The Value of Land: Prosperous Lands and Positive Rewards through Sustainable Land Management*; ELD Initiative: Bonn, Germany, 2015; Available online: www.eld-initiative.org (accessed on 25 April 2018).
19. Yigitcanlar, T.; Dur, F. Developing a Sustainability Assessment Model: The Sustainable Infrastructure, Land-Use, Enviroment and Transport Model. *Sustainability* **2010**, *2*, 321–340. [CrossRef]
20. García, M.P. *Introducción a la Valoración Inmobiliaria*; Centro de Política de Suelo y Valoraciones; Universidad Politécnica de Cataluña: Barcelona, España, 2007.
21. Kim, B.; Kim, T. A Study on Estimation of Land Value Using Spatial Statistics: Focusing on Real Transaction Land Prices in Korea. *Sustainability* **2016**, *8*, 203. [CrossRef]
22. Verheye, W. *The Value and Price of Land. Land Use, Land Cover and Soil Sciences*; UNESCO-Encyclopedia of Life Support Systems, Sample Chapters: Paris, France, 2007; Volume 3.
23. De Lama, F. *Análisis de los Métodos de Valoración Inmobiliaria: Teoría y Casos Prácticos*; Servicio de Publicaciones Universidad de Cádiz: Cádiz, España, 2010.
24. Scarrett, D.; Osborn, S. *Property Valuation: The Five Methods*, 3rd ed.; Routledge Taylor & Francis Group: New York, NY, USA, 2014.
25. The European Group of Valuers Associations. *European Valuation Standars*, 8th ed.; TEGoVA: Bruxelles, Belgium, 2016.
26. Parker, D. *International Valuation Standars: A Guide to the Valuation of Real Property Assessts*; John Wiley & Sons: New York, NY, USA, 2016.
27. International Valuation Standards Council. *International Valuation Standars*; IVSC: London, UK, 2017.
28. Adair, A.; Downie, M.L.; McGreal, S.; Vos, G. *European Valuation Practice: Theory and Techniques*; Taylor & Francis: London, UK, 1996.
29. Barker, K. *Delivering Stability: Securing Our Future Housing Needs. Final Report. Review of Housing Supply*; HMSO: Norwich, UK, 2004.
30. Collier, P.; Glaeser, E.; Venables, A.; Manwaring, P.; Blake, M. *Land and Property Taxes for Municipal Finance*; International Growth Center, London School of Economic and Political Science: London, UK, 2017.
31. Hass, A.; Kopanyi, M. *Taxation of Vacant Urban Land: From Theory to Practice*; International Growth Center, London School of Economic and Political Science: London, UK, 2017.
32. Mangioni, V. Land Value Taxation and the Valuation of Land in Australia. *Nord. J. Surv. Real Estate Res.* **2014**, *10*, 82–98.
33. Chirstensen, F.K. Understanding value changes in the urban development process and the impact of municipal planning. *Land Use Policy* **2014**, *36*, 113–121. [CrossRef]
34. Kalbro, T.; Lindgren, E. *Markexploaterin*, 4th ed.; Norstedts Jurikik: Stockholm, Sweden, 2010.
35. Adams, D.; Watkins, C. *The Value of Planning*; Royal Town Planning Institute: London, UK, 2014.
36. Isaac, D.; O'Leary, J. *Property Valuation Principles*; Palgrave Macmillan: Basingstoke, UK, 2012.
37. Damodaran, A. *Investment Valuation*, 3rd ed.; John Wiley & Sons: New York, NY, USA, 2012.
38. Castanho, R.; Loures, L.; Cabezas, J.; Fernández-Pozo, L. Cross-Border Cooperation in Southern Europe. An Iberian Case Study: The Eurocity Elvas-Badajoz. *Sustainability* **2017**, *9*, 360. [CrossRef]
39. Ayuntamiento de Badajoz. *Plan General Municipal*; Ayuntamiento de Badajoz: Badajoz, España, 2007.
40. Wyatt, P. *Property Valuation*, 2nd ed.; John Wiley & Sons, Inc.: New York, NY, USA, 2013.
41. Blackledge, M. *Introducing Property Valuation*; Routledge, Taylor and Francis Group: New York, NY, USA, 2016.

42. Fernández, P. *Métodos de Valoración de Empresas*; Documento de Investigación, DI-771; IESE Business School, Universidad de Navarra: Navarra, España, 2008. Available online: http://www.iese.edu/research/pdfs/di-0771.pdf (accessed on 25 April 2018).
43. Fetibegovic, A.; Nilsson, A. Real Estate Discounted Cash Flow Model Development and Design. 2011. Available online: http://www.diva-portal.org/smash/get/diva2:490753/fulltext01 (accessed on 3 May 2018).
44. Brealey, R.; Myers, S.; Allen, F. *Principles of Corporate Finance*; McGraw-Hill Irwin: New York, NY, USA, 2011.
45. Damodaran, A. *Investment Valuation. Tools and Techniques for Determinig the Value of Any Asset*; John Wiley & Sons, Inc.: New York, NY, USA, 2012.
46. Benjamin, S.J.; Karrahemi, K.E. A TES of audit committee characteristics and free cash flows. *Corp. Ownersh. Control* **2013**, *10*, 611–626.
47. Begovic, S.V.; Momcilovic, M.; Jovin, S. Advantages and limitations of the discounted cash flow to firm valuation. *Skola Biznisa* **2013**, *1*, 38–47. [CrossRef]
48. Quemada, E. *Cómo Conseguir el Mayor Precio Para Mi Empresa*; Ediciones Deusto: Barcelona, España, 2009.
49. Bodmer, E. *Corporate and Project Finance Modeling: Theory and Practice*; John Wiley & Sons, Inc.: New York, NY, USA, 2014.
50. Steiger, F. The Validity of Company Valuation Using Discounted Cash FlowMethods; Cornell University Working Paper. 2008; Available online: http://arxiv.org/ftp/arxiv/papers/1003/1003.4881.pdf (accessed on 25 April 2018).
51. Gruninger, M.C.; Kind, A.H. WACC Calculations in Practice: Incorrect Results due to Inconsistent Assumptions- Status Quo and Improvements. *Account. Financ. Res.* **2013**, *2*, 36–44. [CrossRef]
52. Blanco, L. Valoración de empresas por descuento de flujos de caja: Proyección de ratios y estimación del valor terminal por múltiplos. *Rev. Universo Contáb.* **2009**, *5*, 125–141. [CrossRef]
53. Stankenvicience, J. Methods for valuacion of restructuring impact on financial rersults of a company. *Econ. Manag.* **2012**, *17*, 1289–1295.
54. Atherton, E.; French, N.; Gabrielli, L. Decision theory and real estate development. A Note on Uncertainty. *J. Eur. Real Estate Res.* **2008**, *1*, 162–182. [CrossRef]
55. Jayaraman, S. *A Review of Monte Carlo Methods in Real Estate*; Term Project Report; Florida State University: Tallahassee, FL, USA, 2013.
56. Pagourtzi, E.; Assimakopoulos, V.; Hatzichristos, T.; French, N. Real estate appraisal: A review of valuation methods. *J. Prop. Invest. Financ.* **2003**, *21*, 383–401. [CrossRef]
57. Fernández, P. *Wacc: Definicion, Interpretaciones Equivocadas y Errores*; Documento de Investigación DI-914; IESE Business School, Universidad de Navarra: Navarra, España, 2011.
58. Farber, A.; Gillet, R.; Szafarz, A. A General Formula for the WACC. *Int. J. Bus.* **2006**, *11*, 211–218.
59. Shyam, B.B. On the Definition, Measurement, and Use of the Free Cash Flow Concept in Financial Reporting and Analysis: A Review and Recommen. *J. Bus. Econ. Manag.* **2016**, *16*, 675–695.
60. Buus, T. A general free cash flow theory of capital structure. *Eur. Financ. Manag.* **2008**, *14*, 152–162. [CrossRef]
61. Frank, M.Z.; Shen, T. Investment and the Weighted Average Cost of Capital. *J. Financ. Econ.* **2016**, *119*, 300–315. [CrossRef]
62. Mascareñas, J. *El Coste del Capital*; Monografías de Juan Mascareñas Sobre Finanzas Corporativas: Madrid, Madrid, España, 2013.
63. Pérez-Carballo, J. *Compitiendo por Crear Valor*; ESIC Editorial: Pozuelo de Alarcón, Madrid, España, 1998.
64. Hail, L.; Leuz, C. International Differents in the Cost of Equity Capital: Do Legal Institutions and Securitis Regulations Matter? *J. Account. Res.* **2006**, *44*, 485–531. [CrossRef]
65. Damodaran, A. *What Is the Risk Free Rate? A Search for the Building Block*; New York University, Stern School of Business: New York, NY, USA, 2006.
66. Codosero, J.M.; Cabezas, J.; Castanho, R.A.; Naranjo, J.M. Estimación de la prima de riesgo para la valoración del suelo con aprovechamiento urbanístico: Un caso de estudio. Suelo urbanizable en Badajoz, España. *Monfragüe Desarro. Resil.* **2017**, *8*, 60–74.
67. Saaty, T.L. Decision-making with the AHP: Why is the principal eigenvector necessary. *Eur. J. Oper. Res.* **2003**, *145*, 85–91. [CrossRef]
68. Saaty, T.L. Decision with the analytic hierarchy process. *Int. J. Serv. Sci.* **2008**, *1*, 83–98.

69. Yalpir, S. Forescasting residential real estate values with AHP method and integrated GIS. *Build. Env.* **2014**, *1*, 694–706.
70. Vaidya, O.S.; Kumar, S. Analytic hierarchy process: An overview of applications. *Eur. J. Oper. Res.* **2006**, *169*, 1–29. [CrossRef]
71. Aznar, J.; Guijarro, F. *Nuevos Métodos de Valoración. Modelos Multicriterio*, 2nd ed.; Universidad Politécnica de Valencia: Valencia, España, 2012.
72. González-Ramiro, A.; Gonçalves, G.; Sánchez-Rios, A.; Jeong, J.S. Using a VGI and GIS-Based Multicriteria Approach for Assessing the Potencial of Rural Tourism in Extremadura (Spain). *Sustainability* **2016**, *8*, 1144. [CrossRef]
73. Michel, G. *Real Estate Risk in Equity Returns: Empirial Evidence from U.S. Stock Markets*, 1st ed.; Gabler Edition Wissenschaft: Wiesbaden, Germany, 2009.
74. Gan, J. The Real Effects of Asset Market Bubbles: Loan- and Firm-Level Evidence of a Lending Channel. *Rev. Financ. Stud.* **2007**, *20*, 1941–1973. [CrossRef]
75. Davis, E.P.; Zhu, H. Commercial propety prices and bank performance. *Q. Rev. Econ. Financ.* **2009**, *49*, 1341–1359. [CrossRef]
76. Tyrrell, N.; Bostwick, J. Leverage in real estate investments: An optimization approach. *Brief. Real Estate Financ.* **2005**, *5*, 143–154. [CrossRef]
77. Brueggeman, W.B.; Fisher, JD. *Real Estate Finance and Investmenty Fisher*, 4th ed.; McGraw-Hill Irwin: New York, NY, USA, 2011.
78. Giacomini, E.; Ling, D.C.; Naranjo, A. Leverage and Returns: A Cross-Country Analysis of Public Real Estate Markets. *J. Real Estate Financ.* **2014**, *51*, 125–159. [CrossRef]
79. Morri, G.; Cristanziani, F. What determines the capital structure of real estate companies? An analysis of the EPRA/NAREIT Europe Index. *J. Prop. Invest. Financ.* **2009**, *27*, 318–372. [CrossRef]
80. Niskanen, J.; Falkenbach, H. European Listed Real Estate: The Capital Structure Perspective. *Nord. J. Surv. Real Estate Res.* **2012**, *9*, 76–97.
81. Klimczak, K. Determinants of Real Estate Investment. *Econ. Sociol.* **2010**, *3*, 58–66. [CrossRef] [PubMed]
82. Psunder, I.; Cirman, A. Discount rate when using methods based on discounted cash flow for the purpose of real estate investment analysis and evaluation. *Geod. Vestnik* **2011**, *55*, 561–575.
83. Miyamoto, K.; Paez, A. Urban and community planning. *Civ. Eng.* **2009**, *1*, 63–85.
84. Ohlson, J.A.; Zhang, X.J. On the Theory of Forescast Horizon in Equity Valuation. *J. Account. Res.* **1999**, *37*, 437–449. [CrossRef]
85. Ministerio de Fomento, Valor Tasado de la Vivienda. Available online: https://www.fomento.gob.es/ (accessed on 26 February 2018).
86. Junta de Extremadura. *Base de Precios de la Construcción 2012*; Junta de Extremadura: Mérida, España, 2012.
87. Emedos Agenda de la Construcción. Available online: http://emedos.es (accessed on 27 February 2018).
88. Deuda del Estado. Available online: http://www.tesoro.es/deuda-publica/estadísticas-mensuales (accessed on 5 March 2018).
89. Ratios Sectoriales de Sociedades no Financieras. Available online: http://app.bde.es/rss_www/Ratios (accessed on 5 March 2018).
90. Solvia Market View. Tendencias del mercado inmobiliario. *Solvia* **2017**, *4*, 1–31.
91. Índice de Precios de Vivienda. Available online: http://www.ine.es/productos-y-servicios/publicaciones/catálogodepublicaciones/sociedad (accessed on 6 March 2018).

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Article

Conflicts of Interest and Change in Original Intent: A Case Study of Vacant and Abandoned Homes Repurposed as Community Gardens in a Shrinking City, Daegu, South Korea

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Abstract: As part of an urban policy designed to revive South Korea's shrinking cities, vacant residential structures are being demolished and the resulting empty plots transformed into public spaces. This study discursively examines this process, its stakeholders, and the sources of conflict among them in the neighborhood of Daebong 2 in Daegu, South Korea. Additionally, solutions for maintaining public interest are explored. Employees and members of relevant municipal authorities and non-profit organizations (NPOs), as well as town residents, were selected through purposive sampling for interviews. The data were then analyzed via open coding. The results reveal conflict between users and non-users in terms of the possession of public goods, as well as conflict between project executives in the creation process. We also found that spatial and policy characteristics are a particular source of conflict in dense, historic residential areas. To overcome problems caused by rivalry and discord, the following actions are required: a change in perspective among policy practitioners; a governance structure that consists of a public/private/community partnership; consensus among community members, and; equitable welfare through programs based on inclusivity and public interest.

Keywords: declining cities; neighborhood regeneration; governance; public goods; temporary transformation into public land; urban policy; green welfare; discursive examination

1. Introduction

Around the globe, many cities are experiencing declines in population. In the 50 years prior to 2007, the populations of over 370 cities dropped significantly, and this decrease is projected to continue [1,2]. The declines of cities and declining populations are especially prominent in cities that developed during the industrial age, such as Detroit and Youngstown in the United States; and Leipzig, Germany [3–7].

Various Korean cities have experienced such declines in population, which has further intensified other societal changes, such as economic recession and low birth rates [7]. Consequently, the number of abandoned and aging properties has increased, which is the clearest physical sign of urban decline [8,9]. Houses that are vacant for extended periods often become breeding grounds for crime [10,11]. Trash and debris can mar their appearance, create odors and fire hazards, and increase the risk of collapse [12]. Subsequently, property values fall [13], and other physical, social, and economic problems arise.

Many studies and policies have addressed the issue of vacant and abandoned homes. For example, the city of Leipzig, Germany, has long demolished properties so that the resulting open spaces can be temporarily converted into public land [14,15].

To date, related studies have focused on the causes of vacant houses [16], utilization plans [16,17], and the effects of vacant houses after demolition [15–18]. While several case studies exist on this topic, there are specific areas that need further attention. An and Park's [17] study was limited to international cases and thus fell short of theorizing and empirically verifying declining Korean cities. Ha et al. [16], moreover, did not go beyond explaining the process of establishing a community garden and fell short of exploring various shareholder positions that emerged along the way. Kim and Lee's [18] research was much needed since it was one of the few studies to focus on a community garden's influence on non-participating members. In contrast to Rall and Haase [15], who mostly focused on assessing the effects of public space, the present study addresses the dynamics between shareholders that emerged during the creation of a public space.

The space created by demolishing vacant residences can reduce the economic and security costs of vacant properties and prevent an area's decline [19]. Furthermore, an area's potential can be discovered through such temporary small-scale developments, contributing to sustainable urban restoration in the future [20]. However, from a different perspective, it is contradictory to consider programs such as vegetable gardens as a type of public good since they are only utilized by a select number of citizens. Moreover, areas procured through the demolition of vacant houses are developed and opened to the public on the condition that certain individuals (e.g., the owner(s) of the vacant residences) receive benefits. Therefore, interest surrounding public goods has become even more pronounced.

Conflicts in a region increase social costs by disrupting local communities and causing policy delays [21,22]. Moreover, disputes involving conflicting values are not easy to mediate and resolve, and they can last for long periods [23]. To successfully revive declining cities, building trust among stakeholders is critically important; to this end, it is necessary to understand the factors involved in the conflicts [24–26].

Given these circumstances, what types of conflict arise in the use of public spaces after vacant residences have been demolished? For what reasons do those conflicts occur? To answer those questions, this study examined vegetable gardens developed through the Daegu Vacant Houses Management Program. Using this approach, the study aimed to identify the sources of conflict between stakeholders intervening in the city's revitalization. Such research can serve to fill gaps in previous studies, such as the perceptions of various stakeholders and the process of dismissal and vacancy utilization. The case study examined here can also provide baseline data for creating sustainable policies and city spaces.

The city of Daegu, South Korea, has experienced steady decline since the mid-1990s [9]. According to survey results, 105 (75.5%) out of a total of 139 districts have been experiencing decline [27]. The city's old districts, including the central, southern, and eastern sections, are plagued by numerous empty houses. Fires and incidents of sexual violence in vacant houses over the past few years have prompted countermeasures. To this end, to induce the demolition of such houses, property tax exemption and subsidized demolition costs have been provided to vacant residence owners since 2013. In return, the vacated areas must be temporarily opened to the public for at least three years after demolition. These areas are developed into facilities such as vegetable gardens, parking spaces, sports facilities, and small parks [28]. According to the data provided by officials of Daegu city hall, 141 spaces had been created by 2015, including 47 vegetable gardens (33%), 67 parking spaces (47%), 11 sports facilities (8%), 12 small parks (9%), and four flower beds (3%).

This study specifically focuses on the paradox of a community garden as a public good, the benefits of which only reach a certain group of community members. Of the 47 vegetable gardens identified as having been created between 2013 and 2015, many are quite small and located in difficult-to-access areas, which results in low utilization rates. For this study, those in declining low-rise residential complexes were visited for usage surveys and preliminary interviews. In contrast, the selected sites

(Figure 1) were relatively large in size and conveniently located by the roadside, which contributed to their robust utilization by community members. Also, the sites were introduced to the media [29] as success cases. However, the preliminary interviews revealed contention surrounding the use of gardens. The results further revealed contention between users and non-users in terms of the possession of public goods, as well as conflict between project executives in the creation process.

Figure 1. (**a**) Site A before vacant house was demolished (source: Daegu city hall); (**b**) Site A after vacant house was demolished (photo: J. Lee, 2 April 2016); (**c**) Site B before vacant house was demolished (photo: Oasis Plan); (**d**) Site B after vacant house was demolished (photo: J. Lee, 23 May 2016).

2. Materials and Methods

The purpose of this study was to understand the phenomenon of the private occupation of public resources and its conflict factors. Therefore, a case study method was adopted by selecting certain cases that could reveal such characteristics though surveys. Case studies are useful for answering "how" and "why" when researchers cannot control circumstances or when relevant phenomena unfold in the present [30]. This approach offers detailed descriptions of truths, phenomena, or social units [31] so that a clear understanding of the situation can be ascertained [32].

Data were sourced from the Daegu city hall website, newspapers, and other publications from relevant agencies, as well as from interviews conducted between March and August 2016 during seven site visits. Since shareholders in the creation and use of the new public spaces were needed for interviews, the initial pool of interviewees was recruited via purposive sampling. Thus, the sampling target consisted of relevant public workers, non-profit members, and community members (garden users and non-users). For the administration, interviews were conducted with relevant employees, and for non-profit organizations, interviewees included people who led the project. For residents, interviews were divided into users and non-users, and when "theoretical saturation" [33] was achieved in the data collection with no further new data to be collected, collection was stopped. By this means, a total of 18 individuals were selected for in-depth interviews (12 community members, four public workers, and two non-profit organization (NPO) members). Ultimately, excluding poor interviews, 12 of these individuals (seven community members, three public workers, and two NPO members), whose interviews were judged to provide qualitative abundance, were selected for the analysis.

Managers of city hall, the district hall, and the community service center associated with the project were recruited via e-mail or phone numbers found online. For members of private organizations, media reports and publications associated with the project were reviewed and relevant individuals recruited via social networking services. Since no entity oversaw community garden users, the researchers waited near the community gardens and recruited community members who were tending their plots. Non-users were recruited on the sites or via snowball sampling from among community members. To build rapport with the community, the researchers met with community members during every site visit. Interviews were typically held at community gardens or at the community pavilion for the convenience and comfort of interviewees, unless otherwise requested, in which case interviews were held at community members' homes. Public workers were interviewed at their places of employment, and the members of non-profits were interviewed at their current offices.

Upon obtaining the participant's consent, all data were recorded and transcribed. To keep sight of the study's aim but avoid steering it in a certain direction, an open and semi-structured interview questionnaire was prepared, which allowed for clear insight into the participants' opinions and emotions. The interviews were designed to grasp the overall process of the project, as well as the perceptions of stakeholders in public goods. To accomplish this, we asked questions about the process before, during, and after the project. In the case of residents, we inquired about the situation before the project's creation, the composition process, and its use after creation. Meanwhile, in the case of administrative authorities and non-profit members, we asked about the occasion and purpose of the project, the creation process, and management after creation (see Appendix B). The interviews, though based on a questionnaire, were conducted flexibly in a way that was responsive to the participants' (Tables 1–3) answers. For the literature data, newsletters and other publications made available by relevant agencies and organizations were used.

Table 1. Demographic data of users and non-users.

Current Usage Status	No./Code	Gender	Age Group	Location Residence	Years of Residence	Years of Use
Users	RU1	F	mid-60s	nearby	25	3
	RU2	F	late 20s	other neighborhood	3	3
	RU3	M	late 60s	nearby	30	3
	RU4	M	mid-70s	nearby	40	3
Non-users	RN1	F	early 70s	nearby	30	0
	RN2	F	early 70s	nearby	40	Less than 1
	RN3	F	mid-70s	nearby	30	0

Table 2. Demographic data of government workers.

Category	No./Code	Gender	Age Group	Educational Attainment	Years of Employment in Relevant Dept.
Government workers	O1	M	late 50s	College degree	Over 10
	O2	M	early 50s	College degree	5
	O3	M	mid-40s	College degree	1

Table 3. Demographic data of non-profit members.

Category	No./Code	Gender	Age Group	Educational Level	Years of Working, Employment, or Membership
Non-profit members	N1	M	mi-40s	College degree	8
	N2	M	early 30s	College degree	4

For the reliability of the study, data were analyzed when two or more interviewees gave a consistent response. To increase the reliability of the interpretation, the contents of the literature and the interviews were verified against each other, and the two researchers analyzed the data and used data that reached the same conclusion.

The collected data were processed (see Appendix A) using the open coding method of the grounded theory approach to analytic induction, which was introduced by Glaser and Strauss [33] and frequently adopted by Werner and Schoepfle [34]. All interview responses were transcribed and processed via segmenting, initial coding, and deep code generation. During the segmenting process, a researcher marked the parts that captured the essence of the interviewees' main concerns. During the subsequent initial coding process, the data processed from the previous stage were thoroughly reviewed to further deduce important meanings. Recurring details, meanings, and themes were then assigned codes. Next, related codes were repeatedly compared with one another to discover their hierarchies, connections, and similarities, from which metaphorical themes could be extracted that could turn one-dimensional data into concepts. These processes revealed causal relationships between community members' perceptions and the series of events that transpired over the course of repurposing vacant lots into community gardens. Based on this discovery, the dynamics between stakeholders were examined over two phases: while creating community gardens and after completing them.

3. Results

3.1. Creating Community Gardens: Conflicts between Private and Public Parties

3.1.1. Beginning to Create a Community Garden Together

The Daegu Community Garden Model was launched in 2013 by a non-public organization, a university student club, and public authorities working in tandem. N1, a research center employee, had been asked about urban agriculture consultation by the district office in 2011. N1 suggested a community garden and cited examples from Chicago. Later, a collaborative model consisting of the district office, the research center, and the university was established to begin creating community gardens. With the help of a K university student club, N1 surveyed the number of vacant and abandoned local houses and began persuading owners to cooperate in service of the project in 2012, which resulted in two experimental community gardens (Figures 2 and 3). N2, who was a K university agriculture student at the time, participated in the community garden project through an acquaintance's connection to N1.

N1 expressed concern that the demolition subsidy was KRW 30 million since it is difficult to sustain the project with a low subsidy. Therefore, N1 thought of measures to reduce costs and promote "sustainability". Rather than developing after completely vacating the area, the vegetable garden was formed through partial reorganization. In addition, N1 and N2 also planned to promote education for environmentally friendly agriculture. They hoped the business would start in urban agriculture, but over time it would be content to solve regional revitalization and regional problems.

Figure 2. The community negotiation process (photo: Regional Revitalization Lab Martello).

Figure 3. Creating a community garden (photo: Regional Revitalization Lab Martello).

3.1.2. Emerging Discord: "Unequal Relationship", "Exclusivity", and "Withdrawal"

Around the time the two community gardens began to take shape, people began complaining about the community service center, claiming it was trying to establish a hierarchical relationship. Staff members of the community center gave the students a lot of chores, similar to those given to hired employees. These complaints intensified after the community service center requested a separate budget and then unbeknownst to the others began building "a community garden of their own". Some of the results from the interviews are as follows. Community gardens started to become separated, and competition increased. In addition, people became sensitive to the performance of the project after it was publicly introduced by the media.

> Now there is "my" garden and "your" garden in that small town, which creates a rivalry. Why? It must be due to pressure to perform. They took the credit for what we created, too. What's the point of all this? The garden belongs to the town community. (N1)
>
> Whenever a newspaper reporter or other such people visited to interview us ... the community service center complained that we were making it sound like we did it [created the garden] by ourselves when, according to them, they did it. And then later we found out in newspaper articles that they had taken credit for our garden as well. (N2)
>
> In the end, the NPO to which N1 and N2 belonged withdrew from the project, convinced it was being "excluded". Currently, the project is being implemented as a residential urban beautification initiative, led by the municipal authority and funded by the city and the county.

> The presence of abandoned and dilapidated houses makes the neighbors very uncomfortable. They stink in the summer, which poses a public health concern. Besides, they are such an eyesore. (O1)
>
> Abandoned and dilapidated houses attract crime, so the primary goal is to demolish those structures. (O2)
>
> There are so many vacant and abandoned properties with dead tree leaves in and around them, which poses a fire hazard. And there's the matter of potential collapse. (O3)

N1 said the project was meaningful and sustainable at first because it was a real "collaboration" between the government and private citizens. However, with disruption in the collaborative relationship, the project became what N2 called a "weekend farm". The public authority had not taken any specific measures regarding how the newly vacant lots should be utilized after razing vacant and abandoned houses, nor did it engage in associated efforts. Speaking with O1, O2, and O3, it became clear that the community garden project changed from what N1 and N2 "dreamed" of to a mere "residential environment improvement" project that aimed to upgrade urban aesthetics for the benefit of the declining town.

3.2. Community Garden Use: Conflict between Residents

3.2.1. Community Gardens for Personal, Economic, and Social Benefits

To learn how the spaces were seen by users and non-users, interviews were conducted with community members. Community garden users perceived the space as having personal meaning and value. For instance, RU4 would visit the garden at night and during the day to water her crops, which gave her a sense of achievement. Plus, taking walks to and from the garden became a kind of hobby. RU2, a kindergarten teacher, felt a sense of achievement while running a school gardening program where students enjoyed planting and harvesting crops each season. The interviews depicted a community garden used for education and personal hobbies, which indicated that participation in the community garden was associated with self-actualization.

In addition, RU1 depicted the community garden as a place that provided food and connection, indicating that participation had economic and social value. However, these values are more closely associated with personal satisfaction and benefits.

> I garden, and then I bring some of my harvest to my son's ... and I also share it with my friends. I just pull it out and bring it to my friends [laughs]. Look at the lettuce. It is different from what you buy at the store. You have no idea how popular it is. ... Everyone wants some. (RU1)

3.2.2. Community Gardens as a Source of Pain, Suffering, and Welfare Frustration for Non-Users

Non-users were upset and disgruntled because some "selfish" community members had summoned their personal connections to acquire multiple plots during the allotment process. This damaged trust among the community members. The situation worsened when those who had been allotted multiple plots neglected them, causing others to "simmer with anger".

> It's no use studying stuff like this. It just sours relationships between neighbors. All this bickering and arguing ... for what? In the end, only those who eat, get to eat, and those who don't, don't get to eat. It's not even done together. Of course it makes you upset, if you are not picked to participate. (RN1)
>
> Some have up to five plots. You pick and see, and I pick and see. Somehow, they all pick. Even people who don't live here sneak in to pick. Like this. It's not right, correct? People shouldn't do that, right? They all put dibs on it in the beginning, and then. ... It makes me angry. (RN3)

> The hardship stemming from the community garden sometimes led to estranged family relationships and discontent with national welfare policies. RN2 was upset because RN2's grandson would not visit for fear of the insects propagated by the community garden. RN3 and RN1 expressed dissatisfaction toward the garden and the welfare policy, while focusing on the fact that it was a public good funded by taxpayers.
>
> My grandson refuses to come visit his grandma because of the mosquitoes. He's ten. I ask him to come for a visit, and he won't, saying that there are too many mosquitoes in my place. Those who haven't experienced it don't understand. (RN2)
>
> Because it would cost money, the district office demolished it for free and told the neighborhood to utilize it. . . . Those who didn't give permission received all sorts of crap. With what money did the district office do it? It just drives up our health insurance. Why don't they help out those in need instead? Several tens of millions of won got poured into that. (RN3)
>
> There's no welfare that doesn't require tax money. The current state of the nation. . . . Young people are struggling to stay alive because of taxes. . . . Do they have money to burn? [profanity]. There's no money to spend like this. . . . Tell them to find jobs for our unemployed youths instead. They are foaming at the mouth to score some easy points for the next election season. (RN1)

Saito [35] mentions the concept of "openness" as a prerequisite condition for "publicness". Here, publicness means "inclusive of everyone" as well as "fair and just". In this sense, the unfair garden plot allotment process and the exclusivity of its benefits (limited only to those who actively participated in gardening) undermined the publicness of the residential environment improvement project, in terms of both procedures and outcomes.

3.2.3. The Meaning of "Trees" and "Fences": A Place of Rivalry and Exclusivity

RN2 was eager to express her frustration to the researcher. According to her, despite the insect-related "stress" caused by inadequate garden care, she "keeps her mouth shut" about others since they were all neighbors. She then talked about two trees she had planted (Figure 4).

> Dude, this place is teeming with flies and mosquitos. They are watered. Sprayed. We have been living with the doors closed for two years now. Look at the water there. Look at the container (Figure 5). You see it's swarming with bugs. But I can't bring myself to talk to them about it. Because we are neighbors, I just keep quiet. And it turns out that from here to over there is my property. I wasn't aware of it before the demolition [of the abandoned house]. . . . So my son told me to plant some trees. . . . Plant some trees because we will get it [our property] back soon. (RN2)

(**a**)

Figure 4. *Cont.*

(**b**)

Figure 4. Pictures of trees and fences on the site (photo: J. Lee, 2 April 2016); (**a**) fences installed by users of the community garden; (**b**) trees planted by non-user (RN2). Translation of the text in the image of Figure 4a: "You may have pulled off stealing, but there are 22 eyes watching you now".

Figure 5. Unmanaged watering can (photo: J. Lee, 2 April 2016).

RN2 learned from her housing deed that part of her property, which she had been unaware of, had been lumped in with the project during the demolition. However, because there was nothing she could do about her property already having been used, she planted the trees to mark her territory (Figure 4). In other words, she used them to signal her presence. Furthermore, attached to the metal gate of the community garden were handmade signs that read "Let's live an honest life" (the backside of the metal gate) and "You may have pulled off stealing, but there are 22 eyes watching you now" (the front side of the metal gate) (Figure 4a).

> It was not stealing. . . . So what if the neighborhood tore off and ate some vegetables? All the ladies do it at times as they hang out here and talk. Isn't it understandable? I say people are so devoid of warmth. Look at the metal fencing. . . . Hell is raised if stuff goes missing. (RN2)

RN2, who had been allotted a plot in the first year following the demolition, was disgruntled that despite her property having been incorporated into the garden unbeknownst to her, she had been designated a plot elsewhere. Her frustration intensified due to the different views held by her and other gardeners. In other words, she thought that sharing was okay when others did not. She went on to suffer from flies and the mosquitoes until she finally stopped participating. She is now counting the days until the program ends.

In the target area, fences were installed by users to block the entry of non-users. Since there were no regulations regarding the management of vegetable gardens, individuals attempted to physically blockade what they perceive as their private vegetable gardens. Such marking of territory indicates that although the residential environment improvement project had been promoted as a public good, it assumed the characteristics of a private good with rivalry and exclusivity. In a broad sense, satisfying either the non-rivalry or non-excludability condition makes goods public [36]. Since space was limited, the community gardens had an element of rivalry. They also imposed an element of excludability for community members who did not participate in gardening, resulting in the inadvertent privatization of a public good.

4. Discussion

According to the survey results, conflicts surrounding public goods existed among stakeholders, and as a result, public goods came to assume the characteristics of a competitive and exclusive space. This suggests the tragic ending of the commons as suggested by Hardin [37], who argued that freedom in the commons brings devastation to everyone, and external force—the "Leviathan" [38]—becomes inevitable. However, while identifying individualism as the major cause of the tragedy of the commons, Hardin does not pay attention to the cause that triggers individualism. Meanwhile, in response to Hardin, there have been studies on "the comedy of the commons" [39] and the continuity of common resources through autonomous operation [40,41]. Aside from such investigations of the factors that keep the commons healthy, further research is needed on conflicts related to the commons and their adverse effects. Such work can help to identify measures that will ultimately achieve the sustainable use of public goods.

In the present study, conflicts between residents began with the process of distributing vegetable gardens. Meanwhile, the illegal acquisition of vegetable gardens by a small number of residents and the random distribution of land caused complaints among neighbors. Moreover, the vegetable gardens that were originally allocated were occupied for almost three years, and vegetable gardens no longer in use were left unattended without changing users. This process of community garden establishment and inadequate operation contributed to conflicts among residents.

Additionally, the spatial characteristics of vacated areas were shown to be a factor in conflict. Since such areas did not have access to a water supply, individuals had to procure the water required to manage the vegetable gardens. The excess water was then mismanaged and left in buckets, causing insects to gather. Moreover, the dense residential environments also make it easier for nearby residents to be exposed to insects. The community service center should invest more effort in consistent management based on an understanding of such special characteristics. Given the high density of the residential environment, unexpected parcels of land were discovered during the demolition of vacant houses, leading to complaints when people marked their territory using methods such as "planting trees". However, the implicit silence that was adopted to protect relationships with longtime neighbors could not resolve the complaints. Since most residents had lived in the neighborhood for a long time, they were reluctant to directly express their complaints. As a result, spatial factors and social characteristics appeared as various factors causing conflict. Therefore, there needs to be a medium to invigorate communication among residents.

The Vacant Houses Management Program stipulates that vacated areas be opened to the public for at least three years. After three years, this term is subject to change according to the landowner's intentions. As such, the uncertainty arising from the unspecified expiration date of this term became a source of dubious hope and caused non-users to stifle their discontent.

In the process of developing community gardens, the implementing body was changed due to conflicts between the private organization and the public institution. As the implementing body changed from private to public, it became a top-down policy centered on administrative authority. This also changed the nature of the project. As the private organization raised complaints about the authoritarian stance of the administrative authority, an asymmetrical relationship formed. This relationship damaged the connections between groups, even though the project was mutually beneficial, and developed into mutual suspicion and cynicism until the partnership was eventually dissolved [42]. The project then progressed as a "residential environment improvement project", with limited public aid for the demolition of vacant or deserted houses and the development of vacated areas. This led to a lack of supervision of the vacated areas and became the main factor instilling a sense of competition and exclusion among residents.

To restore the publicness and function of such areas as communal spaces, there is a need for continuous involvement and interest via the administration and management of programs. To this end, it is crucial that ongoing projects for aesthetic improvements be acknowledged as part of the town restoration project, and that the process for such projects is centered on local residents. It is also essential that the governance involves private and public parties as well as residents to ensure sustainable and effective administration. In addition, because gardening requires continuous work, the creation of community gardens alone does not guarantee the continued existence of such gardens [43,44]. Thus, it is necessary to form governance consisting of a third party along with the community involved in the maintenance and management of the shared spaces [45].

The simple approach of the program, which used the spaces only as vegetable gardens, resulted in limited access. People who do not tend vegetable gardens essentially have limited access since no other facilities aside from vegetable gardens are currently available. If there are resting facilities, such as benches and pagodas, or spaces and facilities that allow for different activities, the users of vacated spaces could be diversified to include those not involved in vegetable gardens. Although an area becomes an exclusive space when ownership exists, various people can use the area if it is versatile and freely available. Areas made available by demolishing vacant houses are a product of public funding. The landowner and user, as well as neighboring residents, possess a sense of psychological ownership of such areas [46]. Such areas should not have the characteristic of being occupied by particular individuals. Thus, it is necessary to create a complex space that allows anyone to use it and stay, rather than one that is occupied by specific individuals.

5. Conclusions

This study examined sources of conflict between stakeholders involved in demolishing and reusing the vacant residences that emerge in shrinking cities and explored solutions for maintaining public interest. The results indicated that the competition that arises among residents during the use of vacated areas is related to the conflicts among implementers that appear during project development, as well as to the resulting changes in the nature of the project. Also contributing to conflict are the spatial characteristics of the vacated area, being located near elderly residences, and policy characteristics, such as the temporary transformation into public land.

This study showed that continuous management and administration are needed to maintain public interest. To this end, a change in perception, transitioning from an aesthetic improvement project to a city restoration project, is necessary, in addition to governance and cooperation efforts involving private and public parties as well as the community.

Many discussions have suggested that it is not plausible to have unconditional tragedy or comedy in the use and management of commons. Therefore, a careful approach is needed on a case-by-case basis; the present study can be considered one such case. This study has provided meaningful data on the process of dismissal and vacancy utilization, as well as the perceptions and attitudes of various stakeholders. Since multiple case studies are needed for the efficient implementation of projects, this study can serve to provide baseline data for creating sustainable projects and spaces. As abandoned houses become more abundant, similar policies will need to be discussed. In this sense, this study provides much needed suggestions. Future studies could perhaps examine vacant land use decision making on a larger scale (such as in an entire city) or in another country, which would reveal the effects of differing cultures.

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Appendix A

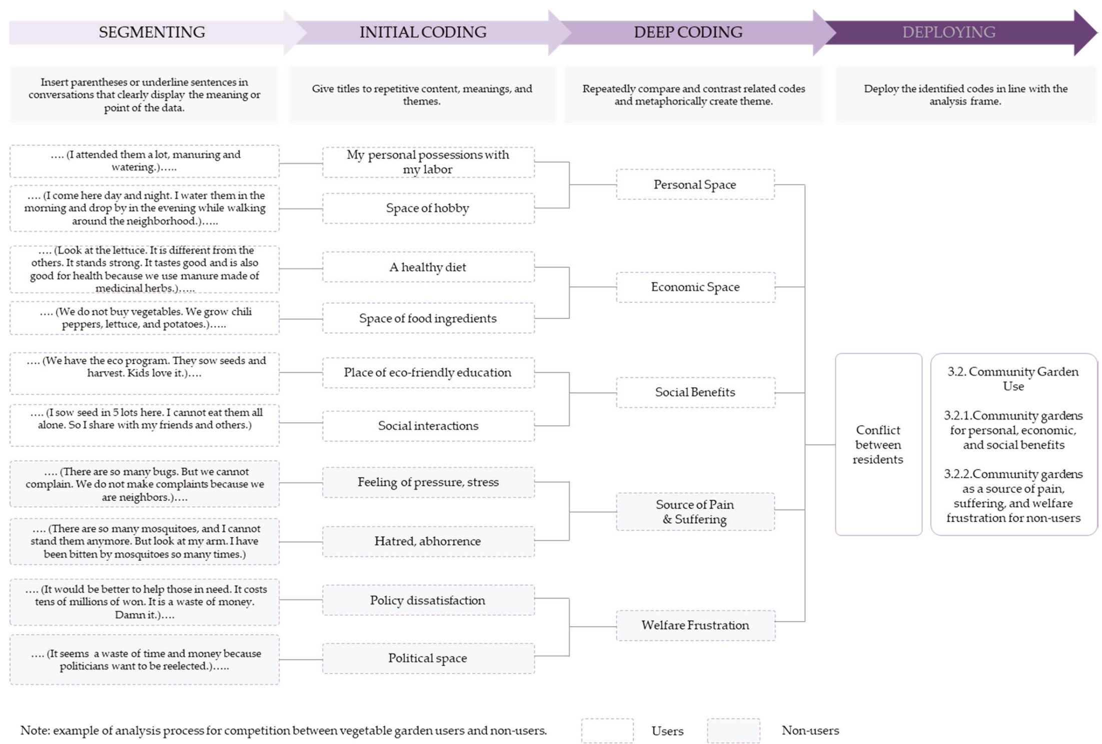

Figure A1. A portion of analysis process using open coding method of the grounded theory approach.

B.

Interview questions
To community members:
Before the creation: What was this space like before, when it contained a vacant house?
Composition process: What was the plot allotment process like following demolition?
After the creation: How does one get to use the garden?
What are the pros and cons of the garden?

To government workers:
Motive and goal of the project: How did the project come to be launched?
What is the project's goal?
Process of creation: Did it incorporate the community members' opinions?
After the creation: How is the established garden managed?

To non-profit members:
Motive and goal of the project: How did the project come to be launched?
What is the project's goal?
Process of creation: What are the events that unfolded during the creation process?
After of creation: How did your level of involvement change after the garden was created?

References

1. Oswalt, P.; Rieniets, T. Global Context. Shrinking Cities. 2007. Available online: http://www.shrinkingcities.com/globaler_kontext.0.html?&L=1 (accessed on 7 November 2017).
2. Newman, G.D.; Bowman, A.O.; Lee, R.J.; Kim, B. A current inventory of vacant urban land in America. *J. Urban Des.* **2016**, *21*, 302–319. [CrossRef]
3. El Nasser, H. As Older Cities Shrink, Some Reinvent Themselves. USA Today. 27 December 2006. Available online: https://usatoday30.usatoday.com/news/nation/2006-12-26-shrinking-cities-cover_x.htm (accessed on 16 November 2017).
4. Lanks, B. Creative Shrinkage. The New York Times Magazine. 10 December 2006. Available online: http://www.nytimes.com/2006/12/10/magazine/10section1B.t-3.html (accessed on 16 November 2017).
5. Bontje, M. Facing the challenge of shrinking cities in East Germany: The case of Leipzig. *GeoJournal* **2005**, *61*, 13–21. [CrossRef]
6. Beauregard, R. Shrinking cities in the United States in historical perspective: A research note. In Proceedings of the Future of Shrinking Cities: Problems, Patterns and Strategies of Urban Transformation in a Global Context. Available online: http://www.rop.tu-dortmund.de/cms/Medienpool/Downloads/The_Future_of_Shrinking_MG-2009-01.pdf (accessed on 7 November 2017).
7. Lee, H.; Han, S. *Where Do Shrinking Cities Go From Here?* Korea Research Institute for Human Settlements: Yanyang, Korea, 2014.
8. Jeon, Y.; Kim, S. The causes and characteristics of housing abandonment in an inner-city neighborhood—Focused on the Sungui-dong area, Nam-gu, Incheon. *J. Urban Des. Inst. Korea Urban Des.* **2016**, *17*, 83–100.
9. Seoul National University R&DB Research Foundation. *Data Collection on Current Condition of Urban Decay and Comprehensive Information System Development*; Ministry of Land, Infrastructure and Transport, the Korea Agency for Infrastructure Technology Advancement, and the Korea Urban Renaissance Center: Seoul, Korea, 2010.
10. Spelman, W. Abandoned buildings: Magnets for crime? *J. Crim. Justice* **1993**, *21*, 481–495. [CrossRef]
11. Stucky, T.D.; Ottensmann, J.R. Land use and violent crime? *Criminology* **2009**, *47*, 1223–1264. [CrossRef]
12. Accordino, J.; Johnson, G.T. Addressing the vacant and abandoned property problem. *J. Urban Aff.* **2000**, *22*, 301–315. [CrossRef]
13. Han, H.S. The impact of abandoned properties on nearby property values. *Hous. Policy Debate* **2014**, *24*, 311–334. [CrossRef]

14. Cabral, I.; Weiland, U. *Urban Gardening in Leipzig and Lisbon: A Comparative Study on Governance*; COST (European Cooperation in Science and Technology): Leipzig, Germany, 2014.
15. Rall, E.L.; Haase, D. Creative intervention in a dynamic city: A sustainability assessment of an interim use strategy for brownfields in Leipzig, Germany. *Landsc. Urban Plan.* **2011**, *100*, 189–201. [CrossRef]
16. Ha, C.; Kwak, H.; Kim, H. A study on utilization and making vegetable garden of vacant land and deserted house in deteriorated low-rise residential area for neighborhood regeneration—Focused on no-song low-rise residence district in Jeonju. *J. Urban Des. Inst. Korea Urban Des.* **2013**, *14*, 81–93.
17. An, H.; Park, H. Flexible urban regeneration: Creative use of empty houses and vacant plots—Focused on temporary uses and tactical urbanism. *J. Korea Plan. Assoc.* **2013**, *48*, 347–366.
18. Kim, J.Y.; Lee, Y.S. A study on design direction of community garden in urban deprived area through analysis of psychological and social effects-Targeting on the community garden of Jeonju-si urban regeneration test-bed area. *Des. Converg. Study* **2013**, *12*, 83–98.
19. Samsung Economic Research Institute. Secret of Rival City, Urban Regeneration. SERI Kyoung-Young Note. 2012. Available online: https://www.google.co.kr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0ahUKEwjV04qekcPXAhVCUrwKHarjBgIQFggoMAE&url=http%3A%2F%2Fmaljong.tistory.com%2Fattachment%2Fcfile27.uf%40230B803D52DE175F0C4781.pdf&usg=AOvVaw1Xl-vaKCBLHrytH8jd0vah (accessed on 9 November 2017).
20. Bishop, P.; Williams, L. *The Temporary City*; Routledge: London, UK; New York, NY, USA, 2012.
21. Hong, J.H. Resolving environmental conflicts in Korea: Issues and solutions. *Environ. Law Rev.* **2010**, *32*, 385–416.
22. Franks, D.M.; Davis, R.; Bebbington, A.J.; Ali, S.H.; Kemp, D.; Scurrah, M. Conflict translates environmental and social risk into business costs. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 7576–7581. [CrossRef] [PubMed]
23. Cho, M.R. Causes and structure of environmental conflicts concerning national development projects. *ECO Korea Assoc. Environ. Soc.* **2003**, *12*, 110–146.
24. Hibbitt, K.; Jones, P.; Meegan, R. Tackling social exclusion: The role of social capital in urban regeneration on Merseyside: From mistrust to trust? *Eur. Plan. Stud.* **2001**, *9*, 141–161.
25. Park, J.W.; Song, T. A conflict minimization scheme in urban regeneration projects. *Korea Policy Stud.* **2013**, *13*, 133–148.
26. Putnam, R.D.; Leonardi, R.; Nanetti, R.Y. *Making Democracy Work: Civic Traditions in Modern Italy*; Princeton University Press: Princeton, NJ, USA, 1994.
27. 2025 Daegu Metropolitan City Urban Regeneration Strategic Plan. Daegu Metropolitan City. 2016. Available online: http://www.daegu.go.kr/cmsh/daegu.go.kr/build/file/2025Urban_renewal_report.pdf (accessed on 5 November 2017).
28. Daegu Metropolitan City. Available online: http://info.daegu.go.kr/newshome/mtnmain.php?mtnkey=articleview&mkey=scatelist&mkey2=26&aid=185036 (accessed on 1 October 2017).
29. The Hankyoreh. Available online: http://www.hani.co.kr/arti/economy/economy_general/608054.html (accessed on 1 October 2017).
30. Yin, R.K. *Case Study Research: Design and Methods*, 2nd ed.; Sage Publications: New York, NY, USA, 1994.
31. Merriam, S.B. *Qualitative Research and Case Study Application in Education*; Jossey-Bass: San Francisco, CA, USA, 1998.
32. Punch, K. *Introduction to Social Research: Quantitative and Qualitative Approaches*; Sage: London, UK, 1998.
33. Glaser, B.G.; Strauss, A.L. *The Discovery of Grounded Theory*; Aldine: Chicago, IL, USA, 1967.
34. Werner, O.J.; Schoepfle, G.M. *Systematic Fieldwork: Ethnographic Analysis and Data Management*; Sage Publications: New York, NY, USA, 1987; Volume 2.
35. Saito, J. *Publicness*; Iwanami Shoten: Tokyo, Japan, 2000.
36. Holcombe, R.G. *Public Sector Economics: The Role of Government in the American Economy*; Pearson Prentice Hall: Upper Saddle River, NJ, USA, 2006.
37. Hardin, G. The tragedy of the commons. *Science* **1968**, *162*, 1243–1248. [CrossRef] [PubMed]
38. Hobbes, T. *Leviathan*; A & C Black: London, UK, 2006.
39. Rose, C. The comedy of the commons: Custom, commerce, and inherently public property. *Univ. Chic. Law Rev.* **1986**, *53*, 711–781. [CrossRef]
40. Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action*; Cambridge University Press: Cambridge, UK, 1990.

41. Ostrom, E. *Crafting Institutions for Self-Governing Irrigation Systems*; ICS Press: San Francisco, CA, USA, 1991.
42. Eisenstadt, S.N.; Roniger, L. *Patrons, Clients and Friends: Interpersonal Relations and the Structure of Trust in Society*; Cambridge University Press: New York, NY, USA, 1984; pp. 48–49.
43. Drake, L.; Lawson, L.J. Validating verdancy or vacancy? The relationship of community gardens and vacant lands in the US. *Cities* **2014**, *40*, 133–142. [CrossRef]
44. Lawson, L.J. *City Bountiful: A Century of Community Gardening in America*; University of California Press: Berkeley, CA, USA, 2005.
45. Dempsey, N.; Burton, M. Defining place-keeping: The long-term management of public spaces. *Urban For. Urban Green.* **2012**, *11*, 11–20. [CrossRef]
46. Mayhew, M.G.; Ashkanasy, N.M.; Bramble, T.; Gardner, J. A study of the antecedents and consequences of psychological ownership in organizational settings. *J. Soc. Psychol.* **2007**, *147*, 477–500. [CrossRef] [PubMed]

sustainability

MDPI

Review

Disease Diagnosis in Smart Healthcare: Innovation, Technologies and Applications

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Abstract: To promote sustainable development, the smart city implies a global vision that merges artificial intelligence, big data, decision making, information and communication technology (ICT), and the internet-of-things (IoT). The ageing issue is an aspect that researchers, companies and government should devote efforts in developing smart healthcare innovative technology and applications. In this paper, the topic of disease diagnosis in smart healthcare is reviewed. Typical emerging optimization algorithms and machine learning algorithms are summarized. Evolutionary optimization, stochastic optimization and combinatorial optimization are covered. Owning to the fact that there are plenty of applications in healthcare, four applications in the field of diseases diagnosis (which also list in the top 10 causes of global death in 2015), namely cardiovascular diseases, diabetes mellitus, Alzheimer's disease and other forms of dementia, and tuberculosis, are considered. In addition, challenges in the deployment of disease diagnosis in healthcare have been discussed.

Keywords: automation; computational intelligence; data analysis; data mining; disease diagnosis; healthcare; smart living; smart city; social progress; sustainability

1. Introduction

There are different definitions and interpretations of a "smart city". In the research area, the smart city is viewed as having characteristics such as: (i) adopting information and communication technology (ICT) to solve the daily life problems in governance, environment, economy, healthcare, etc.; (ii) improving the quality of life of human beings; (iii) using computational intelligence to address real-world issues by mathematical formulations and machine learning algorithms; and (iv) distributing the workload to computers, robots and machines [1].

Human health is wealth; there is nothing more valuable than good health. Researchers have devoted vast efforts in proposing new policies, algorithms, systems and architectures for healthcare. Healthcare is defined as the amelioration of health through the prevention, treatment and examination of physical damage, mental damage, illness, injury and disease.

Today's world is experiencing three challenges in healthcare: shortage of medical personnel, ageing and high total expenditure on healthcare. Reports from the World Health Organization (WHO) stated that the global need and the factual amount of health workforce were 60.4 million and 43 million, respectively, in 2013 [2]. These figures will increase to 81.8 million and 67.3 million, respectively, by 2030. Therefore, the shortage of medical personnel is unsolved and remains serious.

From 2000 to 2050, the percentage of world population over 60 years will double (from 11% to 22%) [3]. One of the major reasons is that the birth rate has remained low in past and it is estimated to keep low in the coming decades. The older the person, the higher is the chance of getting diseases, illnesses and requiring long-term caring and medical treatments. Consequently, more human resources and expenditures should be allocated to the age group of 60 or above.

The total expenditure on healthcare has occupied a significant portion as a percentage of the gross domestic product (GDP). The survey from WHO concluded that the corresponding figures in China, U.S.A., Canada, Brazil, Russian Federation, India, and Australia are 5.6%, 17.1%, 10.5%, 8.3%, 7.1%, 4.7%, and 9.4%, respectively [4]. Attributed to ageing, these figures will be increased in the coming decades.

It is good news that, with the rapid increase in computation power and availability of health data, healthcare applications can include artificial intelligence and thus become smart healthcare. This can certainly help solving some of the aforementioned challenges in healthcare. In addition, it will facilitate sustainable development [5–7]. Healthcare sustainability aims at simultaneously optimizing the financial and social impacts of the health service, without compromising the health of our patients and our ability to provide healthcare in the future. In fact, the inadequate amounts of medical personnel and increase portion of elderly increase government expenditure and lower the social productivity.

Optimization algorithms and machine learning algorithms are core tools that can benefit healthcare applications. Three kinds of optimization algorithms, evolutionary [8–17], stochastic [18–29] and combinatorial optimization [30–38] will be addressed. For machine learning algorithms, the discussion is based on un-supervised learning [39–49], supervised learning [50–70] and semi-supervised learning [71–81]. The technical content in terms of mathematical formulation of these algorithms will not be discussed in this review, but it will illustrate examples to reveal the potential opportunities between optimization/machine learning algorithms and healthcare application.

Due to the multitude of smart healthcare applications, only four applications in the field of diseases diagnosis, cardiovascular diseases [82–99], diabetes mellitus [100–112], Alzheimer's disease and other forms of dementias [113–126], and tuberculosis [127–140] are considered. These are listed on the top 10 causes of annual global death. The applications of various disease diagnosis in smart healthcare are related to automated decision making. If the performance of the classification algorithm is good in terms of overall accuracy and testing time, it may ultimately replace the role of medical doctors in disease diagnosis (and medical doctors can devote their time majorly in complicated surgery). The second case is that the classification algorithm will be utilized as rapid test (fair overall accuracy and rapid decision) for low-cost and large-scale screening.

This paper is organized as follows. Section 2 discusses the emerging optimization algorithms and machine learning algorithms in healthcare. Section 3 provides an up-to-date literature on seven key applications. Finally, a conclusion is drawn.

2. Emerging Optimization Algorithms and Machine Learning Algorithms

When it comes to mathematical or engineering problems, optimization algorithms play an important role because people desire to select the best solution (generally better solution) among plenty of possible solutions based on some criteria. The difficulty of the optimization problem depends on its nature and complexity. Solving convex optimization problems is generally less difficult than non-convex problems because the local minimum must be a global solution and thus first-order conditions are optimally sufficient conditions [141]. Multiobjective optimization problems (that often have multiple conflicting objectives) are more complex than single objective optimization problem.

A tradeoff solution or near optimal solution is sometimes being selected when the global optimal solution is undetermined or requires huge computation power.

The overview of the algorithms and their applications in smart healthcare is provided in the following subsections.

2.1. Optimization Algorithms

There are many types of optimization algorithms, for instance evolutionary optimization, stochastic optimization, and combinatorial optimization. It is worth mentioning that an algorithm can be a mixture of different types of optimization algorithms, depending on their nature and the formulation of the problem. Readers interested in other optimization techniques are encouraged to consult Bellman [142] for dynamic programming, Bertsekas [143] for gradient method, and Glover et al. [144] for metaheuristics.

2.1.1. Evolutionary Optimization

Biological evolution is the inspiration of evolutionary optimization, also known as evolutionary computation. The first idea of evolutionary computation was proposed in the 1950s [8,9]. Biologically, there are many solutions for the population which is subjected to natural selection, breeding and mutation. The population evolves in a way that leads to an increase of its suitability to the environment (in the computational environment, the fitness function is used to measure this suitability). Computationally, a set of candidate solutions is initialized and updated iteratively. For new iterations (also known as generations), the less desired solutions will be removed according to the fitness values. The effectiveness of evolutionary algorithms can be examined by the convergence analysis.

The classical steps for evolutionary algorithms have been summarized in [10] and are as follows: (i) a population of candidate solutions is initialized, and each solution is encoded using alphabet of cardinality; (ii) each solution is evaluated with a fitness value; (iii) new solutions are generated by altering the existing solutions; (iv) each new solution is evaluated with a fitness value and inserted into the population; (v) replace the solutions of population with new solutions; and (vi) return to (iii) until reaching the maximum allowable time.

A problem solved by an evolutionary algorithm can be either single objective or multiobjective. Multiobjective optimization deals with optimization problems involving more than one objective function [12]. In this situation, the objective functions are conflicting. Thus, there exists many (could be infinite) Pareto optimal solutions. If none of the objective functions can be enhanced in value without scarifying other objective values, the solution is named non-dominated Pareto optimal solution.

For healthcare facility location-allocation in smart city (Hong Kong as an example) [13], four objectives were considered: (i) maximization of the population accessibility; (ii) minimization of the inequity of accessibility; (iii) minimization of the number of people beyond the threshold of travel distance; and (iv) minimization of the cost of setting up any new public healthcare facility. The problem is solved by a genetic algorithm (GA) modified to deal with multiple objectives. The cost of the mean solution is 1.7050×10^6, the population out of coverage is reduced from 3.4413×10^6 to 3.1866×10^6, the total accessibility is increased from 2.9633×10^7 to 5.8485×10^7 and inequity of accessibility is reduced from 3.5915×10^6 to 3.1768×10^6.

Another GA based multiobjective optimization problem was formulated in partitioning the healthcare system in Brazil [145]. Minimization of inter-microregion traveling, maximization of population homogeneity and medical procedures are defined as objectives. The improvements in the three objectives are 7.1% (2211×10^8 versus 2380×10^8), 23.5% (76,101 versus 99,537) and 7.8% (1773 versus 1644), respectively.

Emergency services are critical for saving lives and, consequently, a modified artificial bee colony algorithm was applied to solve the multiobjective optimization problem of emergency medical resources allocation [14]. It was important to optimization both the distances between patients and first-aid institutions and available resources requirement.

GA and differential evolution (DE) were employed to deal with the multiobjective optimization for the design of rectangular façade in common space of healthcare building [15]. The objectives were: (i) minimizing the cost of façade construction; and (ii) maximizing the daylight performance. Results indicated that GA achieved better performance in terms of convergence and hyper-volume, whereas DE provided wider range of optimal solutions.

A home healthcare scheduling multiobjective optimization problem was considered to improve the patients' satisfaction [16]. Again, GA was utilized to solve the multiobjective optimization with objectives travel cost, service cost and penalty cost. It was highlighted that home healthcare could reduce the chances for patients' admission to hospitals due to non-emergency healthcare issues and thus relieved the workload of medical personnel.

A multiobjective optimization was illustrated in the healthcare facility planning of location-allocation problem via particle swarm optimization [17]. The conflicting objectives are defined as minimization of travelled distance taken from service seekers outside the facility coverage area and maximization of the demand coverage.

2.1.2. Stochastic Optimization

There are many optimization problems that contain varying parameters, for instance, cost factor, demand parameter and noise factor. These kinds of parameters should be modeled in the form of random variables attributable to stochastic uncertainties. Trivial solutions include: (i) applying parameter estimation to replace the unknown parameters (nevertheless, the performance of the system is lowered); and (ii) online input correction of the system (this is generally time-consuming and has increased costs) [18]. Stochastic optimization via introduction of stochastic parameters into the optimization problem is a way out.

A summary of many techniques for stochastic optimization (for example, procedures of iterative solution, approximate problem, stochastic approximation, stochastic gradient, non-convex optimization, Laplace expansion of integrals, first order reliability method, regression and response surface method, and Taylor expansion) is presented in [19].

Attributed to random parameters variation, the optimal solutions are insensitive and thus a suitable deterministic substitute problem should be formulated. It is often found that the problem is related to probability of success, probability of failure, or expectation. This results in a non-convex optimization problem which is handled by approximation. There are two not uncommon categories of deterministic substitute problems: (i) expected total cost minimization [19–21]; and (ii) reliability-based optimization [22–24].

Recovery beds and operating rooms scheduling was formulated as a stochastic optimization problem [25]. The randomness was from capacity of resources and undetermined in the duration of surgery and recovery. For the objectives, authors have focused on the assignment and plan of surgery and recovery respectively. An orthopedic surgery department was chosen as simulation environment.

Radiotherapy is often used as a treatment to kill or control malignant cells offered to cancer patients. In [26], the management of facility in radiotherapy has been improved by introducing stochastic optimization on the waiting time before the first treatment and its duration. The uncertainty in this problem was defined as the arrival of patients and this follows a Poisson distribution.

Nurse scheduling problem has remained a great concern. A recent sample average approximation based stochastic optimization algorithm was proposed to find the optimal solution in minimizing the assignment cost [27]. There was randomness in the nurse preferences, medical demand and hospitalization.

An excellent management is always sought for in emergency department which specializes in acute care and emergency medicine. Sample average approximation was also employed to optimize the expected waiting time of acute care patients and shift scheduling [28]. The simulation analysis has assumed that the patient arrivals into the emergency department obey inhomogeneous Poisson distribution.

Patient scheduling has been optimally designed by minimizing the completion time of medical treatments and waiting time of patients [29]. Since the service sequences and times are heterogeneous and stochastic, respectively, it increases the complexity of the optimization problem. The Multiobjective Tabu Search (MOTS) method was employed.

2.1.3. Combinatorial Optimization

Many real-world optimization problems are found to be exhaustive where the solution space is composed of multiple solutions. Examples of such type of problems that are solved using combinatorial optimization are minimum spanning tree problem [30] and travelling salesman problem [31]. The solvers aim at finding optimal solution from a finite set of solutions. The feasible solution should be reduced to discrete.

In general, combinatorial optimization problems can be solved by polynomial time algorithms which have the running time bounded by a polynomial expression in the size of the input. Examples include maximum matching in graph, arithmetic operations and selection sort sorting algorithm.

When it comes to public hospitals, the different surgeries taking place in an operating room can be classified into: emergency, urgent and elective [32]. The corresponding waiting times for surgery are immediate, up to a week or up to a few years. It is stressful and frustrated to wait for surgery, especially for those who are classified as elective surgery patients. A combinatorial optimization problem was formulated to solve the objectives of minimizing the number of patients waiting for elective surgery and its cost, and it was solved using genetic algorithm [33].

In private healthcare industries or hospitals, the providers can charge significant differences in price for the identical medical treatment. A report showed that, in United States, the price for an appendectomy was between USD 1529 and USD 182,955 [34]. It is not always true that the quality of service increases with the price and, therefore, in [35], a combinatorial optimization problem was formulated to minimize the patient's cost and maximize the providers' quality.

Another problem is represented by home hospice care scheduling and staffing. It was analyzed in [36] and it was concluded that there should be a balance between quality of hospice care and available manpower. Therefore, the problem was formulated as maximization of the number of patients serviced by medical personnel, while fulfilling the need of the patients.

Attention was drawn to the optimal plan for non-coplanar intensity modulated radiotherapy [37]. It could be characterized by three steps (i) iterative beam selection of solutions (i.e., non-coplanar beam directions); (ii) finding beam trajectory via combinatorial optimization; and (iii) obtaining the optimal non-coplanar intensity modulated radiotherapy plan.

Home care scheduling could be considered as a hierarchical based combinatorial optimization problem [38]. An optimal route with minimal travelled distance was required between staffs offered by medical service companies and patients at home. This is similar to the multiple traveling salesman problem.

2.2. Machine Learning Algorithms

The term machine learning has a long history [146]. Its definition is as follows: the field of study that gives computers the ability to learn without being explicitly programmed. Many real-world problems can be modeled by machine learning algorithms. Some examples are: classification, regression, clustering, dimensionality reduction, structured prediction, face detection, decision making, speech recognition, signal de-noising, anomaly detection, deep learning and reinforcement learning.

Machine learning can be categorized into four types (i) un-supervised learning; (ii) supervised learning; (iii) semi-supervised learning; and (iv) reinforcement learning. Fundamentally, none of the data is labeled in type (i), the training/testing samples are labeled in type (ii) and there are many unlabeled data and few labeled data in type (iii). The comparison of the first three aspects is illustrated in Figure 1.

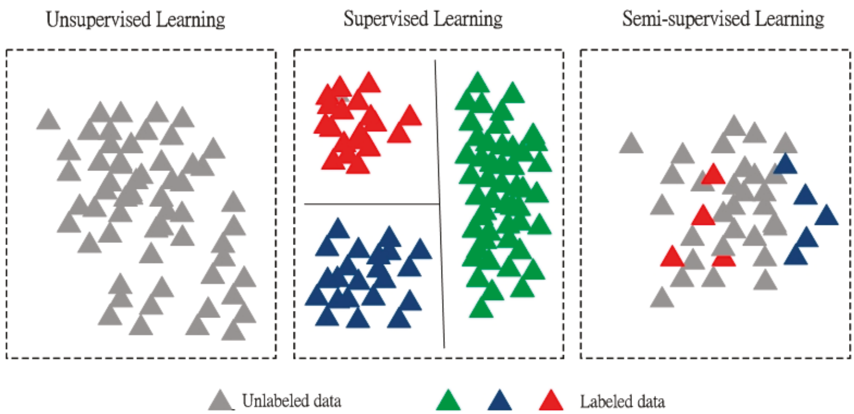

Figure 1. Types of machine learning algorithm: Unsupervised, supervised and semi-supervised.

The challenge that people are confronted with is handling massive amounts of data generated by every entity in the world. Take the Internet as an example, over a billion of people are connected to the Internet every day. As a result, these people generate tremendous data. Appropriate utilization of data is valuable in terms of price and knowledge [147,148]. What we call data should make sense to proceed any further with intelligent data analysis. More important, the limited computational power of personal computer (even supercomputer) cannot solve all real-world problems. Data analytics should remove and neglect some of the data to enjoy a finite and reasonable computation time. In addition, efforts are majorly devoted to the more influencing applications to the society: healthcare, energy crisis, education, food security, overfishing, environmental pollution, migration crisis, urbanization, and water security.

2.2.1. Un-Supervised Learning

In reality, there exist many unlabeled data which can be intentional missing label or unintentional missing label. The former data are usually labeled initially; one may remove the label and formulate the problem as relation or correlation analysis between samples. The reasons for latter data are two-fold. First, the staff may forget to enter the label by mistake. Second, it is possible that the data owner company does not believe that the data are useful so that data collection managing is neglected.

Un-supervised learning deals with the problem of design of model to narrate the hidden pattern and relationship of unlabeled data using machine learning algorithms. Typical methods for unsupervised learning are un-supervised clustering and un-supervised anomaly detection.

Un-supervised clustering aims to organize similar unlabeled data into groups named clusters. Therefore, the data within the same cluster have similar characteristic and are dissimilar to data in other clusters. There are three basic techniques for clustering, proximity measure (similarity or dissimilarity measure), criterion function for clustering evaluation, and algorithms for clustering. It can be further divided into hierarchical clustering (divisive or agglomerative) [39], partitional clustering (centroid, model based, graph theoretic, or spectral) [40] and Bayesian clustering (decision based or non-parametric) [41].

It is curious if it is possible to influence the culture of staff of intensive care unit department to improve the patient satisfactory and safety. Unsupervised clustering was performed to analyze the usual patterns among staff [42]. Results have concluded that we can recognize and group the influencers in developing intervention to alter the culture.

Hidden infectious diseases are frightful because medical experts are generally not familiar with their features. As a result, effective and reliable medical treatments are seldom available and further research studies are necessary. A recent study aimed at identifying hidden infectious diseases based on data retrieved from unlabeled social media messages [43].

Un-supervised anomaly detection is defined as the recognition of outliers, noise, deviations, exceptions or novelties which comply with the majority of the unlabeled data. In healthcare, medical errors [44], healthcare sensor faults [45], healthcare monitoring system [46], abnormal ECG signal [47], anomalous behavior signs [48] and clinical pathway [49] are examples of anomaly detection. The categories for anomalies are: (i) collective anomalies, a group of data points collectively facilitates the anomaly detection; (ii) contextual anomalies, it is context specific, normally in the form of time-series; and (iii) point anomalies, one instance is anomalous.

2.2.2. Supervised Learning

In machine learning, due to its application in classification and regression, a larger group of researchers focused on supervised learning. The datasets contain individual paired data which have input and output values. Generally, algorithms are selected to create inner relations based on the training data and to generalize unseen data.

There are five general steps for supervised learning model: (i) data collection of training and testing datasets; (ii) feature extraction; (iii) selection of machine learning algorithm; (iv) model construction using the selected algorithm; and (v) algorithm evaluation and comparison to other algorithms.

There exist packages for supervised learning in various programming languages such as MATLAB, Java, C++, and Python which provide build-in functions. Because there are numerous practical challenges, they cannot be simply treated as black-box (simply enter the input features). Some of the difficulties are: large dimensionality of feature vectors [50], bias/variance dilemma [51], input and output noise [52], large-scale training data [53], data heterogeneity [54], data redundancy [55] and non-linearity among features [56].

Applications include but are not limited to prediction of virus-host infectious association [57], human pose detection [58], virtual screening for hyperuricemia [59], speech recognition for remote healthcare [60] and biomedical information retrieval [61]. Some commonly used classification algorithms are nearest neighbors [62], discriminant analysis [63], decision trees [64], naïve Bayes classifier [65], neural network [66] and support vector machine [67]. For regression algorithms, typical examples are support vector regression [68], neural network [66], generalized linear models [69] and linear and non-linear regression [70].

Authors would like to give more elaboration on support vector machine and deep neural network which are believed to be more famous in supervised machine learning.

Many learning algorithms based on non-linear kernels require a kernel function $K(x_i,x_j)$ well defined for all pairs of x_i and x_j. However, the computation times will be significantly increased when predicting the class for new data points. Thus, support vector machine (SVM) becomes more and more popular which offers sparse solutions, the predictions for new data points depend only on the kernel function evaluated at a subset of training data. Another characteristic of SVM is that it deals with convex optimization problem so that any local solution is a global optimal solution. To solve the convex optimization problem, the technique of Lagrange multipliers is adopted. Readers who are not familiar with this are highly encouraged to review the concept in [149].

The recent deep neural network learning application Google DeepMind's AlphaGo is in the limelight [150]. Machine learning, which is popular worldwide, is defined as computers able to learn from data to perform tasks such as prediction, clustering, classification, decision making and dimensionality reduction. Compared with the human beings, computers are superior in computation power and can handle many complex problems. It is noted that the complete theoretical development of the algorithms is out of scope of this paper. Generally speaking, deep neural network is an artificial neural network with multiple hidden layers between input layers and output layers. It is trivial that it is more prone to overfitting and more time-consuming for training. However, it takes more advantages when handling complex problems with large dataset [151].

2.2.3. Semi-Supervised Learning

Semi-supervised learning is relatively young compared to supervised and un-supervised learning. Chances are that there are many unlabeled data but only few labeled data are available. This is the reason for the name semi-supervised as it lies between supervised learning (pairwise labeled inputs and outputs) and un-supervised learning (completely unlabeled data). Nevertheless, it is time consuming and costly to change unlabeled data into labeled data. For instance, web-based health-related questions are seldom being answered by users [71], providing that community-based question answering sites are important to address health information needs.

Here are the typical learning strategies of semi-supervised learning [72]. First, a supervised learning algorithm that sets some learning rules for labeled data is selected. Then, the rules are modified to include unlabeled data. The robustness of such approach depends on the reliability of labeling, i.e., it has poor robustness if it has severe labeling error.

When constructing semi-supervised learning models, at least one of the following assumptions is made: (i) Smoothness assumption is a concept that samples (in the forms of feature vector) which are close to each other have a higher opportunity have the same output label as they share similar characteristic in feature space [73]; (ii) The cluster assumption claims that the datasets have a tendency to form clusters where samples in the same clusters have higher chance to be the same output label [74]; and (iii) Similar to the first assumption, but referring to clustering, manifold assumption means that data lie on a low-dimensional manifold embedded in a higher-dimensional space [75]. It is noted that manifold is a topological space that locally resembles Euclidean space near each point.

Many existing approaches for semi-supervised learning have been discussed. Typical examples are graph-based model [76], self-training [77], co-training [78], generative model [79], low-density separation [80], and heuristic model [81].

2.2.4. Reinforcement Learning

Reinforcement learning is related to agents trying to maximize the total reward under interaction with uncertain and complex environment [152]. In the field of control and operation research, it is also named approximate dynamic programming [153]. Differed from standard supervised learning, reinforcement learning does not possess correct input/output pairs and sub-optimal actions.

Basically, two strategies are commonly used to solve reinforcement learning problems [154]. First, researchers aim at finding a good behavior in the environment via searching the space of behaviors. Second, estimation of the utility of taking actions in states of the world is considered with aid of dynamic programming and statistical techniques.

The lifelong function of dynamic treatment regimes was estimated using reinforcement learning [155]. Testing datasets were retrieved from about 6000 patients of Acute Myeloid Leukemia. The algorithm comprised of deep neural network and deep Q-learning which aimed at handling heterogeneous high dimensional actions and states in practical problems.

A multi-agent system was proposed for continuous patient monitoring for improvement in overall user (with poor motor skills or vision) experience [156]. To learn the behavior of user, the reinforcement learning tracked the errors in the interface use and the actions of users. It is noted that behavior consists of statistical interactions with the graphical user interface, whereas the action consists of user preferences and choices.

A reinforcement learning based neuroprosthesis controller was trained to evaluate target-oriented task performed using planar musculoskeletal human arm [157]. The results reflected that human rewards are effective measures to train the controller.

When it comes to mobile health applications, medical video streaming via adaptive rate control algorithm was studied [158]. Reinforcement learning was applied to fulfill the requirement of high quality of service. The end-to-end delay was lower than the minimum requirement of 350 ms and image quality was improved by 2.5 dB.

3. Smart Healthcare Applications

Since there are numerous applications in smart healthcare, this review only focuses on disease diagnosis. Cardiovascular diseases, diabetes mellitus, Alzheimer's disease and other forms of dementia and tuberculosis are on the list of top 10 causes of annual global death in 2015. Table 1 summarizes the mortality due to these diseases in 2000, 2005, 2010 and 2015 [159]. It can be seen that the first three types of diseases increase, whereas the tuberculosis decreases from 2000 to 2015. The percentage changes in 2000–2005, 2005–2010 and 2010–2015 in each type of disease are6.7%, 8.03%, and 6.4%; 19.9%, 17.7%, and 17.8%; 29.9%, 36.1%, and 33.7%; and −5.58%, −10.6%, and −2.34%, respectively. These diseases led to more than 22 million deaths in 2015.

Table 1. Mortality due to cardiovascular diseases, diabetes mellitus, Alzheimer's disease and other forms of dementia, and tuberculosis in 2000, 2005, 2010 and 2015.

Disease	Deaths ('000) in Particular Year			
	2000	2005	2010	2015
Cardiovascular diseases	14,375	15,338	16,570	17,631
Diabetes mellitus	945	1133	1333	1570
Alzheimer's disease and other forms of dementia	649	843	1147	1534
Tuberculosis	1666	1573	1406	1373

The optimization algorithms and machine learning approaches that have been utilized for smart healthcare covering the diseases from Table 1 will be discussed in the following subsections.

3.1. Cardiovascular Diseases

Cardiovascular diseases are a group of disorders involving heart and blood vessels. Some common conditions include atherosclerosis and may even result in stroke. Most of the risk factors of cardiovascular diseases are related to human lifestyle and the corresponding percentages of factors attributable to mortality are as follows: 40.6% for high blood pressure; 13.7% for smoking; 13.2% for poor diet; 11.9% for insufficient physical activity; 8.8% for abnormal glucose levels; and the rest for other factors [82]. Therefore, improving the eating habit and lifestyle is an effective measure for preventing cardiovascular disease. The main principle of healthy lifestyle includes low-salt and low-fat diet, regular exercising and quitting smoking [83].

Stroke is one kind of cardiovascular disease. A stroke will happen when there is an interruption of the blood supply to brain. The common causes will be burst blood vessels in brain or a blockage by a clot. This in turn cuts off the supply of oxygen and nutrients to brain cell, and causes damages to the brain tissue. Hypertension is the most notable risk factor of stroke [84] and thus having a good management of blood pressure will be a preventive measure of stoke.

The key priority for effective primary stroke prevention should be focusing on behavioral and lifestyle risk factors, including smoking, unhealthy diet, sedentary lifestyle, and improper use of alcohol [85]. Other than diet modification, engaging in physical activity for at least 30 min every day will help to prevent stroke [86].

The surface electrocardiogram (ECG) is the most widely adopted means to record electrical activity of the heart and for diagnosis of cardiovascular diseases [87]. Besides, ECG can be used for risk stratification and selection of optimal management for different types of cardiovascular diseases. An alternative method, vectorcardiography is rarely used in clinical practice [88].

In [89], it was concluded that there are three types of features namely fiducial features (FF), non-fiducial features (NFF) and hybrid features (HF). FF is defined as any feature that is related to the characteristic points (P wave, QRS complex and T wave) of ECG signal, whereas NFF is the opposite of

FF. For HF, it has both FF and NFF. Table 2 shows some of the methodologies that have been proposed for cardiovascular diseases classification [90–94] or ECG recognition [95–99].

Table 2. Summary of related works on cardiovascular diseases classification or heartbeat classification.

Work	Diseases	Methodology	TF	N_s	Performance (%)		
					S_e	S_p	OA
[90]	HC + Ca + MI + Hy + Dy	LS; SVM	NFF	65	/	/	90.34
[91]	HC + Ca	RF; SVM	FF	221	87	92	94
[92]	HC + CHF	CART	FF	41	93.3	63.6	/
[93]	HC + CHF + VT + AF	FL; GA	NFF	300	/	/	93.34
[94]	HC + CA + MI	KNN	NFF	207	99.7	98.5	98.5
[95]	HB	SKF; SVM	HF	48	/	/	98.3
[96]	HB	NN	FF	17	/	/	95
[97]	HB	CNN	NFF	47	96.71	91.64	93.47
[98]	HB	NN; SVM	NFF	48	98.91	97.85	98.91
[99]	HB	FCM	FF	48	/	/	81.21

AF = atrial fibrillation; Ca = cardiomyopathy; CART = classification and regression tree; CHF = congestive heart failure; CNN = convolutional neural network; Dy = dysrhythmia; FCM = fuzzy c-means clustering; FL = fuzzy logic; GA = genetic algorithm; HB = heartbeat; HC = healthy control; Hy = Hypertrophy; KNN = K-nearest neighbor; LS = least-square; MI = myocardial infarction; NN = neural network; N_s = sample size; OA = overall accuracy; RF = random forest; S_e = sensitivity; SKF = switching Kalman filter; S_p = specificity; SVM = support vector machine; TF = type of features; VT = ventricular tachyarrhtthmia.

Eleven machine learning or optimization algorithms have been applied in [90–99]. Different algorithms may have their superiorities in particular application. The number of patients, N_s, is very small compared to the number of cardiovascular diseases sufferers (more than 10 million). However, it is difficult for researcher to tackle the problem of small sample size because the datasets are generally retrieved from public domain (hospitals). It depends on the willingness of the policy of government that the data from patients can be fully disclosed to public. The performances are good (>90%) in most of the works, except [92,99].

3.2. Diabetes Mellitus

Diabetes mellitus, or simply called diabetes, is one of the serious epidemic diseases in the world. Over 400 million people are living with diabetes [100]. It is expected that by 2035, the total number of adults with diabetes would increase to 592 million [101]. Its subsequent macrovascular complications could be fetal. Enormous financial burden is putting on diabetes related area. Many patients have to rely on medication in their lifetimes to control diabetes.

There are two types of diabetes, insulin-dependent diabetes (or type 1 diabetes) and noninsulin-dependent diabetes (or type 2). Generally speaking, most diabetes cases belong to type 2 as it is often onset in adulthood and caused by unhealthy lifestyle, improper diet and obesity [102]. These factors then cause a combined defect of insulin secretion and insulin resistance resulting in different severity of diabetes.

Recently, there are many studies in diabetes mellitus via machine learning algorithms. The applications are summarized in Table 3. The applications on diabetes are type 2 diabetes diagnosis [103–105], prediction of fasting plasma glucose status [106], analysis of predictive power of hypertriglyceridemic waist phenotype [107], detection of hypoglycemic episodes in children [108], prediction of protein–protein interaction [109], prediction of vascular occlusion [110], prediction of development of liver cancer for diabetes sufferers [111] and detection of microalbuminuria [112] related to diabetes.

Table 3. Summary of related works on machine learning applications in diabetes mellitus.

Work	Applications	Methodology	N_s	Performance
[103]	Diagnosis of type 2 diabetes	RF; SVM	7913	Precision: 94.2%; Recall: 93.97%
[104]	Diagnosis of type 2 diabetes	DT; KNN; NBC LR; RF; SVM	300	average AUC = 98%
[105]	Diagnosis of type 2 diabetes	ACO; FL	768	Accuracy = 84.24%
[106]	Predicting of fasting plasma glucose status	LR; NBC	4870	AUC (Female): 0.74; (Male): 0.68
[107]	Analysis of predictive power of hypertriglyceridemic waist phenotype for type 2 diabetes	LR; NBC	11,937	waist-to-hip ratio + triglyceride (men): AUC = 0.653; rib-to-hip ratio + triglyceride (women): AUC = 0.73
[108]	Detection of hypoglycemic episodes for type 1 diabetes children	NN	16	Sensitivity = 78%; Specificity = 60%
[109]	Prediction of type 2 diabetes related proteins	SVM	1296	Accuracy = 78.2%
[110]	Prediction of peripheral vascular occlusion in type 2‘diabetes	SVM; WPS	33	Accuracy = 100%
[111]	Predicting the development of liver cancer in type 2 diabetes	LR; NN	2060	Sensitivity = 75.7%; Specificity = 75.5%
[112]	Detection microalbuminuria in type 2 diabetes	FL; LR; PSO	200	Sensitivity = 95%; Specificity = 85%; Accuracy = 92%

ACO = ant colony optimization; AUC = area under the curve; DT = decision tree; FL = fuzzy logic; KNN = k-nearest neighbor; LR = logistic regression; NBC = Naive Bayes classifier; NN = neural network; PSO = particle swarm optimization; RF = random forest; SVM = support vector machine; WPS = wolf pack search.

Similar to the cases in cardiovascular diseases (Table 2), there are 12 types of algorithms that have been utilized for diabetes mellitus. The number of samples has an increase tendency, which leads to more trustworthy results in evaluating the algorithms. It is still challenging (less than 80% in performance) in the fields of prediction of fasting plasma glucose status, analysis of predictive power of hypertriglyceridemic waist phenotype, detection of hypoglycemic episodes in children, prediction of protein–protein interaction and prediction of development of liver cancer for diabetes sufferers.

3.3. Alzheimer's Disease and Other Forms of Dementia

Dementia is a general term describing the decline in mental ability including memory and thinking skills that affect the human daily living activities. Dementia is resulted from damages of brain cells making them unable to communicate with each other [113]. Alzheimer's disease is the most common form of dementia, making around 60–80% of all cases. Some Alzheimer's disease patients in final stages may have lost basic bodily functions, including swallowing and moving their limbs. They will need around-the-clock care and this puts a huge financial burden on the medical system and social welfare department of government.

The number of dementia cases increases with aging. This leads to a huge concern among healthcare professionals. Dementia, unlike other forms of chronic illness, has a higher prevalence in developed countries. It is a pandemic disease that affects people in different regions. Moreover, studies have found that people with metabolic syndromes like diabetes and obesity are at higher risk of Alzheimer's disease [114]. Therefore, Alzheimer's disease and dementia will be one of the most challenging non-communicable diseases to battle in this era.

Table 4 shows some studies in Alzheimer's disease and other forms of dementia via machine learning algorithms. The applications include diagnosis of Alzheimer's disease [115,116], diagnosis of dementias [117], and detection of Alzheimer's disease related regions [118], prediction of mild cognitive impairment patients for conversion to Alzheimer's disease [119,120], detection of dissociable multivariate morphological patterns [121], diagnosis of both Alzheimer's disease and mild cognitive impairment [122] and identification of genes related to Alzheimer's disease [125,126].

Table 4. Summary of related works on machine learning applications in Alzheimer's disease and other forms of dementias.

Work	Applications	Methodology	N_s	Performance
[115]	Diagnosis of Alzheimer's disease	NBC; RF; RLO; RS; SVM	27	Accuracy = 97.14%
[116]	Diagnosis of Alzheimer's disease	SVM	53	Accuracy = 96.23%
[117]	Diagnosis of dementias	LR; SVM	29	Accuracy = 93%
[118]	Detection of Alzheimer's disease related regions	SVM	126	Accuracy = 92.36%
[119]	Predicting mild cognitive impairment patients for conversion to Alzheimer's disease	LDS	164	AUC = 0.7661
[120]	Predicting mild cognitive impairment patients for conversion to Alzheimer's disease	GA; SVM	458	Sensitivity = 76.92%; Specificity = 73.23%; Accuracy = 75%
[121]	Identification of dissociable multivariate morphological patterns	LC	801	AUC = 0.93
[122]	Identification for Alzheimer's disease and mild cognitive impairment	EM; SVM	338	Alzheimer's disease: sensitivity = 84.86%, specificity = 91.69%, accuracy = 88.73%; Mild cognitive impairment: sensitivity = 79.07%, specificity = 82.7%, accuracy = 80.91%
[123]	Identification for Alzheimer's disease and mild cognitive impairment	DCNN	900	Alzheimer's disease: sensitivity = 98.89%, specificity = 97.78%, accuracy = 98.33%; Mild cognitive impairment: sensitivity = 92.23%, specificity = 91.11%, accuracy = 92.12%
[124]	Identification for Alzheimer's disease and mild cognitive impairment	DCNN	142	Alzheimer's disease: sensitivity = 85%, specificity = 82%, accuracy = 85%; Mild cognitive impairment: sensitivity = 84%, specificity = 81%, accuracy = 85%
[125]	Identification of genes related to Alzheimer's disease	DT; QAR	33	90 genes are related to Alzheimer's disease
[126]	Identification of genes related to Alzheimer's disease	ELM; RF; SVM	31	Sensitivity= 78.77%; Specificity= 83.1%; Accuracy = 74.67%

DCNN = deep convolutional neural network; DT = decision tree; ELM = extreme learning machine; EM = expectation maximization; GA = genetic algorithm; LC = lasso classification; LDS = low density separation; LR = logistic regression; NBC = Naive Bayes classifier; QAR = quantitative association rules; RF = random forest; RLO = random linear oracle; RS = random subspace; SVM = support vector machine.

Fourteen different algorithms were employed in [115–126]. The datasets of Alzheimer's disease and other forms of dementia have relatively small sample size. Three applications, prediction of mild cognitive impairment patients for conversion to Alzheimer's disease [119,120], prediction of mild cognitive impairment [122–124] and identification of genes related to Alzheimer's disease [125,126] are required to have further improvement3.4. Tuberculosis

Tuberculosis (TB) was a lethal infectious disease caused by bacteria mycobacterium tuberculosis that usually attacks the lung. The transmission way is mainly through the air, and thus TB is actively spread among the community. It was a public health concern in early 19th century. With the development of drugs and hygiene awareness, the incidence rate has declined slowly since the 1990s [127].

People in poor and undeveloped countries are more vulnerable to TB because of poor environmental conditions, food insecurity, and inconvenient access to healthcare services [127]. Early detection is important for TB control. Without proper diagnosis, infected people are the major source of infection in the community [128]. It is estimated that about 3 million people remain undiagnosed or are not notified [129].

Intensive research was carried out on prevention and fighting against TB [130]. TB control is crucial with effective surveillance system for instantaneous reporting. With the development of science and technology, it is hoped that TB would not be a major public health issue in next generation.

Smart healthcare applications on tuberculosis include identification of drug resistance-associated mutations [131], detection of tuberculosis [132–135], detection of multidrug resistance tuberculosis [136], prediction of treatment failure [137], identification between tuberculosis and human immunodeficiency virus (HIV) [138], predicting recent transmission of tuberculosis [139] and detection of smear-negative pulmonary tuberculosis [140]. These are summarized in Table 5. Similar findings can be observed in applications in tuberculosis. There are 12 types of algorithms in seven applications in tuberculosis and the sample sizes of datasets are limited. The performance of two of the works [133,139] can be improved in the future. Other algorithms can be applied to obtain a favorable performance (>90%).

Table 5. Summary of related works on machine learning applications in tuberculosis.

Work	Applications	Methodology	N_s	Performance
[131]	Identification of drug resistance-associated mutations in tuberculosis	LMM; LR; MOSS	144	Accuracy of over 90% in selected 9 drugs
[132]	Detection of tuberculosis	KNN; SVM	917; 869; 850	KNN: AUC = 0.84; 0.78; 0.82 SVM: AUC = 0.88; 0.79; 0.85
[133]	Detection of tuberculosis	CNN	4701	Accuracy = 62.07%
[134]	Detection of tuberculosis	CNN	138;662	Accuracy = 82.6%; 92.6% AUC = 84.7%; 92.6%
[135]	Detection of tuberculosis	SVM	150	Accuracy = 96.68%
[136]	Detection of multidrug resistance tuberculosis	NN	280	Sensitivity = 95.1%; Specificity = 85%
[137]	Prediction of tuberculosis treatment failure	Xpert; Response5	153	Sensitivity = 83–100%; Specificity = 26–100%
[138]	Identification between tuberculosis and HIV	Filtering	54	Accuracy = 79–93%
[139]	Predicting recent transmission of tuberculosis	LR	1552	Sensitivity = 53%; Specificity = 67%
[140]	Detection of smear-negative pulmonary tuberculosis	MLP	136	Sensitivity = 100%; Specificity = 80%; Accuracy = 88%; AUC = 91.8%

CNN = convolutional neural network; KNN = k-nearest neighbor; LMM = linear mixed model; LR = logistic regression; MLP = multilayer perception; MOSS = mode oriented stochastic search; NN = neural network; SVM = support vector machine.

4. Challenges in Smart Healthcare

For the transition of healthcare to smart healthcare, numerous challenges are normally encountered and research is still ongoing. In the following subsections, privacy, pilot studies and real project, communication between data scientist and medical personnel, no free lunch theorem and increase short-term to medium-term expenditure are discussed.

4.1. Privacy

Medical data contain meaningful information for modeling and analysis, which ultimately can improve medical practice and research. The privacy must be protected from misuse and violation so that patients and medical institutions will agree to release and share the data. The increase in the data availability will improve the quality of healthcare [160]. A report has stated that about 60% of patients realize that the wide-ranging employment of electronic health record will lead to more personal information being stolen or lost and about half of patients think that the privacy of medical data is not protected [161].

Ideally, medical data should be accessible to authorized parties or public institutions only if security and privacy are guaranteed. More important, researchers need medical data for carrying out data analysis, statistical analysis and machine learning applications. Common privacy-preserving methods include disclosure control [162,163], output perturbation [164,165] and anonymization [166,167].

It is hoped that, in the future, the shared datasets for medical applications (especially disease diagnosis) will be increased in sample size. The key elements will be medical data privacy and the government policies.

4.2. Pilot Studies and Real Projects

Since, in the long run, they reduce the risk of non-professional project deployment, pilot projects are important and they help to select the appropriate risk mitigation strategies and application directions. There is an increasing tendency to carry out pilot studies [168].

Professionals gain experience and intuition to improve the protocol design, algorithms, and hardware design of smart healthcare. However, in reality, only a few companies and researchers may take part in real projects in healthcare. Most researchers fail to learn from the experience since it is not uncommon that there are no timely publications, reports and feedbacks provided by the pilot projects. Usually, the projects are target-oriented [169]. However, chances are that there exist alternate solutions that are cost-effective which may replace the current solution.

It is highly encouraged that before the technology platforms are adopted, various algorithms and technologies that are tested and selected for adoption should be consolidated into technical reports and papers, and shared to the public.

Economically, it is desired that governments can support basic research and innovation [170]. Regarding the private sectors, they take up the responsible for the commercial and applied research since they are keen on market needs and demands.

For the selection of the policy tool, the features of basic research are essential. If there is a large-scale and highly focused project, conduct of research or direct government support is reliable to maintain a good project management with numerous researchers and staffs [171].

The effectiveness in research, innovation and development will be increased if government serves as long-term investor. The time lag between basic research and real deployment commercially can be large. Here are two examples for the benefit of long-term investment. The Internet revolution in the 1990s was the results of long-term investment covering twenty years [172]. The second example is that the biotechnology commercialization was facilitated by the research findings in the 1950s [173].

4.3. Communication between Data Scientists and Medical Personnel

Data scientists generally lack sufficient medical knowledge and they require medical experts. Similar situation happens for medical personnel. When data scientists would like to enter the medical institutions, medical personnel and management teams often refuse [174]. From the data scientists' perspective, medical data are useful for statistical analysis, prediction, classification and knowledge discovery. From medical personnel perspective, they are used to diagnose patients via their medical knowledge and rarely rely on the decision generated by machines.

Medical workers may argue that smart healthcare via machine learning and optimization algorithms has a conflict of interest with them; however, this is not the case [175]. First, most of the countries are suffering from a shortage of medical personnel and the medical shortage will become more accentuated. Second, smart healthcare is mainly targeting routine works so that medical workers can spend more time on professional consultation and surgery activities. Third, medical workers will earn a higher social status and better job satisfaction because patients are more satisfied with the medical services.

Both data scientists and medical personnel should make a step forward to see what the best collaboration method is. The ultimate goal is to improve the quality of life.

4.4. No-Free Lunch Theorem

However, it can be seen that there are numerous approaches in different machine learning application in smart healthcare. There is a "No free lunch" theorem in machine learning which says that no unique algorithm works best for every application [176]. As a result, when people design algorithm for smart healthcare application, the analysis becomes tedious as one should go through many algorithms and select the one with best performance. An important knowhow is to only try appropriate algorithms for the problem. For instance, clustering algorithms seem inappropriate in solving classification problems.

Deep learning has gained popularity in recent years, attributable to its superiority in solving complex problem. However, it is reminded that deep learning is not always the best or necessary for all problems. It depends on the complexity of the problem, available amount of data, computational power and training time [177].

4.5. Increase Short-Term to Medium-Term Expenditure

Authors would like to emphasis that owing to the fact that machine learning in smart healthcare is still young, government and institutions should spend more money as short-term to medium-term expenditure. Many applications are only in initial stage where data collection, feature extraction, and methodology are key criteria for successful deployment.

Ultimately, the smart healthcare applications will benefit human beings by increase of human life expectancy, early disease examination, ambient assisted living, patient monitoring, etc. As a result, we are in a sense making profit in the long-term using machine learning.

5. Conclusions

This review has provided an up-to-date literature on emerging machine learning algorithms, optimization algorithms and applications in smart healthcare. Important challenges, including privacy, pilot studies and real project and communication between data analytics and medical staffs, have been discussed. These challenges are essential for the breakthrough of smart healthcare; otherwise, the wide adoption of machine learning and optimization algorithms in real deployment is difficult to succeed. To conclude, it is believed that human beings will enjoy more and more smart healthcare applications in the coming decades. It is worth ensuring the health services are financially viable and environmentally sustainable to safeguard the future health of our patients and the health services availability in the future.

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References

1. Kondepudi, S.N.; Ramanarayanan, V.; Jain, A.; Singh, G.N.; Nitin Agarwal, N.K.; Kumar, R.; Singh, R.; Bergmark, P.; Hashitani, T.; Gemma, P.; et al. *Smart Sustainable Cities: An Analysis of Definitions*; International Telecommunication Union: Geneva, Switzerland, 2014.
2. Scheffler, R.; Cometto, G.; Tulenko, K.; Bruckner, T.; Liu, J.; Keuffel, E.L.; Preker, A.; Stilwell, B.; Brasileiro, J.; Campbell, J. *Health Workforce Requirements for Universal Health Coverage and the Sustainable Development Goals*; World Health Organization: Geneva, Switzerland, 2016.
3. Beard, J.; Ferguson, L.; Marmot, M.; Nash, P.; Phillips, D.; Staudinge, U.; Dua, T.; Saxena, S.; Ogawa, H.; Petersen, P.E.; et al. *World Report on Ageing and Health 2015*; World Health Organization: Geneva, Switzerland, 2015.

4. *Total Expenditure on Health as a Percentage of Gross Domestic product (US$)*; Global Health Observatory (GHO) Data; World Health Organization: Geneva, Switzerland, 2017. Available online: http://www.who.int/gho/health_financing/total_expenditure/en/ (accessed on 15 September 2017).
5. Du, G.; Sun, C. Location planning problem of service centers for sustainable home healthcare: Evidence from the empirical analysis of Shanghai. *Sustainability* **2015**, *7*, 15812–15832. [CrossRef]
6. Castro, M.D.F.; Mateus, R.; Serôdio, F.; Bragança, L. Development of benchmarks for operating costs and resources consumption to be used in healthcare building sustainability assessment methods. *Sustainability* **2015**, *7*, 13222–13248. [CrossRef]
7. Momete, D.C. Building a sustainable healthcare model: A cross-country analysis. *Sustainability* **2016**, *8*, 836. [CrossRef]
8. Friedman, G.J. Selective Feedback Computers for Engineering Synthesis and Nervous System Analogy. Master's Thesis, University of California, Los Angeles, CA, USA, 1956.
9. Friedberg, R.M. A Learning Machine: Part I. *IBM J. Res. Dev.* **1958**, *2*, 2–13. [CrossRef]
10. Fogel, D.B. *Evolutionary Computation: Toward a New Philosophy of Machine Intelligence*; Wiley-IEEE Press: Hoboken, NJ, USA, 2006.
11. Bäck, T. Selective Pressure in Evolutionary Algorithms: A Characterization of Selection Methods. In Proceedings of the First IEEE Conference on Evolutionary Computation, Orlando, FL, USA, 27–29 June 1994; IEEE Press: Piscataway, NJ, USA, 1994.
12. Deb, K. Multi-objective optimization. In *Search Methodologies*; Springer: Berlin, Germany, 2014; pp. 403–449.
13. Zhang, W.; Cao, K.; Liu, S.; Huang, B. A multi-objective optimization approach for health-care facility location-allocation problems in highly developed cities such as Hong Kong. *Comput. Environ. Urban Syst.* **2016**, *59*, 220–230. [CrossRef]
14. Wen, T.; Zhang, Z.; Qiu, M.; Wu, Q.; Li, C. A Multi-Objective Optimization Method for Emergency Medical Resources Allocation. *J. Med. Imaging Health Inform.* **2017**, *7*, 393–399. [CrossRef]
15. Karaman, S.; Ekici, B.; Cubukcuoglu, C.; Koyunbaba, B.K.; Kahraman, I. Design of rectangular façade modules through computational intelligence. In Proceedings of the 2017 IEEE Congress Evolutionary Computation (CEC), San Sebastián, Spain, 5–8 June 2017; IEEE Press: Piscataway, NJ, USA, 2017.
16. Du, G.; Liang, X.; Sun, C. Scheduling Optimization of Home Health Care Service Considering Patients' Priorities and Time Windows. *Sustainability* **2017**, *9*, 253. [CrossRef]
17. Elkady, S.K.; Abdelsalam, H.M. A modified multi-objective particle swarm optimisation algorithm for healthcare facility planning. *Int. J. Bus. Syst. Res.* **2016**, *10*, 1–22. [CrossRef]
18. Marti, K. *Stochastic Optimization Methods*; Springer: Berlin, Germany, 2008.
19. Martin, B.; Correia, M.; Cruz, J. A certified Branch & Bound approach for reliability-based optimization problems. *J. Glob. Optim.* **2017**, 1–24. [CrossRef]
20. Duan, L.; Li, G.; Cheng, A.; Sun, G.; Song, K. Multi-objective system reliability-based optimization method for design of a fully parametric concept car body. *Eng. Optim.* **2017**, *49*, 1247–1263. [CrossRef]
21. Zhang, L.Z. A reliability-based optimization of membrane-type total heat exchangers under uncertain design parameters. *Energy* **2016**, *101*, 390–401. [CrossRef]
22. Rostami, M.A.; Kavousi-Fard, A.; Niknam, T. Expected cost minimization of smart grids with plug-in hybrid electric vehicles using optimal distribution feeder reconfiguration. *IEEE Trans. Ind. Inform.* **2015**, *11*, 388–397. [CrossRef]
23. Noor, E.; Flamholz, A.; Bar-Even, A.; Davidi, D.; Milo, R.; Liebermeister, W. The protein cost of metabolic fluxes: Prediction from enzymatic rate laws and cost minimization. *PLoS Comput. Biol.* **2016**, *12*, e1005167. [CrossRef] [PubMed]
24. Yong, K.L.; Nguyen, H.V.; Cajucom-Uy, H.Y.; Foo, V.; Tan, D.; Finkelstein, E.A.; Mehta, J.S. Cost minimization analysis of precut cornea grafts in Descemet stripping automated endothelial keratoplasty. *Medicine* **2016**, *95*. [CrossRef] [PubMed]
25. Saadouli, H.; Jerbi, B.; Dammak, A.; Masmoudi, L.; Bouaziz, A. A stochastic optimization and simulation approach for scheduling operating rooms and recovery beds in an orthopedic surgery department. *Comput. Ind. Eng.* **2015**, *80*, 72–79. [CrossRef]
26. Legrain, A.; Fortin, M.A.; Lahrichi, N.; Rousseau, L.M. Online stochastic optimization of radiotherapy patient scheduling. *Health Care Manag. Sci.* **2015**, *18*, 110–123. [CrossRef] [PubMed]

27. Bagheri, M.; Devin, A.G.; Izanloo, A. An application of stochastic programming method for nurse scheduling problem in real word hospital. *Comput. Ind. Eng.* **2016**, *96*, 192–200. [CrossRef]
28. Omar, E.R.; Garaix, T.; Augusto, V.; Xie, X. A stochastic optimization model for shift scheduling in emergency departments. *Health Care Manag. Sci.* **2015**, *18*, 289–302. [CrossRef]
29. Saremi, A.; Jula, P.; ElMekkawy, T.; Wang, G.G. Bi-criteria appointment scheduling of patients with heterogeneous service sequences. *Expert Syst. Appl.* **2015**, *42*, 4029–4041. [CrossRef]
30. Graham, R.L.; Hell, P. On the history of the minimum spanning tree problem. *Ann. Hist. Comput.* **1985**, *7*, 43–57. [CrossRef]
31. Dorigo, M.; Gambardella, L.M. Ant colonies for the travelling salesman problem. *Biosystems* **1997**, *43*, 73–81. [CrossRef]
32. Cardoen, B.; Demeulemeester, E.; Beliën, J. Operating room planning and scheduling: A literature review. *Eur. J. Oper. Res.* **2010**, *201*, 921–932. [CrossRef]
33. Malik, M.M.; Khan, M.; Abdallah, S. Aggregate capacity planning for elective surgeries: A bi-objective optimization approach to balance patients waiting with healthcare costs. *Oper. Res. Health Care* **2015**, *7*, 3–13. [CrossRef]
34. Hsia, R.Y.; Kothari, A.H.; Srebotnjak, T.; Maselli, J. Health care as a "market good"? Appendicitis as a case study. *Arch. Intern. Med.* **2012**, *172*, 818–819. [CrossRef] [PubMed]
35. Denoyel, V.; Alfandari, L.; Thiele, A. Optimizing healthcare network design under Reference Pricing and parameter uncertainty. *Eur. J. Oper. Res.* **2017**, *263*, 996–1006. [CrossRef]
36. Heching, A.; Hooker, J.N. Scheduling home hospice care with logic-based Benders decomposition. In Proceedings of the International Conference on AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems, Banff, AB, Canada, 29 May–1 June 2016; Springer International Publishing: Cham, Switzerland, 2016.
37. Papp, D.; Bortfeld, T.; Unkelbach, J. A modular approach to intensity-modulated arc therapy optimization with noncoplanar trajectories. *Phys. Med. Biol.* **2015**, *60*. [CrossRef] [PubMed]
38. Jemai, J.; Chaieb, M.; Mellouli, K. The home care scheduling problem: A modeling and solving issue. In Proceedings of the 2013 5th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO), Hammamet, Tunisia, 28–30 April 2013; IEEE Press: Piscataway, NJ, USA, 2013.
39. Corpet, F. Multiple sequence alignment with hierarchical clustering. *Nucleic Acids Res.* **1988**, *16*, 10881–10890. [CrossRef] [PubMed]
40. Tarabalka, Y.; Benediktsson, J.A.; Chanussot, J. Spectral-spatial classification of hyperspectral imagery based on partitional clustering techniques. *IEEE Trans. Geosci. Remote Sens.* **2009**, *47*, 2973–2987. [CrossRef]
41. Wallstrom, G.L.; Hogan, W.R. Unsupervised clustering of over-the-counter healthcare products into product categories. *J. Biomed. Inform.* **2007**, *40*, 642–648. [CrossRef] [PubMed]
42. Fong, A.; Clark, L.; Cheng, T.; Franklin, E.; Fernandez, N.; Ratwani, R.; Parker, S.H. Identifying influential individuals on intensive care units: Using cluster analysis to explore culture. *J. Nurs. Manag.* **2017**, *25*, 384–391. [CrossRef] [PubMed]
43. Lim, S.; Tucker, C.S.; Kumara, S. An unsupervised machine learning model for discovering latent infectious diseases using social media data. *J. Biomed. Inform.* **2017**, *66*, 82–94. [CrossRef] [PubMed]
44. Sipes, T.; Jiang, S.; Moore, K.; Li, N.; Karimabadi, H.; Barr, J.R. Anomaly Detection in Healthcare: Detecting Erroneous Treatment Plans in Time Series Radiotherapy Data. *Int. J. Semant. Comput.* **2014**, *8*, 257–278. [CrossRef]
45. Haque, S.A.; Rahman, M.; Aziz, S.M. Sensor anomaly detection in wireless sensor networks for healthcare. *Sensors* **2015**, *15*, 8764–8786. [CrossRef] [PubMed]
46. Kadri, F.; Harrou, F.; Chaabane, S.; Sun, Y.; Tahon, C. Seasonal ARMA-based SPC charts for anomaly detection: Application to emergency department systems. *Neurocomputing* **2016**, *173*, 2102–2114. [CrossRef]
47. Khan, F.A.; Haldar, N.; Ali, A.; Iftikhar, M.; Zia, T.; Zomaya, A. A Continuous Change Detection Mechanism to Identify Anomalies in ECG Signals for WBAN-based Healthcare Environments. *IEEE Access* **2017**, *5*, 13531–13544. [CrossRef]
48. Ordóñez, F.J.; de Toledo, P.; Sanchis, A. Sensor-based Bayesian detection of anomalous living patterns in a home setting. *Pers. Ubiquitous Comput.* **2015**, *19*, 259–270. [CrossRef]
49. Huang, Z.; Dong, W.; Ji, L.; Yin, L.; Duan, H. On local anomaly detection and analysis for clinical pathways. *Artif. Intell. Med.* **2015**, *65*, 167–177. [CrossRef] [PubMed]

50. Fukumizu, K.; Bach, F.R.; Jordan, M.I. Dimensionality reduction for supervised learning with reproducing kernel Hilbert spaces. *J. Mach. Learn. Res.* **2004**, *5*, 73–99.
51. Geman, S.; Bienenstock, E.; Doursat, R. Neural networks and the bias/variance dilemma. *Neural Netw.* **2008**, *4*, 1–58. [CrossRef]
52. Nettleton, D.F.; Orriols-Puig, A.; Fornells, A. A study of the effect of different types of noise on the precision of supervised learning techniques. *Artif. Intell. Rev.* **2010**, *33*, 275–306. [CrossRef]
53. Akata, Z.; Perronnin, F.; Harchaoui, Z.; Schmid, C. Good practice in large-scale learning for image classification. *IEEE Trans. Pattern Anal. Mach. Intell.* **2014**, *36*, 507–520. [CrossRef] [PubMed]
54. Lewis, D.D.; Catlett, J. Heterogeneous uncertainty sampling for supervised learning. In Proceedings of the Eleventh International Conference on Machine Learning, New Brunswick, NJ, USA, 10–13 July 1994; Morgan Kaufmann Publishers: San Francisco, CA, USA, 1994.
55. Unler, A.; Murat, A.; Chinnam, R.B. MR 2 PSO: A maximum relevance minimum redundancy feature selection method based on swarm intelligence for support vector machine classification. *Inf. Sci.* **2011**, *181*, 4625–4641. [CrossRef]
56. Raducanu, B.; Dornaika, F. A supervised non-linear dimensionality reduction approach for manifold learning. *Pattern Recognit.* **2012**, *45*, 2432–2444. [CrossRef]
57. Zhang, M.; Yang, L.; Ren, J.; Ahlgren, N.A.; Fuhrman, J.A.; Sun, F. Prediction of virus-host infectious association by supervised learning methods. *BMC Bioinform.* **2017**, *18*. [CrossRef] [PubMed]
58. Cai, Y.; Tan, X.; Tan, X. Selective weakly supervised human detection under arbitrary poses. *Pattern Recognit.* **2017**, *65*, 223–237. [CrossRef]
59. Ichikawa, D.; Saito, T.; Ujita, W.; Oyama, H. How can machine-learning methods assist in virtual screening for hyperuricemia? A healthcare machine learning approach. *J. Biomed. Inform.* **2016**, *64*, 20–24. [CrossRef] [PubMed]
60. Muhammad, G. Automatic speech recognition using interlaced derivative pattern for cloud based healthcare system. *Clust. Comput.* **2015**, *18*, 795–802. [CrossRef]
61. Wang, Y.; Wu, S.; Li, D.; Mehrabi, S.; Liu, H. A Part-Of-Speech term weighting scheme for biomedical information retrieval. *J. Biomed. Inform.* **2016**, *63*, 379–389. [CrossRef] [PubMed]
62. Aydın, E.A.; Kaya Keleş, M. Breast cancer detection using K-nearest neighbors data mining method obtained from the bow-tie antenna dataset. *Int. J. RF Microw. Comput. Aided Eng.* **2017**, *27*, e21098. [CrossRef]
63. Li, H.; Luo, M.; Luo, J.; Zheng, J.; Zeng, R.; Du, Q.; Ouyang, N. A discriminant analysis prediction model of non-syndromic cleft lip with or without cleft palate based on risk factors. *BMC Pregnancy Childbirth* **2016**, *16*, 368. [CrossRef] [PubMed]
64. Li, J.; Fong, S.; Mohammed, S.; Fiaidhi, J.; Chen, Q.; Tan, Z. Solving the under-fitting problem for decision tree algorithms by incremental swarm optimization in rare-event healthcare classification. *J. Med. Imaging Health Inform.* **2016**, *6*, 1102–1110. [CrossRef]
65. Miranda, E.; Irwansyah, E.; Amelga, A.Y.; Maribondang, M.M.; Salim, M. Detection of cardiovascular disease risk's level for adults using naive Bayes classifier. *Healthcare Inform. Res.* **2016**, *22*, 196–205. [CrossRef] [PubMed]
66. Choi, E.; Schuetz, A.; Stewart, W.F.; Sun, J. Using recurrent neural network models for early detection of heart failure onset. *J. Am. Med. Inform. Assoc.* **2016**, *24*, 361–370. [CrossRef] [PubMed]
67. Hsu, W.C.; Lin, L.F.; Chou, C.W.; Hsiao, Y.T.; Liu, Y.H. EEG classification of imaginary lower limb stepping movements based on fuzzy support vector machine with Kernel-induced membership function. *Int. J. Fuzzy Syst.* **2017**, *19*, 566–579. [CrossRef]
68. Gu, B.; Sheng, V.S.; Tay, K.Y.; Romano, W.; Li, S. Incremental support vector learning for ordinal regression. *IEEE Trans. Neural Netw. Learn. Syst.* **2015**, *26*, 1403–1416. [CrossRef] [PubMed]
69. Eckardt, M.; Brettschneider, C.; Bussche, H.; König, H.H. Analysis of health care costs in elderly patients with multiple chronic conditions using a finite mixture of generalized linear models. *Health Econ.* **2017**, *26*, 582–599. [CrossRef] [PubMed]
70. Hahne, J.M.; Biessmann, F.; Jiang, N.; Rehbaum, H.; Farina, D.; Meinecke, F.C.; Parra, L.C. Linear and nonlinear regression techniques for simultaneous and proportional myoelectric control. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2014**, *22*, 269–279. [CrossRef] [PubMed]

71. Wongchaisuwat, P.; Klabjan, D.; Jonnalagadda, S.R. A Semi-Supervised Learning Approach to Enhance Health Care Community-Based Question Answering: A Case Study in Alcoholism. *JMIR Med. Inform.* **2016**, *4*. [CrossRef] [PubMed]
72. Albalate, A.; Minker, W. *Semi-Supervised and Unsupervised Machine Learning: Novel Strategies*; John Wiley & Sons: Hoboken, NJ, USA, 2013.
73. Shi, D.; Zurada, J.; Guan, J. A Neuro-fuzzy System with Semi-supervised Learning for Bad Debt Recovery in the Healthcare Industry. In Proceedings of the 2015 48th Hawaii International Conference on System Sciences (HICSS), Kauai, HI, USA, 5–8 January 2015; IEEE Press: Piscataway, NJ, USA, 2015.
74. Reitmaier, T.; Sick, B. The responsibility weighted Mahalanobis kernel for semi-supervised training of support vector machines for classification. *Inform. Sci.* **2015**, *323*, 179–198. [CrossRef]
75. Wang, Y.; Chen, S.; Xue, H.; Fu, Z. Semi-supervised classification learning by discrimination-aware manifold regularization. *Neurocomputing* **2015**, *147*, 299–306. [CrossRef]
76. Nie, L.; Zhao, Y.L.; Akbari, M.; Shen, J.; Chua, T.S. Bridging the vocabulary gap between health seekers and healthcare knowledge. *IEEE Trans. Knowl. Data Eng.* **2015**, *27*, 396–409. [CrossRef]
77. Cvetković, B.; Kaluža, B.; Gams, M.; Luštrek, M. Adapting activity recognition to a person with Multi-Classifier Adaptive Training. *J. Ambient Intell. Smart Environ.* **2015**, *7*, 171–185. [CrossRef]
78. Jin, L.; Xue, Y.; Li, Q.; Feng, L. Integrating human mobility and social media for adolescent psychological stress detection. In Proceedings of the International Conference on Database Systems for Advanced Applications, Dallas, TX, USA, 16–19 April 2016; Springer: Cham, Switzerland, 2016.
79. Ashfaq, R.A.R.; Wang, X.Z.; Huang, J.Z.; Abbas, H.; He, Y.L. Fuzziness based semi-supervised learning approach for intrusion detection system. *Inf. Sci.* **2017**, *378*, 484–497. [CrossRef]
80. Zhang, X.; Guan, N.; Jia, Z.; Qiu, X.; Luo, Z. Semi-supervised projective non-negative matrix factorization for cancer classification. *PLoS ONE* **2015**, *10*, e0138814. [CrossRef] [PubMed]
81. Yan, Y.; Chen, L.; Tjhi, W.C. Fuzzy semi-supervised co-clustering for text documents. *Fuzzy Sets Syst.* **2013**, *215*, 74–89. [CrossRef]
82. Go, A.S.; Mozaffarian, D.; Roger, V.L.; Benjamin, E.J.; Berry, J.D.; Borden, W.B.; Franco, S. Executive summary: Heart disease and stroke statistics—2013 update: A report from the American Heart Association. *Circulation* **2013**, *127*, 143–152. [CrossRef] [PubMed]
83. Thompson, P.D.; Buchner, D.; Piña, I.L.; Balady, G.J.; Williams, M.A.; Marcus, B.H.; Fletcher, G.F. Exercise and physical activity in the prevention and treatment of atherosclerotic cardiovascular disease. *Circulation* **2003**, *107*, 3109–3116. [CrossRef] [PubMed]
84. Ohira, T.; Iso, H. Cardiovascular disease epidemiology in Asia. *Circ. J.* **2013**, *77*, 1646–1652. [CrossRef] [PubMed]
85. Feigin, V.L.; Norrving, B.; George, M.G.; Foltz, J.L.; Roth, G.A.; Mensah, G.A. Prevention of stroke: A strategic global imperative. *Nat. Rev. Neurol.* **2016**, *12*, 501–512. [CrossRef] [PubMed]
86. Wannamethee, S.G.; Shaper, A.G. Physical activity and cardiovascular disease. In *Seminars in Vascular Medicine*; Thieme Medical Publishers: New York, NY, USA, 2002.
87. Luna, A.B.D. *Clinical Electrocardiography: A Textbook*; Wiley-Blackwell: Oxford, UK, 2012.
88. Macfarlane, P.W.; Edenbrandy, L.; Pahlm, O. *12-Lead Vectorcardiography*; Butterworth Heinemann: Oxford, UK, 1995.
89. Odinaka, I.; Lai, P.H.; Kaplan, A.D.; O'Sullivan, J.A.; Sirevaag, E.J.; Rohrbaugh, J.W. ECG biometric recognition: A comparative analysis. *IEEE Trans. Inf. Forensics Secur.* **2012**, *7*, 1812–1824. [CrossRef]
90. Tripathy, R.K.; Sharma, L.N.; Dandapat, S. A new way of quantifying diagnostic information from multilead electrocardiogram for cardiac disease classification. *Healthcare Technol. Lett.* **2014**, *1*, 98–103. [CrossRef] [PubMed]
91. Rahman, Q.A.; Tereshchenko, L.G.; Kongkatong, M.; Abraham, T.; Abraham, M.R.; Shatkay, H. Utilizing ECG-based heartbeat classification for hypertrophic cardiomyopathy identification. *IEEE Trans. Nanobiosci.* **2015**, *14*, 505–512. [CrossRef] [PubMed]
92. Melillo, P.; De Luca, N.; Bracale, M.; Pecchia, L. Classification tree for risk assessment in patients suffering from congestive heart failure via long-term heart rate variability. *IEEE J. Biomed. Health Inform.* **2013**, *17*, 727–733. [CrossRef] [PubMed]

93. Vafaie, M.H.; Ataei, M.; Koofigar, H.R. Heart diseases prediction based on ECG signals' classification using a genetic-fuzzy system and dynamical model of ECG signals. *Biomed. Signal Process. Control* **2014**, *14*, 291–296. [CrossRef]
94. Acharya, U.R.; Fujita, H.; Adam, M.; Lih, O.S.; Sudarshan, V.K.; Hong, T.J.; San, T.R. Automated characterization and classification of coronary artery disease and myocardial infarction by decomposition of ECG signals: A comparative study. *Inf. Sci.* **2017**, *377*, 17–29. [CrossRef]
95. Oster, J.; Behar, J.; Sayadi, O.; Nemati, S.; Johnson, A.E.; Clifford, G.D. Semisupervised ECG ventricular beat classification with novelty detection based on switching Kalman filters. *IEEE Trans. Biomed. Eng.* **2015**, *62*, 2125–2134. [CrossRef] [PubMed]
96. Li, P.; Wang, Y.; He, J.; Wang, L.; Tian, Y.; Zhou, T.S.; Li, J.S. High-Performance Personalized Heartbeat Classification Model for Long-Term ECG Signal. *IEEE Trans. Biomed. Eng.* **2017**, *64*, 78–86. [CrossRef] [PubMed]
97. Acharya, U.R.; Oh, S.L.; Hagiwara, Y.; Tan, J.H.; Adam, M.; Gertych, A.; San, T.R. A deep convolutional neural network model to classify heartbeats. *Comput. Biol. Med.* **2017**, *89*, 389–396. [CrossRef] [PubMed]
98. Elhaj, F.A.; Salim, N.; Harris, A.R.; Swee, T.T.; Ahmed, T. Arrhythmia recognition and classification using combined linear and nonlinear features of ECG signals. *Comput. Methods Programs Biomed.* **2016**, *127*, 52–63. [CrossRef] [PubMed]
99. Haldar, N.A.H.; Khan, F.A.; Ali, A.; Abbas, H. Arrhythmia classification using Mahalanobis distance based improved Fuzzy C-Means clustering for mobile health monitoring systems. *Neurocomputing* **2017**, *220*, 221–235. [CrossRef]
100. *Global Report on Diabetes*; World Health Organization: Geneva, Switzerland, 2016; Available online: http://apps.who.int/iris/bitstream/10665/204871/1/9789241565257_eng.pdf (accessed on 15 September 2017).
101. Guariguata, L.; Whiting, D.R.; Hambleton, I.; Beagley, J.; Linnenkamp, U.; Shaw, J.E. Global estimates of diabetes prevalence for 2013 and projections for 2035. *Diabetes Res. Clin. Pract.* **2014**, *103*, 137–149. [CrossRef] [PubMed]
102. Rodger, W. Non-insulin-dependent (type II) diabetes mellitus. *Can. Med. Assoc. J.* **1991**, *145*, 1571–1581.
103. Han, L.; Luo, S.; Yu, J.; Pan, L.; Chen, S. Rule extraction from support vector machines using ensemble learning approach: An application for diagnosis of diabetes. *IEEE J. Biomed. Health Inform.* **2015**, *19*, 728–734. [CrossRef] [PubMed]
104. Zheng, T.; Xie, W.; Xu, L.; He, X.; Zhang, Y.; You, M.; Chen, Y. A machine learning-based framework to identify type 2 diabetes through electronic health records. *Int. J. Med. Inform.* **2017**, *97*, 120–127. [CrossRef] [PubMed]
105. Ganji, M.F.; Abadeh, M.S. A fuzzy classification system based on ant colony optimization for diabetes disease diagnosis. *Expert Syst. Appl.* **2011**, *38*, 14650–14659. [CrossRef]
106. Lee, B.J.; Ku, B.; Nam, J.; Pham, D.D.; Kim, J.Y. Prediction of fasting plasma glucose status using anthropometric measures for diagnosing type 2 diabetes. *IEEE J. Biomed. Health Inform.* **2014**, *18*, 555–561. [CrossRef] [PubMed]
107. Lee, B.J.; Kim, J.Y. Identification of type 2 diabetes risk factors using phenotypes consisting of anthropometry and triglycerides based on machine learning. *IEEE J. Biomed. Health Inform.* **2016**, *20*, 39–46. [CrossRef] [PubMed]
108. Ling, S.H.; San, P.P.; Nguyen, H.T. Non-invasive hypoglycemia monitoring system using extreme learning machine for Type 1 diabetes. *ISA Trans.* **2016**, *64*, 440–446. [CrossRef] [PubMed]
109. Vyas, R.; Bapat, S.; Jain, E.; Karthikeyan, M.; Tambe, S.; Kulkarni, B.D. Building and analysis of protein-protein interactions related to diabetes mellitus using support vector machine, biomedical text mining and network analysis. *Comput. Biol. Chem.* **2016**, *65*, 37–44. [CrossRef] [PubMed]
110. Li, C.M.; Du, Y.C.; Wu, J.X.; Lin, C.H.; Ho, Y.R.; Lin, Y.J.; Chen, T. Synchronizing chaotification with support vector machine and wolf pack search algorithm for estimation of peripheral vascular occlusion in diabetes mellitus. *Biomed. Signal Process. Control* **2014**, *9*, 45–55. [CrossRef]
111. Rau, H.H.; Hsu, C.Y.; Lin, Y.A.; Atique, S.; Fuad, A.; Wei, L.M.; Hsu, M.H. Development of a web-based liver cancer prediction model for type II diabetes patients by using an artificial neural network. *Comput. Methods Programs Biomed.* **2016**, *125*, 58–65. [CrossRef] [PubMed]
112. Marateb, H.R.; Mansourian, M.; Faghihimani, E.; Amini, M.; Farina, D. A hybrid intelligent system for diagnosing microalbuminuria in type 2 diabetes patients without having to measure urinary albumin. *Comput. Biol. Med.* **2014**, *45*, 34–42. [CrossRef] [PubMed]

113. Gaugler, J.; James, B.; Johnson, T.; Weuve, J. *2017 Alzheimer's Disease Facts and Figures*; Alzheimer's Association: Chicago, IL, USA, 2017; Available online: https://www.alz.org/documents_custom/2017-facts-and-figures.pdf (accessed on 15 September 2017).
114. Rizzi, L.; Rosset, I.; Roriz-Cruz, M. Global epidemiology of dementia: Alzheimer's and vascular types. *BioMed Res. Int.* **2014**, *2014*, 908915. [CrossRef] [PubMed]
115. Armañanzas, R.; Iglesias, M.; Morales, D.A.; Alonso-Nanclares, L. Voxel-Based Diagnosis of Alzheimer's Disease Using Classifier Ensembles. *IEEE J. Biomed. Health Inform.* **2017**, *21*, 778–784. [CrossRef] [PubMed]
116. Chen, Y.; Sha, M.; Zhao, X.; Ma, J.; Ni, H.; Gao, W.; Ming, D. Automated detection of pathologic white matter alterations in Alzheimer's disease using combined diffusivity and kurtosis method. *Psychiatry Res. Neuroimaging* **2017**, *264*, 35–45. [CrossRef] [PubMed]
117. Tanaka, H.; Adachi, H.; Ukita, N.; Ikeda, M.; Kazui, H.; Kudo, T.; Nakamura, S. Detecting Dementia through Interactive Computer Avatars. *IEEE J. Transl. Eng. Health Med.* **2017**, *5*, 1–11. [CrossRef] [PubMed]
118. Zhang, Y.; Dong, Z.; Phillips, P.; Wang, S.; Ji, G.; Yang, J.; Yuan, T.F. Detection of subjects and brain regions related to Alzheimer's disease using 3D MRI scans based on eigenbrain and machine learning. *Front. Comput. Neurosci.* **2015**, *9*. [CrossRef] [PubMed]
119. Moradi, E.; Pepe, A.; Gaser, C.; Huttunen, H.; Tohka, J.; Alzheimer's Disease Neuroimaging Initiative. Machine learning framework for early MRI-based Alzheimer's conversion prediction in MCI subjects. *Neuroimage* **2015**, *104*, 398–412. [CrossRef] [PubMed]
120. Beheshti, I.; Demirel, H.; Matsuda, H. Classification of Alzheimer's disease and prediction of mild cognitive impairment-to-Alzheimer's conversion from structural magnetic resource imaging using feature ranking and a genetic algorithm. *Comput. Biol. Med.* **2017**, *83*, 109–119. [CrossRef] [PubMed]
121. Doan, N.T.; Engvig, A.; Zaske, K.; Persson, K.; Lund, M.J.; Kaufmann, T.; Barca, M.L. Distinguishing early and late brain aging from the Alzheimer's disease spectrum: Consistent morphological patterns across independent samples. *NeuroImage* **2017**, *158*, 282–295. [CrossRef] [PubMed]
122. Shi, B.; Chen, Y.; Zhang, P.; Smith, C.D.; Liu, J. Nonlinear feature transformation and deep fusion for Alzheimer's Disease staging analysis. *Pattern Recognit.* **2017**, *63*, 487–498. [CrossRef]
123. Billones, C.D.; Demetria, O.J.L.D.; Hostallero, D.E.D.; Naval, P.C. DemNet: A convolutional neural network for the detection of Alzheimer's disease and mild cognitive impairment. In Proceedings of the 2016 IEEE Region 10 Conference (TENCON), Singapore, 22–25 November 2016; IEEE Press: Piscataway, NJ, USA, 2016.
124. Morabito, F.C.; Campolo, M.; Ieracitano, C.; Ebadi, J.M.; Bonano, L.; Bramanti, A.; Desalvo, S.; Mammone, N.; Bramanti, P. Deep convolutional neural networks for classification of mild cognitive impaired and Alzheimer's disease patients from scalp EEG recordings. In Proceedings of the 2016 IEEE 2nd International Forum on Research and Technologies for Society and Industry Leveraging a Better Tomorrow (RTSI), Bologna, Italy, 7–9 September 2016; IEEE Press: Piscataway, NJ, USA, 2016.
125. Martínez-Ballesteros, M.; García-Heredia, J.M.; Nepomuceno-Chamorro, I.A.; Riquelme-Santos, J.C. Machine learning techniques to discover genes with potential prognosis role in Alzheimer's disease using different biological sources. *Inf. Fusion* **2017**, *36*, 114–129. [CrossRef]
126. Miao, Y.; Jiang, H.; Liu, H.; Yao, Y.D. An Alzheimers disease related genes identification method based on multiple classifier integration. *Comput. Methods Programs Biomed.* **2017**, *150*, 107–115. [CrossRef] [PubMed]
127. *Global Tuberculosis Report 2013*; World Health Organization: Geneva, Switzerland, 2013; Available online: http://apps.who.int/iris/bitstream/10665/91355/1/9789241564656_eng.pdf (accessed on 15 September 2017).
128. Lacerda, S.N.B.; de Abreu Temoteo, R.C.; de Figueiredo, T.M.R.M.; de Luna, F.D.T.; de Sousa, M.A.N.; de Abreu, L.C.; Fonseca, F.L.A. Individual and social vulnerabilities upon acquiring tuberculosis: A literature systematic review. *Int. Arch. Med.* **2014**, *7*, 35. [CrossRef] [PubMed]
129. Hwang, L.Y.; Grimes, C.Z.; Beasley, R.P.; Graviss, E.A. Latent tuberculosis infections in hard-to-reach drug using population-detection, prevention and control. *Tuberculosis* **2009**, *89*, S41–S45. [CrossRef]
130. Sulis, G.; Roggi, A.; Matteelli, A.; Raviglione, M.C. Tuberculosis: Epidemiology and control. *Mediterr. J. Hematol. Infect. Dis.* **2014**, *6*. [CrossRef] [PubMed]
131. Sergeev, R.S.; Kavaliou, I.; Sataneuski, U.; Gabrielian, A.; Rosenthal, A.; Tartakovsky, M.; Tuzikov, A. Genome-wide Analysis of MDR and XDR Tuberculosis from Belarus: Machine-learning Approach. *IEEE/ACM Trans. Comput. Biol. Bioinform.* **2017**. [CrossRef] [PubMed]

132. Melendez, J.; van Ginneken, B.; Maduskar, P.; Philipsen, R.H.; Reither, K.; Breuninger, M.; Sánchez, C.I. A novel multiple-instance learning-based approach to computer-aided detection of tuberculosis on chest X-rays. *IEEE Trans. Med. Imaging* **2015**, *34*, 179–192. [CrossRef] [PubMed]
133. Alcantara, M.F.; Cao, Y.; Liu, C.; Liu, B.; Brunette, M.; Curioso, W.H. Improving tuberculosis diagnostics using deep learning and mobile health technologies among resource-poor communities in Perú. *Smart Health* **2017**, *1*, 66–76. [CrossRef]
134. Lopes, U.K.; Valiati, J.F. Pre-trained convolutional neural networks as feature extractors for tuberculosis detection. *Comput. Biol. Med.* **2017**, *89*, 135–143. [CrossRef] [PubMed]
135. Yahiaoui, A.; Er, O.; Yumusak, N. A new method of automatic recognition for tuberculosis disease diagnosis using support vector machines. *Biomed. Res.* **2017**, *28*, 4208–4212.
136. Évora, L.H.R.A.; Seixas, J.M.; Kritski, A.L. Neural network models for supporting drug and multidrug resistant tuberculosis screening diagnosis. *Neurocomputing* **2017**, *265*, 116–126. [CrossRef]
137. Thompson, E.G.; Du, Y.; Malherbe, S.T.; Shankar, S.; Braun, J.; Valvo, J.; Shenai, S. Host blood RNA signatures predict the outcome of tuberculosis treatment. *Tuberculosis* **2017**, *107*, 48–58. [CrossRef] [PubMed]
138. Sambarey, A.; Devaprasad, A.; Mohan, A.; Ahmed, A.; Nayak, S.; Swaminathan, S.; Vyakarnam, A. Unbiased Identification of Blood-based Biomarkers for Pulmonary Tuberculosis by Modeling and Mining Molecular Interaction Networks. *EBioMedicine* **2017**, *15*, 112–126. [CrossRef] [PubMed]
139. Mamiya, H.; Schwartzman, K.; Verma, A.; Jauvin, C.; Behr, M.; Buckeridge, D. Towards probabilistic decision support in public health practice: Predicting recent transmission of tuberculosis from patient attributes. *J. Biomed. Inform.* **2015**, *53*, 237–242. [CrossRef] [PubMed]
140. JoãoFilho, B.D.O.; de Seixas, J.M.; Galliez, R.; de Bragança Pereira, B.; de Q Mello, F.C.; dos Santos, A.M.; Kritski, A.L. A screening system for smear-negative pulmonary tuberculosis using artificial neural networks. *Int. J. Infect. Dis.* **2016**, *49*, 33–39. [CrossRef]
141. Rockafellar, R.T. Lagrange multipliers and optimality. *SIAM Rev.* **1993**, *35*, 183–238. [CrossRef]
142. Bellman, R. *Dynamic Programming*; Dover Publication: New York, NY, USA, 2013.
143. Bertsekas, D.P. *Nonlinear Programming*; Athena Scientific: Belmont, CA, USA, 1999.
144. Glover, F.W.; Kochenberger, G.A. *Handbook of Metaheuristics*; Kluwer Academic Publishers: New York, NY, USA, 2006.
145. Steiner, M.T.A.; Datta, D.; Neto, R.J.S.; Scarpin, C.T.; Figueira, J.R. Multi-objective optimization in partitioning the healthcare system of Parana State in Brazil. *Omega* **2015**, *52*, 53–64. [CrossRef]
146. Samuel, A.L. Some studies in machine learning using the game of checkers. *IBM J. Res. Dev.* **1959**, *3*, 210–229. [CrossRef]
147. Lanza, J.; Sotres, P.; Sánchez, L.; Galache, J.A.; Santana, J.R.; Gutiérrez, V.; Muñoz, L. Managing Large Amounts of Data Generated by a Smart City Internet of Things Deployment. *Int. J. Semant. Web Inf. Syst.* **2016**, *12*, 22–42. [CrossRef]
148. Assaf, A.; Senart, A.; Troncy, R. Towards an Objective Assessment Framework for Linked Data Quality: Enriching Dataset Profiles with Quality Indicators. *Int. J. Semant. Web Inf. Syst.* **2016**, *12*, 111–133. [CrossRef]
149. Bertsekas, D.P.; Rheinboldt, W. *Constrained Optimization and Lagrange Multiplier Methods*; Athena Scientific: Belmont, MA, USA, 1982.
150. Silver, D.; Huang, A.; Maddison, C.J.; Guez, A.; Sifre, L.; Van Den Driessche, G.; Schrittwieser, J.; Antonoglou, I.; Panneershelvan, V.; Lanctot, M.; et al. Mastering the game of Go with deep neural networks and tree search. *Nature* **2016**, 484–489. [CrossRef] [PubMed]
151. Schmidhuber, J. Deep learning in neural networks: An overview. *Neural Netw.* **2015**, *61*, 85–117. [CrossRef] [PubMed]
152. Gatti, C. *Design of Experiments for Reinforcement Learning*; Springer: New York, NY, USA, 2014.
153. Si, J. *Handbook of Learning and Approximate Dynamic Programming*; John Wiley & Sons: Hoboken, NJ, USA, 2004.
154. Kaelbling, L.P.; Littman, M.L.; Moore, A.W. Reinforcement learning: A survey. *J. Artif. Intell. Res.* **1996**, *4*, 237–285.
155. Liu, Y.; Logan, B.; Liu, N.; Xu, Z.; Tang, J.; Wang, Y. Deep Reinforcement Learning for Dynamic Treatment Regimes on Medical Registry Data. In Proceedings of the 2017 IEEE International Conference on Healthcare Informatics (ICHI), Park City, UT, USA, 23–26 August 2017; IEEE Press: Piscataway, NJ, USA, 2017.
156. Shakshuki, E.M.; Reid, M.; Sheltami, T.R. Dynamic healthcare interface for patients. *Procedia Comput. Sci.* **2015**, *63*, 356–365. [CrossRef]

157. Jagodnik, K.; Thomas, P.; Bogert, A.V.D.; Branicky, M.; Kirsch, R. Training an Actor-Critic Reinforcement Learning Controller for Arm Movement Using Human-Generated Rewards. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2017**, *25*, 1892–1905. [CrossRef] [PubMed]
158. Istepanian, R.S.; Philip, N.Y.; Martini, M.G. Medical QoS provision based on reinforcement learning in ultrasound streaming over 3.5G wireless systems. *IEEE J. Sel. Areas Commun.* **2009**, *27*. [CrossRef]
159. *Global Health Estimates 2015: Deaths by Cause, Age, Sex, by Country and by Region, 2000–2015*; World Health Organization: Geneva, Switzerland, 2016; Available online: http://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html (accessed on 15 September 2017).
160. Makoul, G.; Curry, R.H.; Tang, P.C. The use of electronic medical records: Communication patterns in outpatient encounters. *J. Am. Med. Inform. Assoc.* **2001**, *8*, 610–615. [CrossRef] [PubMed]
161. Westin, A.; Krane, D.; Capps, K.; Peterson, T.; Kliner, S. *Making It Meaningful: How Consumers Value and Trust Health It Survey*; National Partnership for Women & Families: Washington, DC, USA, 2012; Available online: http://go.nationalpartnership.org/site/DocServer/HIT_Making_IT_Meaningful_National_Partnership_February_2.pdf (accessed on 15 September 2017).
162. Sweeney, L. Computational disclosure control for medical microdata: The Datafly system. In *Record Linkage Techniques 1997: Proceedings of an International Workshop and Exposition*; The National Academies Press: Washington, DC, USA, 1997; pp. 442–453.
163. Chang, C.C.; Li, Y.C.; Huang, W.H. TFRP: An efficient microaggregation algorithm for statistical disclosure control. *J. Syst. Softw.* **2007**, *80*, 1866–1878. [CrossRef]
164. Yang, J.J.; Li, J.Q.; Niu, Y. A hybrid solution for privacy preserving medical data sharing in the cloud environment. *Future Gener. Comput. Syst.* **2015**, *43*, 74–86. [CrossRef]
165. Liu, K.; Kargupta, H.; Ryan, J. Random projection-based multiplicative data perturbation for privacy preserving distributed data mining. *IEEE Trans. Knowl. Data Eng.* **2006**, *18*, 92–106. [CrossRef]
166. Fung, B.C.; Wang, K.; Philip, S.Y. Anonymizing classification data for privacy preservation. *IEEE Trans. Knowl. Data Eng.* **2007**, *19*, 711–725. [CrossRef]
167. Loukides, G.; Gkoulalas-Divanis, A.; Malin, B. Anonymization of electronic medical records for validating genome-wide association studies. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 7898–7903. [CrossRef] [PubMed]
168. Turner, J.R. The role of pilot studies in reducing risk on projects and programmes. *Int. J. Proj. Manag.* **2005**, *23*, 1–6. [CrossRef]
169. Zingg, W.; Holmes, A.; Dettenkofer, M.; Goetting, T.; Secci, F.; Clack, L.; Allegranzi, B.; Magiorakos, A.; Pittet, D. Hospital organization, management, and structure for prevention of health-care-associated infection: A systematic review and expert consensus. *Lancet Infect. Dis.* **2015**, *15*, 212–224. [CrossRef]
170. Lichtenberg, F.R. The effect of government funding on private industrial research and development: A re-assessment. *J. Ind. Econ.* **1987**, 97–104. [CrossRef]
171. VomBrocke, J.; Lippe, S. Managing collaborative research projects: A synthesis of project management literature and directives for future research. *Int. J. Proj. Manag.* **2015**, *33*, 1022–1039. [CrossRef]
172. Forkner-Dunn, J. Internet-based patient self-care: The next generation of health care delivery. *J. Med. Internet Res.* **2005**, *5*. [CrossRef] [PubMed]
173. James, C. *Global Status of Commercialized Biotech/GM Crops*; The International Service for the Acquisition of Agri-biotech Applications (ISAAA): Metro Manila, Philippines, 2016. Available online: http://africenter.isaaa.org/wp-content/uploads/2017/06/ISAAA-Briefs-No-52.pdf (accessed on 15 September 2017).
174. Huesch, M.D.; Mosher, T.J. Using It or Losing It? The Case for Data Scientists inside Health Care. 2017. Available online: http://catalyst.nejm.org/case-data-scientists-inside-health-care/ (accessed on 1 December 2017).
175. Oaldem-Rayner, L. Artificial Intelligence Won't Replace Doctors Soon But It Can Help with Diagnosis. 2017. Available online: http://www.abc.net.au/news/2017-09-19/ai-wont-replace-doctors-soon-but-it-can-help-diagnosis/8960530 (accessed on 1 December 2017).
176. Wolpert, D.H. *The Supervised Learning No-Free Lunch*; Springer: London, UK, 2002.
177. LeCun, Y.; Bengio, Y.; Hinton, G. Deep learning. *Nature* **2015**, *521*, 436–444. [CrossRef] [PubMed]

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Article

Smart Cities in Taiwan: A Perspective on Big Data Applications

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Abstract: In this paper, we discuss the concept of a smart city based on information and communication technology (ICT), analyze the objectives of smart city development in Taiwan, and explain the supporting technologies that make such development possible. Subsequently, we propose a hierarchical structure framework of smart city systems with levels of complexity ranging from low to high and interconnections and interactive relationships in five dimensions: the Internet of Things (IoT), cloud computing, Big Data, Mobile Network, and smart business. We integrate each key resource of the core operation systems of cities to promote the innovative operation of cities and further optimize city development. We then propose a Big Data platform data flow framework that uses information from ubiquitous sensor networks and information equipment to analyze the Big Data application process of smart cities and determine the resulting advantages and challenges. Additionally, we analyze the current state of development of smart cities in Taiwan. Finally, we discuss a new philosophy of smart city development and provide a practical blueprint for the formation, operation, and development of the smart cities with the aim of creating a bright future for the smart cities of Taiwan.

Keywords: smart cities; big data; Internet of Things; mobile network; information and communication technology; Taiwan

1. Introduction

1.1. The Smart City

A city's various infrastructure investments are all oriented toward sustainable development, enhancing the quality of life of city residents, and increasing the city's competitiveness. As the world becomes increasingly datafied, cities are becoming digital replicas of the cyber worlds in which people reside [1], and the development and application of information and communication technology (ICT) is playing a decisive role in this transformation. The expansion of Big Data and development of the Internet of Things (IoT) are increasing the feasibility of smart city initiatives [2]. Cloud computing platforms store large amounts of data, handle computing, analysis, and decision-making processes, and perform automation control based on the results of these analyses and processes [3]. Smart cities are the realization of digital city development based on ICT infrastructure and employ Big Data, the IoT, and cloud computing. In the five-tier structure of a smart city's operation cycle, we collect data on IoT as the bottom-tier device of the smart city. After all data are collected and converted for cloud computing, the IoT can integrate the useful data into a big database for storage, analysis, and computation. Next, through a mobile network, the results will be presented in various forms, such as reports and webpages, in order to answer users' inquiries and fulfill the application needs of top smart businesses. This entire structure cycle will form the operational function of the smart city. Figure 1 is the five-layered framework of a smart city, which we will explain by different layers in the paper. A smart city is a structure with the core of big data, as is presented in Figure 1. This paper introduces its functions and concepts in the following sections.

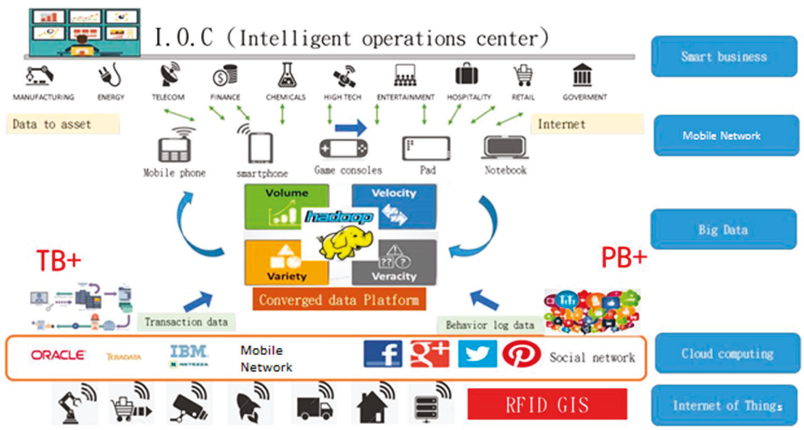

Figure 1. Enterprise application architecture of smart cities.

1.2. Big Data

The world is becoming increasingly datafied, and ubiquitous digital data on all aspects of human life have emerged in analyses of human activity rhythms and the digital breadcrumbs left by human activity. Data activation and the analysis of applications are essential in smart cities. Big Data is extensive datasets—primarily in terms of their volume, variety, velocity, and/or variability—that require a scalable architecture for their efficient storage, manipulation, and analysis [4]. Different concerns may be encountered during the capture, storage, management, mining, and analysis of Big Data depending on the usage context. Banks worldwide use Big Data to achieve their sustainable development goals. Big Data is also used for the following:

- to foster decision-making and accountability;
- to determine where funds are sent;
- to determine whether funding is being sent to the right place;
- for monitoring and evaluation;
- to identify changes over time;
- to determine whether such changes were caused by a specific intervention;
- to identify other factors that may have caused the outcome [5].

Big Data from satellite imagery and sensor networks are enabling increased measurement of environmental and developmental indicators [5]. There are 6 billion mobile phones in use worldwide, and 80% of them belong to people in developing countries. This prevalence provides researchers with a network of social sensors that are constantly obtaining information every day [6]. Big Data is a revolution that will change the ways in which people live, work, and think. Following Mobile Network and Cloud Computing, Big Data has gradually become a technology that has a far-reaching influence on the ICT industry [7].

1.3. ICT

The primary functions of ICT are terminals with data input and output capabilities, networks with data transmission capability, and computing power with data accumulation, processing, and analysis capabilities. In 1998, the Organization for Economic Cooperation and Development defined ICT as a combination of the manufacturing and service industries for electronic capture, transmission, data display, and electronic information. In 2016, the China Academy of Information and Communications Technology divided categories of the ICT industry into the types narrow and broad. Narrow industries included those of electronic components (integrated circuits, discrete devices, display devices, printed circuit boards, and other components), control devices and measurement instruments (equipment and instruments), terminal devices (mobile phones, personal computers or tablets, televisions, and wearables), cable devices (telecommunication network equipment), and cloud devices (servers, memory systems, and enterprise network equipment). Conversely, broad industries include those of software (basic software, application software, software especially used in vertical domains) and IT services (commercial IT services and IT product support services). By 2020 in the ICT industry, clouds (Big Data) and terminals (smart hardware) are predicted to become vertically stackable using the vertical integration (cloud and terminal) model of a horizontal platform [8]. Japan's ICT strategy focuses on IoT and artificial intelligence (AI) investments in Big Data and other telecommunication technologies to assist related firms achieve revolutionary innovation in the ICT field. The Industrial Economics and Knowledge Center (IEK) stated that the primary concept of Taiwan's ICT industry in 2017 is "The AI X Era Begins: Digital Innovation, AI Synergy". In a post-IoT era, AI smart devices are expected to gradually enter our lives, and the focus of industry will transfer from the IoT to AI [9].

1.4. Planning of Smart Cities in Taiwan

By applying innovative ICT, Taiwan continues to promote various programs related to smart technology and plans to build a modernized smart city that is low-carbon, green, and harmonious and has sustainable development. The IEK indicated that the development of smart cities must proceed from the perspective of solving problems to meet market demands and have the opportunity to create value and foster industry. Su et al. [10] expressed that after a global economic recession and the rise of local economy, the development of smart cities worldwide has gradually shifted to encouraging civic participation, using a bottom-up design, and employing an innovative economic model of digital economic value added (EVA). The benefits of smart city development can be viewed in four dimensions: ecological sustainability, social sustainability, economic sustainability, and governance [10]. The attitudes to the environment of citizens and firms actively participating in smart city development are of great importance [11]. The "Smart City Introduction Reference Manual" compiled by IDEAS (department of Institute for Information Industry, III) in 2012 details the eight primary application items of smart cities: smart education, smart tourism, smart transportation, a smart sustainable environment, smart health care, smart governance, smart and happy living, and smart industry. In 2015, the Executive Yuan of Taiwan began drafting the "ide@ Taiwan 2020 Policy: White Paper" and proposed five dimensions and 18 measures for implementation to forge a new Taiwan that is high-quality, innovative, and sustainable [12].

2. Development of a Smart City

Cities are densely populated areas with highly developed industry and commerce. They generally include functional zones such as residential, industrial, and commercial areas and have administrative jurisdiction. Smart cities use information technology in these zones to provide a variety of convenient smart applications and services for promoting more coordinated societal and natural development.

2.1. Development Indicators and Rating Mechanisms of International Smart Cities

The concept of a smart city continues to spread around the world. Governments have successively created relevant policy guidelines and urban vision plans. Furthermore, because development is different for each city due to the natural environment and social background characteristics and because long-term efforts and resource investment are required, a variety of smart city indicators and rating mechanisms have been developed internationally to ensure that the strategies employed are economic and effective. This paper discusses only the four indicators and rating mechanisms commonly used by Taiwan's neighboring countries (Table 1). They are as follows:

- The European Smart City Index [13] employs the dimensions smart economy, smart people, smart governance, smart mobility, smart environment, and smart living and refines them into different indicators, assigning weights to assist ratings.
- After an overall assessment and formation of indicators, the Intelligent Community Forum (ICF) [14] promotes city or community management philosophies and operating models to city leaders. Additionally, they commend the achievements of cities in using ICT to develop a smart city through the ICF Awards, promoting exchange and learning between cities.
- SMART [15], the theoretical model of China's smart city evaluation indicator system, comprises five key elements: service, management and maintenance, application platform, resources, and technology.
- The Foreseeing Innovative New Digiservices (FIND) model [16] was designed by the Institute for Information Industry in hopes of employing rational research data and physical examination analysis to enhance the quality of life of urban residents and firm competitiveness.

Cities in Taiwan have obtained ICF smart city ratings on several occasions and have received different awards.

Table 1. Indicators and rating mechanisms commonly used by Taiwan and neighboring countries.

Rating Name	First Use	Place of Origin	Originating Institution	Indicator Orientation	Object of Evaluation
European Smart City Index	2007	Austria/Slovenia/ the Netherlands	Vienna University of Technology, University of Ljubljana, Delft University of Technology	Smart economy, smart people, smart governance, smart mobility, smart environment, smart living	Medium-sized cities in Europe
Intelligent Community Awards	1985	United States	World Teleport Association, WTA (Intelligent Community Forum, ICF)	Broadband connectivity, knowledge-based workforce, innovation, digital inclusion, marketing and publicity	Cities worldwide (communities)
SMART	2013	China	China Software Testing Center	Intellectualized city infrastructure, intellectualized city management, intellectualized city services, open information resource integration, intellectualized city industry	Cities in China
FIND	2010	Taiwan	Foreseeing Innovative New Digiservices	Intellectualized city ability, citizen satisfaction, benefits of intellectualized city construction	Cities in Taiwan

Source: [13–16], organization of this study.

2.2. Smart City Commercial Application Structure

Following IoT development, Big Data is used as a core to compose the application architecture of smart cities. The applications of Big Data in various fields were determined in this study, and after summarization and organization, the enterprise application architecture of smart cities was constructed and is shown in Figure 1.

- The underlying sensing equipment (e.g., Internet of Vehicles (IoV), QR codes, IP Cam, radio-frequency identification (RFID), eTag, and geographic information systems (GIS)) generate data, which are collected and converted using the interface.
- The IoT technology is used to collect information. Information is gathered through mobile networks or social networks into a database or data warehouse (e.g., Oracle, DB2, and Teradata) for information-related storage cloud operations.
- Subsequently, after extraction of various types of databases, transaction data and behavior log data are separately imported into the big database (such as Hadoop) of the converged data platform. This is the core of Big Data.
- After processing of the data, customers can use the Mobile Network to search for information.
- Various types of smart business applications are thus generated.

The convenience of the Mobile Network has contributed to the booming business applications in smart cities.

2.3. Mobile Network

The searchability of network attributes establishes the relationship between geographical proximity and social interaction [17]. City data are approximately divided into the categories of cartographic data, public data, and commercial data. These types of data are widely used and are provided by the Big Data platform and resource core in the information-based infrastructures of smart cities. The popularization of various new types of smart mobile devices has resulted in the generation of massive volumes of data. The rapid development of the Mobile Network has resulted in explosive growth in the number of smartphone users, number of apps, and the volume of network data traffic. According to statistics determined by the market research firm Sensor Tower regarding app downloads, the number of iOS and Android app downloads in 2016Q1 was 17.2 billion, and gaming and social interaction apps were the most downloaded app types [18].

Mobile Networks are gradually permeating people's lives and workplaces and has become a new channel for people's living, working, and entertainment, online or offline. The rapid development of Mobile Networks was the cornerstone of mobile Big Data. The sharp increase in the number of mobile apps has spurred the generation of massive user data, and ubiquitous access to information anytime has enabled Mobile Networks to become handier in daily life.

Services are available to users anytime and anywhere via the Internet, thanks to big data and the results of cloud computing.

2.4. Cloud Computing

Cloud computing is not a new technology or technique, but a concept [19]. The cloud represents the Internet. The Internet now provides substitutes for the software installed on computers and acts as an external hard disk space; the cloud in turn uses Internet services to perform various tasks and stores file data in a massive virtual space. According to the National Institute of Standards and Technology (NIST) sp800-145 definition, cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, apps, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [20]. In October 2014, the International Organization for Standardization (ISO) published ISO/IEC 17788 and ISO/IEC 17789, which both propose a standard definition of cloud computing and frames of reference. Furthermore, the roles of cloud computing, cloud computing activities, and cloud computing components, as well as the relationships between them, were clearly described. Cloud computing is provided as a service to customers through the Internet.

In October 2015, the Executive Yuan launched a cloud computing development plan [21]. The government plans to use Taiwan's existing ICT industry advantage to consider Taiwan's industrial needs and the development of its application services. Trusted group procurement will be employed and the use of existing cloud computing solutions will be centralized to help industries establish economies of scale. Simultaneously, cloud computing application infrastructures will be established in related industries to accelerate the adoption of data development, Big Data, the IoT, smart cities, and Industry 4.0. Five strategies have been proposed: the promotion of public sensor application, expansion of application development power, establishment of software research and development technology, implementation of a cloud infrastructure, and consideration of the efficiency of green energy.

Information security has been predicted to be an obstacle to sustainable computing in the future [22]. The development of cloud computing has resulted in more convenience in the lives of ordinary people. However, information security and personal information privacy in cloud computing services must be carefully evaluated.

Big data and cloud computing enable IoT devices to have ultimate functions. Data produced by such devices can be stored in big data for ready application by a big data processing module after format conversion.

2.5. The IoT

According to IEEE P2413, the IoT has three layers: a sensing layer, networking and data communications layer, and applications layer. Accordingly, the International Telecommunication Union endorses the definition of the IoT as a network that is "available anywhere, anytime, by anything and anyone". In this context, consumer products can be tracked using minute radio transmitters or tagged or embedded hyperlinks and sensors [23].

The interconnection of the IoT with smart devices, the upgrades of cloud technology, an easy-to-operate natural human–machine interface, and a good user experience can be combined with various types of media content such as broadcast television, video, audio, text, images, and data. Various crucial applications can be integrated to provide multimedia services with high service quality, a favorable user experience, and high security, interactivity, and reliability; these are the factors that increase customers' willingness to make a purchase. Available technology and system architectures are used to effectively integrate the relevant signals, networks, and protocols of the underlying sensors and micro-components. Then, using the operating system, the middleware, cloud solutions, application interfacing, information management, and the Big Data of the software architecture, most devices should have self-management and self-optimization capabilities. In this manner, the need for automatic transmission of data in the complex IoT system can be met. The IoT acts as a bridge connecting people with machines and machines with machines [24].

The IoT is one of the largest sources of Big Data, and when large amounts of data require high-frequency processing, transmission, and analysis, the IoT and Big Data interact to transmit and store data. "Data security and privacy will play an important role in IoT deployments. Because IoT systems will produce and deal with personally identifiable information, data security and privacy will be critical from the very beginning [25]".

The IoT is the creator of data, and different types of data can be useful information after format conversion. Making IoT smart renders the data it produces more meaningful. Therefore, big data can be available. We offer a more detailed introduction to big data in Section 3.

2.6. Range of Application of Smart Cities in Taiwan

Following Cohen [26], we measure the development outcomes of a smart city from six dimensions. We hereby summarize the opinions of experts and scholars in all cities of Taiwan and the application and service programs are summarized as follows. Smart government includes weather forecast system, population census, open data platform, integrated disaster prevention system and waste management, electronic voting, smart city operation center, and smart policing. Smart environment consists of energy demand response system, solar photoelectricity, wind power generation, smart meter, exploration, collection and storage, smart water resources, water pollution monitoring, earthquake early warning system, forest fire prevention, and air quality monitoring. Smart living is composed of the digital convergence of video and audio platforms, accessibility services, smart tourism, mobile citizen cards, e-health information, smart hospitals, medical applications of artificial intelligence, care robots, and smart kits. Smart mobility includes in-car Internet, smart transport system ETC applications, smart parking lots, traffic flow, traffic detection, logistics vehicles and cargo management, smart retail, cross-border custom clearance, agricultural product traceability, and smart packaging. Smart people consist of smart learning, smart administration, smart health care, smart community, smart energy, smart home care, home safety control, smart community, and smart care. Smart economy is composed of smart finance (payment, insurance, financing, fundraising, investment management, and market supply). Cities shall prioritize these applications based on their respective characteristics and budget and work with available enterprises to implement such applications.

3. Big Data

The operation of big data is the core of smart city construction. First, data collection and awareness should be enhanced [1]. Cities should improve their data awareness and promote the extensive application of new technologies, such as wireless identification technologies, sensors, and wireless networks, to achieve smart infrastructure and smart city operation and management. Second, digital resources should be further integrated and different government departments should share data with each other [12]. Third, attention should be paid to the training of professionals in cities, and industrial advantages should be fully tapped. The construction of smart cities will certainly contribute to progress in big data [3]. In the future, the application market of big data in smart cities will constantly grow, and external development and exchange should be expanded. Concentration and development of the urban industrial chain should be fueled with the promotion and application of innovative technologies. Finally, we should also attach importance to setting up a sound data security system and strengthening network security protection. Data assetization is an inevitable trend, and data about the internal operations of enterprises and customer data are valuable data assets. Therefore, it is necessary to improve the security of urban information network. At the same time, we should also establish security monitoring and emergency response mechanisms [22], coordinate departments for monitoring and prevention, and thwart and reduce network threats to public and enterprise networks.

3.1. Big Data Management

Data can generally be divided into structured data, semistructured data, and unstructured data. Preprocessing unstructured data, converting them into structured data, and then storing the data is highly crucial for subsequent data mining. Complete use of Big Data depends on effective management to facilitate subsequent mining and cross analysis. A distributed file system (DFS) is a type of file system that allows files to be shared across multiple hosts using a network and enables multiple users on multiple machines to share files and storage space. The industry often uses the NIST SP800-1500 Big Data specifications as a template for operation management. The Hadoop DFS (HDFS) is widely used in the industry. Employing different designs, Big Data can be efficiently stored, managed, mined, and analyzed.

Building a data-centric smart city requires the vigorous support of data mining technology and the integration of different data formats. The application of data is the key to conducting data mining research on smart cities. Data visualization technology can present complex city data to customers in a concise and orderly form, favorably filling the understanding gap between the technology and its users.

3.2. Big Data Activation and Application

The data mining of business intelligence use statistics, AI, or other analytical techniques in the depths of Big Data is employed to identify unknown or hidden relationships and regulations. This achieves classification, estimation, prediction, affinity grouping, and homogeneous grouping, followed by presentation to the user using methods such as reports or web portals. This paper organizes the framework of Big Data applications in Taiwan's general industries as illustrated in Figure 2.

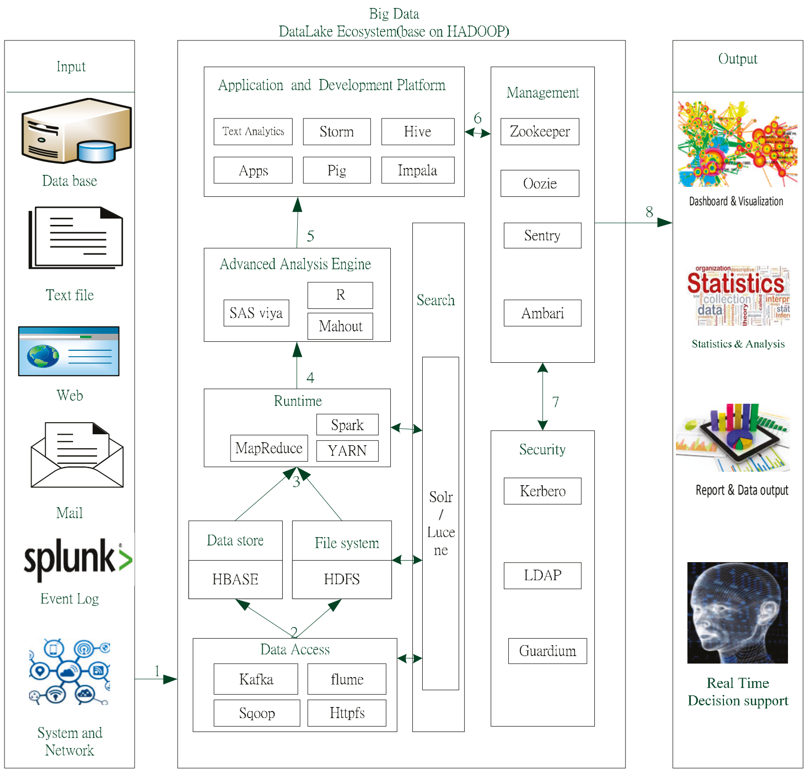

Figure 2. Big Data operations model.

The Big Data operational process, data flow sequence, and various functions of the platform in Figure 2 are described as follows:

- Input: Different types of data are input through the system and network interface to the data access module.
- Data Access: For the access interface, which is responsible for connecting to external heterogeneous platforms and applications, the commonly used kits and functions are Kafka distributed messaging, Sqoop for relational database connectivity, flume data clustering, and HttpFS (Hadoop Distributed File System, HDFS) supported HTTP (Hypertext Transfer Protocol) links and operations.
- The data store is the primary data storage system for a Big Data platform. HBASE is the database system used by Hadoop. The file system is the primary file storage system for the Big Data platform, and HDFS is the DFS (Distributed File System) used by Hadoop.
- RUN TIME is primarily responsible for parallel operations and program execution. MapReduce processes large volumes of data for Hadoop and complies with system architecture with a high fault tolerance. Spark is a cluster computing framework that uses in-memory computing technology. YARN (Hadoop MapReduceV2) processes large volumes of data for Hadoop 2.0, complies with system architecture with a high fault tolerance, and is also called MapReduce 2.0.

- The advanced analysis engine is used for kits related to statistical analysis and machine learning. R language is employed for statistical analysis and machine learning. Mahout and SAS Viya are approximately similar; it is most convenient to use the MapReduce function library for distributed analysis and machine learning operations.
- The application and development platform uses related development tools for various developments and applications of Big Data. Text Analytics is employed for text mining and analysis, and Apps is used for mobile application development. Storms is a fault-tolerant distributed open-source computing system and Hive uses SQL syntax to access Hadoop data; Pig is employed for data manipulation and processing, and Impala is used for high-performance SQL-like access of Hadoop data.
- Management: The collaborations between each component and resource management include the monitoring and setting of files, databases, and system resources. ZooKeeper collaborates with the internal servers of Hadoop, and Oozie is a workflow manager on Hadoop. The purpose of Sentry for Apache Sentry is to handle privilege management; it is a policy engine used by data processing tools to verify access rights. Ambari is a tool for establishing, managing, and monitoring Hadoop clusters.
- Security: The system 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. 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.
- The output module renders outputs using visualization, statistical graphs, and reports.

The aforementioned steps form the data flow cycle of the Big Data platform. This cycle must be supported by infrastructure such as the IoT, cloud computing, and a Mobile Network, synergizing commercial applications.

4. Current Developments in the Smart Cities of Taiwan

A secondary qualitative study was employed in this paper for research and analysis, and we needed to garner tons of reliable data. Therefore, we visited official websites of governments at all levels via the Internet and downloaded public budget statements, plans, policy plans, and other electronic documents of official public data and summarized budgets, infrastructure expenses, and enterprise investments of different cities. We analyzed and integrated these data in different years to probe into the strengths and weaknesses of smart city projects in six major cities of Taiwan.

This study uses the ICF's five dimensions to evaluate six special municipalities in Taiwan (New Taipei city, Taipei city, Taoyuan city, Tainan city, and Kaohsiung city) and promote research on the developmental characteristics of smart cities (due to the small size of cities in Taiwan, collaboration, leadership, and sustainability are largely similar and are not included in the statistical evaluations). The demographics of the cities are detailed in Table 2, and the developmental characteristics of the cities are shown in Table 3.

Table 2. Demographics.

City	Area (km^2)	Population	Population Density (Person/km^2)	Number of Motor Vehicles	Number of Factories
New Taipei city	2053	3,970,644	1934.48	3,193,363	18,251
Taipei city	272	2,704,810	9951.48	1,756,877	1098
Taoyuan city	1221	2,105,780	1724.70	1,877,439	10,297
Taichung city	2215	2,744,445	1239.08	2,725,634	16,955
Tainan city	2192	1,885,541	860.33	1,947,077	8621
Kaohsiung city	2952	2,778,918	940.50	2,879,176	6992

Source: Yearbook 2016, [26–30].

Table 3. Developmental characteristics of the six cities.

City	Developmental Characteristics	Implementation Characteristics	Current Status
New Taipei city	Mobile applications	Perform public service mobilization and informatization, reduce the urban–rural information gap, and increase public service efficiency and the degree of public participation	Implementation stage
Taipei city	Network convenience Mobile applications	Promote the Taipei free (TPE-Free) wireless Internet in the city and use the open data platform to create an innovative industry development environment	Implementation stage
Taoyuan city	Regional development	Use the Taoyuan Aerotropolis as a center, promote various smart applications, and diffuse and copy successful models to corners of the city	Planning stage
Taichung city	Industry investment	Use vigorous local commercial power; the introduction of crucial large-scale construction and investment in key economic parks will create innovative industrial development environments and create a new look for the city	Planning and implementation stages
Tainan city	Low-carbon sustainability	Low-carbon city development as a primary idea; promote the value-added application of smart electric cars, a smart grid, a mobile sightseeing service. and smart agricultural marketing-related business	Planning and implementation stages
Kaohsiung city	Humanistic transportation	Promote green transportation information services, enhance public service efficiency, create a new mobile objective for the city, and establish a favorable environment that is low-carbon and sustainable	Implementation stage

Source: Chieh (2015) [31,32], organized by this study.

According to information contained in the 2017 Statistical Yearbook of relevant departments of the Executive Yuan and various city governments, a comparison of data from 2014–2016, after weighted conversion is presented in Table 4 (10 the highest, 0 the lowest). The crucial data items include:

- Broadband connectivity: Including subscribers of various telecom services and penetration rates of various telecom services (total 4G subscribers for mobile subscribers in 2014; mobile broadband subscribers including data transmission services for 3G, 4G subscribers and Wireless Broadband Alliance (WBA) subscribers; fixed networks including ADSL (Asymmetric Digital Subscriber Loop), FTTx (Fiber To The x), Cable Modem, leased lines and Public WLAN (PWLAN) subscribers; other broadband subscribers include PWLANs and leased lines) [29,30,33].
- Knowledge workforce: Calculated by the ratio of the following factors—Population by Educational Attainment, Education budget, Number of teachers, Number of college, Number of college students and graduate students, Ratio of Classes, Teachers and Students of All School Levels [34–40].
- Innovation: Calculated by the ratio of the following factors—Number and Capital of Companies Registered—by Organization and Industrial Classification, Number and Capital of Registered Business Enterprises, Annual Expenditure for General Budget and Financial Statement [27,28,34–39].
- Digital inclusion: Calculated by the ratio of the following Items—Cultural Activities Social Educations, the Special Education Taiwan Cultural and Creative Industry Classifications, Number of Cultural and Creative Industries [29,34–39,41,42].
- Marketing and advocacy: Calculated by the ratio of the following Items—Internet Services, the Principal Indicators of Family Income and Expenditures, Result of Promotion for Community Development/Revenue and Expense for Operations Funds, Tourist Businesses and Inbound Visitors, Number of Visitors to the Principal Scenic Spots, Number and Capital of Companies Registered—by Organization and Industrial Classifications, Actual Number of Personnel in the Organic Structure with Subsidiaries [27,28,34–39].
- Sum: The sum of above.

Table 4. Statistical analysis scores of the five Intelligent Community Forum (ICF) dimensions for the six cities in Taiwan.

	Broadband Connectivity	Knowledge Workforce	Innovation	Digital Inclusion	Marketing & Advocacy	Sum
New Taipei city	9.12	5.8	6.8	0.2	7.0	28.92
Taipei city	9.46	9.2	2.7	6.2	6.3	33.86
Taoyuan city	9.13	4.5	1.3	3.9	2.9	21.73
Taichung city	9.14	6.3	1.4	8.2	5.5	30.54
Tainan city	8.8	5.8	1.2	9.8	5.7	31.30
Kaohsiung city	8.85	6.1	8.4	2.7	6.9	32.95

Sources: 1. 2016 report of a survey on broadband Internet usage in Taiwan, TWNIC. 2. Directorate-General of Budget, Accounting and Statistics, Executive Yuan, Yearbook 2017; Yearbook of Environmental Protection Statistics, 2017 [30–32]. 3. 2017 Yearbooks—Ministry of Education (MOE), Ministry of Economic Affairs (MOEA), Ministry of Interior (MOI), Ministry of Transportation and Communications (MOTC), Ministry of Culture(MOC), Ministry of Education (MOE), National Communications Commission (NCC), New Taipei city, Taipei city, Taoyuan city, Taichung city, Tainan city, Kaohsiung city [33–39,41,42].

Explanation: The strengths of the five ICF dimensions are scored, with 0 points indicating the weakest and 10 points indicating the strongest in Figure 3.

Figure 3 illustrates the strengths of the six cities in the five dimensions. Regarding broadband connectivity, Taipei city was the most favorable, whereas Tainan city was the weakest; regarding knowledge workforce, Taipei city was again the most favorable, whereas Taoyuan city was the weakest; Kaohsiung city was discovered to have the most favorable innovation and Tainan city the weakest. For digital inclusion, however, Tainan city was the most favorable; New Taipei city was the weakest. New Taipei city had the most favorable marketing and advocacy, and Taoyuan city the weakest. The smart city implementation characteristics for which each city has made plans (as shown in Figure 3) can also be used to strengthen the cities according to these weaknesses.

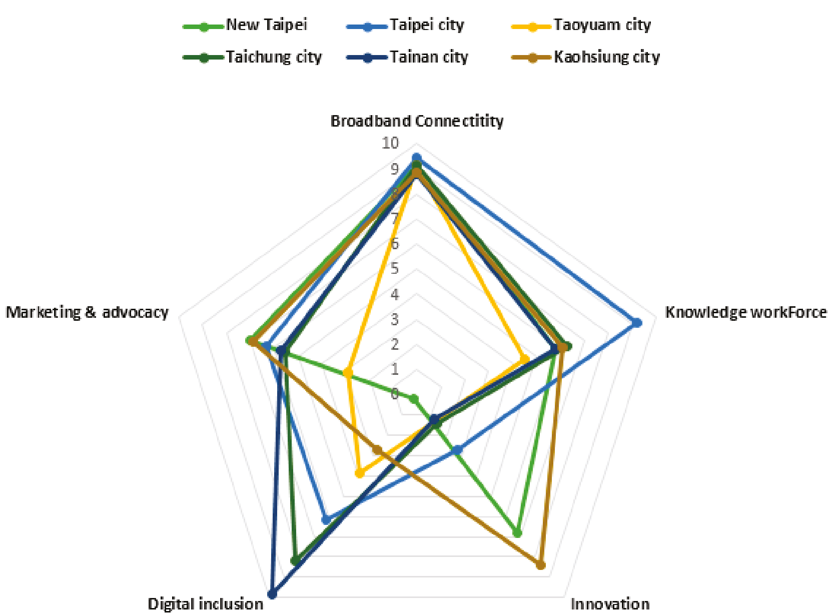

Figure 3. Strengths of the six special municipalities in the five dimensions.

From the weighted scores of the statistical annual report analyses of each city, it was determined that Taipei city had the overall highest score (33.86 points), followed by Kaohsiung city (32.95 points), Tainan city (31.30 points), Taichung city (30.54 points), New Taipei city (28.92 points), and Taoyuan city (21.73 points). These results are in line with Taiwan's political and economic development profile. Taipei city was the first special municipality of Taiwan and is also Taiwan's political and economic center. Its overall development began the earliest and is mostly complete; in broadband connectivity and knowledge workforce, it ranks first of the six cities. Kaohsiung city was Taiwan's second special municipality and is the political and economic center of southern Taiwan. Its overall development is more complete than that of other cities, excluding Taipei city. Tainan city and Taichung city are provincial cities and cultural centers with relatively more cultural atmosphere; thus, their digital inclusion scores rank highly. New Taipei city and Taoyuan city are relatively new special municipalities; a larger gap between urban and rural residents and services exists within its area of jurisdiction. Because early government budgets (2010–2016) were relatively small and infrastructure development occurred relatively late, it is anticipated that these cities will catch up rapidly and increase infrastructure funds to balance regional development.

5. Conclusions

Whether the sustainable development of a city is judged successful is primarily based on residents' perception of space and their space requirements [43]. Smart cities are now being developed worldwide; the purpose of establishing various evaluation indicators is to uncover the individual characteristics and service capabilities of each city. Verifying the effectiveness of a smart city plan provides a direction that guides the development of other cities. Measurements of smart cities do not have a definite standard; if a smart city with favorable development performance in the past did not take advantage of ICT development and continue to uncover new horizons and produce innovative services, the function of the smart city may be relatively deceased.

Because each city in Taiwan is promoting intellectualization, it is necessary—in addition to referencing smart city evaluation indicators—to evaluate the local advantages and needs of Taiwan. Consolidating existing resources, utilizing local characteristics, planning the sustainable operation of cities, and increasing the convenience of residents' lives can produce a smart city that truly meets the needs of residents and ultimately results in a more favorable quality of life and friendlier living environment with sustainable development.

Due to the special island environment of Taiwan and its limited local resources, smart city development must be people-oriented and ICT advantages should be used to solve local issues. This study builds a reliable and general automated evaluation model [41] as a response to the question of how to use sustainable city planning for the effective use and distribution of resources. Second, 4P public–private partnerships should be formed to promote innovative entrepreneurship platforms and enhance economic growth. Third, interdepartmental management of the government must be conducted to promote mutual cooperation between each competency department and realize open data and the effective integration and maintenance of a Big Data platform. Fourth, planning for information security has been implemented. Big Data analysis equipment, environment, resources, and data collection followed by re-analysis and application must be ensured. During the process, due to the crucial confidentiality of customer information and how to de-identify personal information and the sharing of comprehensive precautionary measures, it is necessary to pay attention to whether data sources comply with confidentiality principles, whether the analysis method employed is suitable, and whether the Big Data analysis results are fully used to ensure the confidentiality of data and the rights of customers. Finally, under the influence of the new trend of smart city development, how to adjust traditional laws, regulations, rules, norms, and implementation standards in response to changes in planning methods is dependent on the efforts of government departments and large-scale enterprises in taking the lead for planning and implementation. The innovative smart city solutions resulting from digital technologies, such as smart energy, smart food security, and smart environments, must be applied properly to achieve the sustainable goal of smart cities with low-carbon, ecofriendly, green-energy, recycling, and livable environments.

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References

1. Li, D.R.; Yao, Y.; Shao, Z.F. From digital Earth to smart Earth. *Chin. Sci. Bull.* **2014**, *59*, 722–733. [CrossRef]
2. Hashem, I.A.T.; Chang, V.; Anuar, N.B.; Adewole, K.; Yaqoob, I.; Gani, A.; Ahmed, E.; Chiroma, H. The role of big data in smart city. *Int. J. Inf. Manag.* **2016**, *36*, 748–758. [CrossRef]
3. Li, D.R.; Shan, J.; Shao, Z.F. Geomatics for smart cities-concept, key techniques, and applications. *Geo-Spat. Inf. Sci.* **2013**, *16*, 13–24. [CrossRef]
4. NIST Special Publication 1500-1. *NIST Big Data Interoperability Framework: Definitions*; NIST: Gaithersburg, MD, USA, 2015; Volume 1.
5. Big Data for Social Good LUCA Data-Driven Decisions. Available online: https://www.luca-d3.com/big-data-social-good/index.html (accessed on 10 October 2017).
6. Anupam, A. The Big Data Revolution for Sustainable Development. In Proceedings of the XI Meeting of the Latin America and the Caribbean Monitoring and Evaluation Network, Santiago, Chile, 28–30 June 2016; Independent Evaluation Office, Global environment Facity: Santiago, Chile, 2016.
7. China Electronics Standardization Institute. *Big Data Standardization White Paper*; China Electronics Standardization Institute: Beijing, China, 2016.
8. China Academy of Information and Communications Technology (CAICT). ICT Manufacturing Development Report 2016. Available online: http://www.caict.ac.cn/kxyj/caictgd/xxh/ (accessed on 22 October 2017).
9. Industrial Economics and Knowledge Center (IEK). Available online: http://ieknet.iek.org.tw/ieknews/news_more.aspx?nsl_id=14f5326242074c95a3f07a6c514a0081 (accessed on 15 October 2017).
10. Su, S.; Chi, C.; Su, M.Y.; Chao, T.Y. Opportunities and Challenges with Digital Economy Trends. 2017. Available online: https://www.itri.org.tw/Chi/Content/NewsLetter/contents.aspx?SiteID=1&MmmID=5000&MSID=744474650526526402 (accessed on 20 October 2017).
11. Yu, J.; Lee, S. The Impact of Greenhouse Gas Emissions on Corporate Social Responsibility in Korea. *Sustainability* **2017**, *9*, 1135. [CrossRef]
12. National Development Council. *Ide @ Taiwan 2020 (Creative Taiwan) Policy White Paper*; National Development Council, Public Governance Quarterly: Taipei, Taiwan, 2015; Volume 3, pp. 93–100.
13. Europeansmart. Available online: http://www.smart-cities.eu/ (accessed on 18 October 2017).
14. Intelligent Community Forum. Available online: http://www.intelligentcommunity.org/ (accessed on 22 October 2017).
15. Smart city China. Available online: http://www.smartcitychina.cn/ (accessed on 22 October 2017).
16. Foreseeing Innovative New Digi Services. Available online: https://www.find.org.tw/ (accessed on 20 October 2017).
17. Nicola, I.; Duccio, S.; Enrico, C. Smart Cities, Big Data, and Communities: Reasoning from the Viewpoint of Attractors. *IEEE Access* **2016**, *4*, 41–47.
18. 2016 Q1 Global APP Downloads TOP20 List. 21 April 2016. Available online: http://3c.yipee.cc/69866/2016-q1-%E5%85%A8%E7%90%83-app-%E4%B8%8B%E8%BC%89%E9%87%8F-top-20-%E6%8E%92%E8%A1%8C%E6%A6%9C%EF%BC%8C%E4%BD%A0%E6%9C%89%E5%93%AA%E5%B9%BE%E5%80%8B%EF%BC%9F (accessed on 17 October 2017).
19. Huang, T.S. Talking about Cloud Computing. NTU ePaper, 20 March 2009; Volume 0008. Available online: http://www.cc.ntu.edu.tw/chinese/epaper/0008/20090320_8008.htm (accessed on 12 October 2017).
20. Mell, P.; Grance, T. The NIST Definition of Cloud Computing, sp800-145, September 2011. Available online: https://www.tasclinx.com/wp-content/uploads/2013/02/141103-US-SP800-145.pdf (accessed on 12 October 2017).

21. 2016–2018 Cloud Computing Development Programs. Board of Science and Technology, Executive Yuan, 5 October 2017. Available online: https://www.bost.ey.gov.tw/cp.aspx?n=B56ED9F993B2EFA5 (accessed on 16 October 2017).
22. Choi, M. Leadership of Information Security Manager on the Effectiveness of Information Systems Security for Secure Sustainable Computing. *Sustainability* **2016**, *8*, 638. [CrossRef]
23. Abiy, B.C.; Domenico, R.; Roberto, M. Towards a Definition of the Internet of Things (IoT). 2015. Available online: https://www.researchgate.net/publication/317588072_Towards_a_definition_of_the_Internet_of_Things_IoT (accessed on 12 October 2017).
24. International Telecommunication Union. *The Internet of Things*; ITU: Geneva, Switzerland, 2005.
25. European Research Cluster on Internet of Things (TERC). IoT Business Models Framework. Deliverable 02.01. Available online: http://www.internet-of-things-research.eu/pdf/D02_01_WP02_UNIFY-IoT_Final.pdf (accessed on 10 October 2017).
26. Cohen, B. Methodology for 2014 Smart Cities Benchmarking. Available online: https://www.fastcompany.com/3038818/the-smartest-cities-in-the-world-2015-methodology (accessed on 12 December 2017).
27. MOEA 2016 Yearbook. Available online: http://dmz9.moea.gov.tw/gmweb/investigate/InvestigateG.aspx (accessed on 20 October 2017).
28. MOI 2017 Yearbook. Available online: http://dmz9.moea.gov.tw/gmweb/investigate/InvestigateG.aspx (accessed on 20 October 2017).
29. NCC 2017 Yearbook. Available online: https://www.ncc.gov.tw/chinese/gradation.aspx?site_content_sn=1967 (accessed on 12 October 2017).
30. A Survey on Broadband Internet Usage in Taiwan-A Summary Report. Taiwan Network Information Center, July 2016. Available online: https://www.twnic.net.tw/download/200307/20160922e.pdf (accessed on 20 October 2017).
31. MOTC 2017 Yearbook. Available online: https://www.motc.gov.tw/ch/home.jsp?id=59&parentpath=0,6 (accessed on 16 October 2017).
32. Executive Yuan 2017 Yearbook. Available online: https://www.dgbas.gov.tw/lp.asp?CtNode=3120&CtUnit=1049&BaseDSD=34&mp=1 (accessed on 10 October 2017).
33. National Development Council. Smart City Development under Land Planning. *Public Gov. Quart.* **2015**, *3*, 19–31. Available online: https://www.ndc.gov.tw/Advanced_Search.aspx?q=Public (accessed on 12 October 2017).
34. New Taipei City Yearbook 2017. Available online: http://www.bas.ntpc.gov.tw/content/?parent_id=10239 (accessed on 11 October 2017).
35. Taipei City Yearbook 2017. Available online: http://dbas.gov.taipei/ct.asp?xItem=61803&CtNode=6154&mp=120001 (accessed on 20 October 2017).
36. Taoyuan City Yearbook 2017. Available online: http://dbas.tycg.gov.tw/home.jsp?id=156&parentpath=0%2C153&mcustomize=picture_view.jsp&dataserno=201403310001 (accessed on 20 October 2017).
37. Taichung City Yearbook 2017. Available online: http://www.dbas.taichung.gov.tw/np.asp?ctNode=12288&mp=113010 (accessed on 13 October 2017).
38. Tainan City Yearbook 2017. Available online: http://web.tainan.gov.tw//account/list.asp?nsub=F3A300 (accessed on 18 October 2017).
39. Kaohsiung City Yearbook 2017. Available online: http://kcgdg.kcg.gov.tw/KCGSTAT/Page/ (accessed on 20 October 2017).
40. MOE 2017 Yearbook. Available online: https://www.edu.tw/News_Content.aspx?n=829446EED325AD02&sms=26FB481681F7B203&s=B19AF3B0B4D7BFAC (accessed on 20 October 2017).
41. Yearbook of Environmental Protection Statistics 2017. Available online: https://www.epa.gov.tw/public/Data/78239563771.pdf (accessed on 20 October 2017).
42. Taiwan Cultural Creative Industries Annual Report 2016. Available online: http://cci.culture.tw/cht/index.php?code=list&ids=20 (accessed on 20 October 2017).
43. Zhang, Y.; Lu, H.; Luo, S.; Sun, Z.; Qu, W. Human-Scale Sustainability Assessment of Urban Intersections Based upon Multi-Source Big Data. *Sustainability* **2017**, *9*, 1148. [CrossRef]

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Improving Operational Risk Management Using Business Performance Management Technologies

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Abstract: Operational Risk Management (ORM) comprises the continuous management of risks resulting from: human actions, internal processes, systems, and external events. With increasing requirements, complexity and a growing volume of risks, information systems provide benefits for integrating risk management activities and optimizing performance. Business Performance Management (BPM) technologies are believed to provide a solution for effective Operational Risk Management by offering several combined technologies including: work flow, data warehousing, (advanced) analytics, reporting and dashboards. BPM technologies can be integrated with an organization's Planning & Control cycle and related to strategic objectives. This manuscript aims to show how ORM can benefit from BPM technologies via the development and practical validation of a new maturity model. The B4ORM maturity model was developed following the Design Science Research approach. The maturity model relates specific maturity levels of ORM processes with BPM technologies applicable for a specific maturity stage. There appears to be a strong relationship (0.78) with ORM process maturity and supporting BPM technologies. The B4ORM maturity model as described in this manuscript provides an ideal path of BPM technologies related to six distinctive stages of ORM, leading towards technologies suitable for continuous improvement of ORM processes and organization-wide integration.

Keywords: risk management; Enterprise Risk Management; Business Intelligence; Corporate Performance Management; maturity model

1. Introduction

Operational risks are the root cause for many of the (large scale) financial failures in the past decades [1–4]. The aforementioned studies note that operational risks are not new: human mistakes, fraud, theft, process failures, system errors and external hazards, such as fires and floods, have been around for decades. However, the impact of operational risks was most often relatively insignificant. In contrast, recent trends such as globalization, global internet connectivity, and (value) chain dependencies, have made operational risks more significant than ever before. With increasing requirements, complexity and volume of risks, information systems are believed to provide benefits for risk management activities [5–8].

An increasing number of organizations, mainly in the financial sector, are required by regulatory authorities or by law to manage their operational risks. Fontnouvelle, et al. [9] found that in the early 2000s most international banks were already allocating more financial reserves to account for operational risks than for market risks. Operational risks tend to become more relevant in different types of organizations [10,11]. For example, operational risks have been studied for years in the healthcare sector [12,13]. Marques [14] and Cruz [15] describe how effective risk management influences the results in infrastructure contracts. Additionally, operational risks are becoming increasingly important in the energy sector [16]. Mitra, et al. [17] describe that the importance of operational risks varies depending on industry and the markets that an organization operates in. They found that financial organizations have the lowest expected returns on operational risk, and basic material producers have the highest return. Operational risk is different from other risks, such as credit risk or market risk, because operational risk is usually not taken to retrieve an expected return. Operational risk exists in every organizational activity. Inappropriate management of operational risks can result in significant losses.

With increasing requirements, complexity and volume of risks, information systems provide benefits for integrating risk management activities and optimizing risk management performance. Information systems and technologies can support the improvement of operational risk management processes [6–8]. Lam [18] and Arnold, et al. [19] describe performance management systems as a set of technologies from the information systems domain suitable for application to support the operational risk management process. In recent years, this recognition is supported from practice by consulting firms, PwC [20] and Deloitte [21] who state Business Performance Management and its supporting technologies could provide effective support for risk management processes.

Nyenrode Business University [22] performed a large scale study about the state of risk management practices in the Netherlands. Nyenrode writes risk management should be part of the Planning and Control cycle, aligned with strategic goals of the organization. Integrated risk management and better collaboration lead to a more mature risk management. These benefits could only effectively be achieved by using appropriate software. However, Nyenrode concludes that many organizations do not appear to know what software features to use for effectively improving risk management.

Several sources [19,23,24] describe Business Performance Management (BPM) related technologies such as workflow, centralized storage, and dashboarding, which could provide a solution for Operational Risk Management (ORM) issues. However, it remains unclear whether the full spectrum of Business Performance Management technologies is suitable for improving operational risk management processes and whether the same set of BPM technologies are applicable for all types of organizations. Additionally, there appears to be no existing or specific guidance for organizations seeking to improve operational risk management processes using Business Performance Management Technologies (BPMT).

The following section describes important background information about the context and the domains of Operational Risk Management and Business Performance Management Technologies. This research follows the Design Science approach using the methodology as described by Hevner, et al. [25]. The Design Science approach describes an artifact to be studied and validated. The section Materials and Methods describes and motivates the development of the maturity model artifact. Maturity models are used to guide improvements of certain processes using capabilities or technologies, corresponding to levels of maturity. Sections four and five show the results of validating the maturity model in practice from two different perspectives: ORM as process and the use of BPM technologies. The results are concluded with some recommendations for further research and potential applications in practice. The scientific contribution, some remarks and implications regarding quality are the points of discussion in the final section of this manuscript.

2. Theoretical Framework

Several studies [1,26–30] describe that risk management approaches throughout the 1980s and 1990s had grown into different silos of risk management practices; each type of risk was managed independently. Different silos of risk management practices lacked organization wide overview and insights. This led to concepts of integrating organization wide risk management practices with the objective of eliminating redundancies in double activities and other inefficiencies.

Culp [31] describes that the classical view on risk management was mostly financial and insurance focused on reducing financial drawbacks, rather than actually managing risks. In the

1990s, a transformation started towards more integrated risk management practices, combining all risk management activities in Enterprise Risk Management and appointing a Chief Risk Officer (CRO) on board level of organizations. According to Olson and Wu [32], the concept of Enterprise Risk Management (ERM) developed from the 1990s into a discipline around the 2000s. In this period the Committee of Sponsoring Organizations of the Treadway Commission (COSO) developed an internal control framework that was aimed to counter fraud. The first internal control framework was published in 1992, but gained wide acceptance following financial failures of the early 2000s, such as the Enron and WorldCom scandals.

Nowadays COSO ERM is a de facto standard risk and control framework used within many larger organizations. COSO is aimed at corporate wide governance including enterprise wide risk management. Gordon, et al. [33] state Enterprise Risk Management is a subset of an organization's management internal control system. Enterprise Risk Management is the domain that provides a holistic approach on risk management practices throughout an entire organization and is related to the organization's objectives. ERM combines different risk management practices into a holistic discipline.

Another perspective on enterprise wide integration of risk management practices, comes from a technology perspective [34]. The Open Compliance and Ethics Group (OCEG) is a nonprofit organization with roots in the IT services industry. The OCEG developed standards and guidance on integrating Corporate Governance, Risk Management and Compliance (GRC) practices. Integrated Governance, Risk Management and Compliance consists of four holistic and organization wide components: strategy, people, processes and technology. Correctly managing and supporting operations with integrated GRC results in ethically correct behavior, improvements of efficiency and effectiveness [35]. Racz, et al. [36] researched the relationships between ERM and GRC, as shown in Table 1. The authors describe two different perspectives:

1. ERM is a full subset of GRC, where GRC is the umbrella concept, overreaching ERM;
2. ERM and GRC overlap. Both share common objectives, processes and technologies, however both domains have their own specific processes as well.

Table 1. Comparison of different perspectives on ERM and GRC.

Factors	Enterprise Risk Management (*ERM*)	Governance, Risk and Compliance (*GRC*)
Root domain	Accounting	Information Technologies
Goal	Reasonable assurance regarding the achievement of entity objectives [37].	Ethically correct improving efficiency and effectiveness trough GRC [35].
Type	ERM is a continuous **process** across the enterprise [37].	GRC is an integrated, holistic **approach** [35].
Approach on integration	Integrating silos of different types of risk management [30,38].	Silos of duplicating efforts in the different areas of governance, risk and compliance [39].
Role of Information Technology	Information Technology as enabler of firm agility and flexibility [19].	Information technologies as an enabler for GRC to increase compliance procedures and concurrently reducing costs [40].

2.1. Operational Risk Defined

Power [3] writes that the term "*operations risk*" first appeared in the early 1990s. When the Committee of Sponsoring Organizations of the Treadway Commission (COSO) officially introduced its first version of the integrated internal control framework in 1991. According to Power, the term "operations risk" did not gain full attention until 1999 when the Basel Committee introduced Basel II.

Around the 2000s the Basel committee identified a need for a new type of risk appearing from fraud and human misbehaviors such as theft, mistakes or fraudulent actions, which were not covered by any other type of risk management. Therefore the Basel committee defined operational risk as: "*the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events.*

This definition includes legal risk, but excludes strategic and reputation risk" [41]. The committee states organizations can adapt or modify the definition to their own specific context.

The Basel committee [42] detailed operational risks further into specific event type categories:

1. **Internal fraud**, losses related to intentional or inappropriate acts. Circumventing laws, regulations or organization policy, involving at least one internal stakeholder;
2. **External fraud**, losses related to intentional or inappropriate acts regarding misappropriate property, information breaches (cyber-crime) or acts that circumvent the law by a third party;
3. **Employment practices and workplace safety**, losses related to acts inconsistent with health, safety or employment laws or agreements;
4. **Clients, products and business practices**, losses arising from a failure to meet professional obligations to clients or from the nature or design of a product;
5. **Damage to physical assets**, losses or damage related to natural disasters or other events;
6. **Business disruptions and system failures**, loss from business disruptions and system failures;
7. **Execution, Delivery & Process Management**, losses resulting from process management, transaction processing or external relations, such as trade counter parties and vendors.

Operational risk, as defined by the Basel Committee, is a financial term, meaning the term operational risk is well known and understood by banking and insurance organizations. Within the financial services industry, operational risks are often part of COSO ERM activities and related to corporate governance activities.

2.2. Operational Risk Management

Properly managing operational risks is described as a 'three lines of defense' model [11,43,44]. Operational risk events and their consequences should be handled at the organization function in which they occur, however, severe consequences should be directly reported to the board and other stakeholders. Proper execution of the operational risk actions on the first lines should be managed and monitored by an (independent) function within the organization, called a second line of defense. A third line of defense is formed by an (independent) audit committee assessing the complete operational risk management structure, process and implementation on a regular basis. An audit team can be internal, external or both.

Effective risk management practices require a structured process. In 1974 Gustav Hamilton developed the "risk management circle" that shows risk management as a continuous process. Hamilton's publication is described as the first to depict risk management types and activities as applied in an organizational risk management context [45]. Over the following years from several different domains in engineering, accounting and more disciplines developed their own risk management best practices. For example, Carr, Konda, Monarch, Ulrich and Walker [46] from Carnegie-Mellon university created a risk management process for use in software engineering.

In 1995, Standards Australia (AS) and Standards New Zealand (NZS) published the first official Risk Management Standard. Purdy [47] writes that the AS/NZS 4360:1995 standard was created by a team from multiple disciplines working together to create a common frame of reference for risk management.

In 2004, COSO ERM was published, providing an internal control framework including risk management from an accounting perspective. COSO ERM aimed to provide a framework including risk management activities as an essential part in steering organizational objectives.

In 2005, The International Organization for Standardization (ISO) identified a need for resolving inconsistencies and ambiguous practices from different disciplines. The ISO created a working group including hundreds of experts from 28 different countries to write a global standard providing a definition, generic application practices, and one language of risk management. Four years later the ISO Committee for risk management published ISO 31000. Purdy describes that the plan, do, check, act cycle by Deming and structure from the Australian and New Zealand standards were used as an important source by the ISO committee to develop ISO 31000 for risk management. However, most of their content was completely rewritten.

Although COSO ERM and ISO 31000 use a different language, both risk management processes appear to have a similar structure. As presented in Table 2, both frameworks are structured in a similar way, however their approach, some activities and terminology are different.

Table 2. Comparing process activities between COSO ERM and ISO 31000.

COSO ERM [37]	ISO 31000 [48]
Internal Environment	Internal and external environment
Objective setting	Identifying and describing objectives
Risk Assessment: 1. Event identification 2. Risk assessment 3. Risk response	Risk Assessment: 1. Risk identification 2. Risk analysis 3. Risk evaluation
Control activities	Risk Treatment
Information and communication	Communication and consultation
Monitoring activities	Monitoring and review

2.3. *Performance Management*

Performance management is an abstract term that can be confusing because of its broad nature and the meaning of the words 'performance' and 'management'. It all depends on what kind of performance is intended to be managed.

Hoffmann [1] defined performance as "valued contribution to reach the goals of an organization". In general, Performance Management can be seen as a way for organizations to become more successful and make sure they are delivering against their strategic priorities. The process of performance management starts at the highest level of the organization by translating a mission and vision statement into a strategy, composed of objectives and priorities. These objectives and priorities should then be translated to high level measures and then by middle management into measures on operational levels. These high-level measures and operational measures express organizational performance. The performance should then be communicated by reporting the measured performance and managed to align people and culture with strategic goals.

2.4. *Performance Measurement*

Performance can only be managed when the actual performance is known. Performance Measurement is the method of developing performance indicators and relating them to contextual factors to enable measurement of performance. Performance could then be actively improved by management. According to Lebas [49], Performance Measurement is a critical and inseparable component of Performance Management.

Simons [50] describes performance measurement systems: "Assist managers in tracking the implementations of business strategy by comparing actual results against strategic goals and objectives. A performance measurement system typically comprises systematic methods of setting business goals together with periodic feedback reports that indicate progress against goals".

2.5. *Business Performance Management*

Business Performance Management evolved from Decision Support Systems (DSS) in the 1960s and developed throughout the following years into Executive Information Systems (EIS). The development of aggregated data storage, known as Data Warehousing (DW), led to the inception of

Business Intelligence (BI) in the late 1980s [51]. Business Performance Management (BPM) builds on the foundations of BI, extending BI with planning, consolidation and process automation [52].

Business Performance Management (BPM) is defined by Sharda et al. [53] as "the business processes, methodologies, metrics and technologies used by enterprises to measure, monitor and manage business performance." Synonyms for BPM are Corporate Performance Management (CPM) by Gartner research, Enterprise Performance Management (EPM) by Oracle and Strategic Enterprise Management (SEM) by SAP. In this research the term Business Performance Management (BPM) is used, because this term is not related to a specific organization or technology vendor.

BPM is supported by a set of technologies for integrating and analyzing performance-relevant data, supporting decision making and facilitating the communication of decisions. Frolick and Ariyachandra [51] describe BPM developed from DSS to EIS, then combined with Data Warehousing into Business Intelligence. Melchert et al. [54] describe Business Performance Management as a combination of technologies from the domains: Business Intelligence, Business Process Modelling and Enterprise Application Integration. Combined with elements from Process Performance Management, Business Process Automation and Real-time Analytics. Figure 1 combines all BPM related technologies.

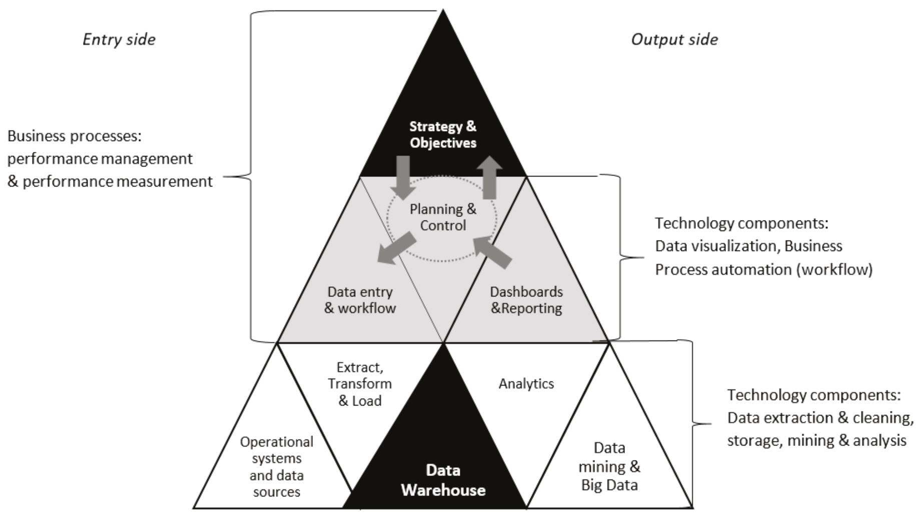

Figure 1. The Business Performance Management (BPM) pyramid; BPM related processes and supporting technologies, based on: Melchert, et al. [54], Frolick and Ariyachandra [51], Samsonowa [55].

The BPM pyramid is intended to summarize the domain of Business Performance Management. It is composed of three different layers: Strategy and objective setting at the top, because that is the ultimate goal related to (*strategic*) management, similar to the [56] BI pyramid. The middle layer is an important interface layer between organizational planning & control and supporting technologies. Data entry and workflow enable planning on the entry side. Dashboards and reporting interface the results and enable controlling on the output side. Proper implementation of this interface layer may also be facilitated by descriptive meta-algorithmic models as best practices process guides [57]. The bottom layer is only technology related, facilitating input of clean source data on the entry side. Building on a Data Warehouse as central data storage, data mining and big data enhancing the data on the output side with analytics, as source for dashboards and reporting [58].

Business Performance Management technologies as described can support any process with a continuous improvement cycle—using goal setting, performance measurement and reporting.

Integration of operational risk management practices appears to benefit from several Business Performance Management technologies, such as workflow and data entry to support collaboration between the three lines of defense and other stakeholders, such as the board of directors and shareholders. Analysis, dashboarding and reporting could support communication and process monitoring activities.

3. Materials and Methods

According to McCormack et al. [59] process maturity is increasingly important. Since the 1980s, maturity models were developed to guide an organization through the process of improving maturity that leads to competitive advantage. A maturity model artefact, developed through the Design Science approach was considered the most suitable for this research. Following from the research objective, the main research question is formulated as follows:

> *"How can organizations incrementally improve their Operational Risk Management processes using Business Performance Management technologies?"*

This research project follows the design science approach and the related design science guidelines as shown in Figure 2 and described by Hevner et al. [25]. Additionally, this research follows the design science processes as described by Hevner [60]. Hevner clarified the design science process as an iterative process of continuously building knowledge base used for developing an artifact to be evaluated and tested for relevance in practice. The process cycles as followed are shown below.

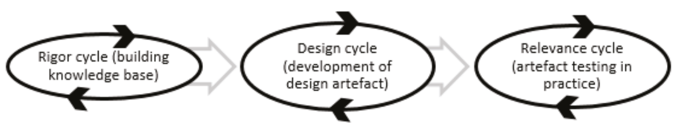

Figure 2. The Design Science cycles, adapted from Hevner [60].

3.1. The Need for a New Maturity Model

Maturity models appear to be strongly influenced by developments in the domains of Information Technology and Quality management. In 1973 Richard Nolan [61] developed the stages of growth model for mature use of computer resources within businesses. This model included six different stages, describing key elements and controls for successfully integrating information technologies within a business organization. In 1979 Crosby [62] developed a quality management maturity grid (QMMG) from a quality management perspective, intended to improve business processes. This grid was focused on improving quality management processes based on five levels of maturity: uncertainty, awakening, enlightenment, wisdom and certainty. Crosby's work was adapted by Watt Humphrey [63] to create the first process maturity framework, aimed at improving software development practices. Watts Humphrey's work laid the foundations for the Capability Maturity Model (CMM). The Capability Maturity Model (CMM) was developed by Paulk et al. [64] from the Carnegie Mellon University Software Engineering Institute (SEI).

Since the introduction of the Capability Maturity Model (CMM) and CMM Integration (CMMI), many different maturity models have been developed. The concepts of maturity models expanded to different industries and specific applications. Notable applications of advanced maturity models have been developed for information security management [65], master data management [66], and datawarehousing [52], among many others. Furthermore, several maturity models for risk management have been proposed. From a technology perspective there are also maturity models on the domains of Business Intelligence and Business Performance Management.

Seven different maturity models related to risk management were examined in more detail:

- Hillson's Risk Maturity Model [67];
- Risk Management Society (*RIMS*) Risk Maturity Model [68];
- BDO's Operational Risk Management Maturity Model [69];
- Assessment Framework for Information Security from the Dutch National Bank [70];
- U.S. Department of Energy's Cybersecurity Capability Maturity Model (*C*2*M*2) [71];
- Deloitte Enterprise Risk Management Maturity [21];
- RSA's Maturity Model for operational risk management [72].

From a technology perspective there are also maturity models on the domains of Business Intelligence and Business Performance Management, the following were studied:

- Wettstein & Kueng's maturity model for performance measurement systems [73];
- AMR Research's Business Intelligence/Performance Management Maturity Model, Version 2 [74];
- Gartner's Business Intelligence & Performance Management Maturity Model [75];
- Aho's (*Logica*) Capability Maturity Model for Corporate Performance Management [76];
- IBM's Big Data & Analytics Maturity Model [77];
- UU's Business Intelligence Development Model [78].

From the maturity models studied, the following became clear:

- Most risk management related maturity models do not include a relationship with software technologies; when they do acknowledge this relation, these models are not detailed and are incomplete about specific requirements suitable;
- Technology related maturity models often appeared to be focused on one silo of ORM, for example only the Information Technology or Information systems part of ORM. Additionally these models do not include a risk management cycle, these models do not support risk management processes sufficiently;
- Only RSA's ORM maturity model appears to focus on both software technologies and risk management, however it is developed commercially and therefore it is vague about specific features. Additionally, the RSA model appears to be very focused on their own product ('*RSAArcher*') rather than supporting generic risk management practices with other solutions.

Next to the theoretical gap in knowledge, this appears to be a problem with practical relevance as well. In practice there appear to be several issues with ORM software. Nyenrode Business University [22] and Sadgrove [44] describe unsatisfied users of current ORM software. Specific issues relate to reporting and insights and (*complicated*) integration with the Plan and Control cycle. Business Performance Management includes tools for measurement, reporting and work flow. BPM is specifically developed towards the improvement of organizational performance to meet its strategic objectives. BPM technologies appears to be a reasonably complete set of software technologies to be suitable specifically for improving operational risk management. No such maturity model exists, while there appears to be a need for a detailed description of suitable technologies related to ORM.

3.2. Maturity Model Development

Since no maturity model appears to exist for improving ORM using BPM technologies, a new maturity model was developed for this purpose: B4ORM. From the exploration of existing maturity models, as described in the previous section, it became clear that a maturity model is composed of a (business) process that needs to be improved and the means (technologies) that need to advance to a more mature process. The following procedure was followed for maturity model development:

1. Process part: ORM detailed from literature and standards
    - Process maturity levels adapted from literature, CMM(I) based;
    - Process structure from literature, COSO ERM and ISO 31000;
2. Technology part: mostly unclear, explored in this research as following:

- Identification of BPM technologies or features suitable for ORM trough literature study;
- Market analysis of existing ORM software products for identification of suitable technologies;
- Expert panel for validation and ranking suitable technologies;

3. Mapping features to ORM processes, based on expert panel ranking;
4. Initial maturity model.

The maturity model as developed in this research is structured with enterprise wide risk management integration in mind. An important part of operational risk management are the processes to manage risk. From literature it appears that operational risk management is often part of enterprise risk management (ERM) and its related risk management processes. Therefore, the process structures for ERM are used for ORM.

Based on the existing maturity models for risk management and their different approaches with a proliferation of terminology, this maturity model uses standard terminology as found in the COSO ERM and ISO 31000 frameworks.

As a starting point for maturity model development, it is presumed important to know what software products already exist and what features are provided for use with operational risk management. Therefore, 65 existing software products were selected on occurrence and relevance. The software products were selected based on their self-promoted or marketed terminology.

On average, a software product for operational risk management is marketed at around five different sectors or industries. Most software for operational risk related practices is marketed for financial services, even though this research also included products for different terminology, such as Health, Safety, Environment and Quality (HSEQ) and specific areas of operational risk management, as used and known in other industries. Enterprise wide risk management practices such as ERM and GRC appear to be well known. ORM is known as a term in financial services and energy and appears also in the most marketed sectors. Interestingly, HSEQ is mentioned by just 18%, while the sectors using the term HSEQ are addressed and marketed by about 30% of ORM software vendors.

The possible options to measure operational risk management regarding process implementation and process maturity were rated by the five experts for suitability. The software features were grouped according to their relating process steps and the experts were asked to determine a ranking of software features according to importance regarding operational risk. For validation of the practical completeness regarding features found during market analysis, each expert was asked to indicate missing software features. All five experts indicated that all of the identified software features were sufficient to support operational risk management processes.

3.3. Expert Panel Driven Development

Table 3 introduces our expert panel of five operational risk management experts whom we consulted using the score voting method. The votes were given anonymously using a voting system that worked with Kahoot, via the participants' mobile/smart phones. On points where no dominant vote was given by the experts, a discussion was held. All experts received all questions and possible answers two weeks before the actual panel session. The scores as given by the experts were mapped to ORM maturity levels and the results of this mapping resulted in a maturity model as shown in the diagram (Figure 3).

Table 3. Expert panel members and their experience with ORM.

Type of Organization	Org. Size in FTE	Experience with ORM
Business Consulting	18	13 years
Business Consulting	18	14 years
Business University	290	10 years
Financial services	3600	3 years
Financial services	390	15 years

3.4. BPM for ORM (B4ORM) Maturity Model

The diagram in Figure 3 visualizes the B4ORM maturity model structure in a matrix. The horizontal axle shows the different maturity levels of the B4ORM maturity model. The vertical axle describes each of the different risk management process stages according to ISO 31000. Each cell of the matrix is filled with a technology requirement, that can be created using BPM technologies.

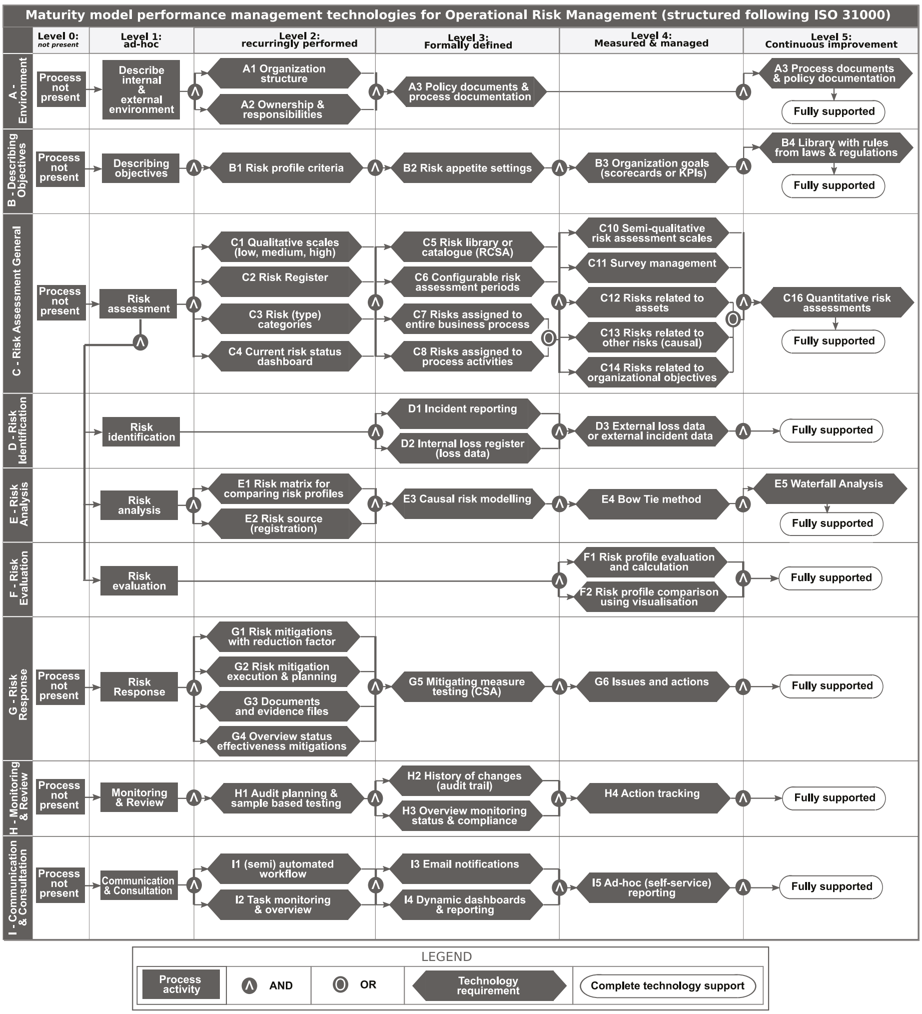

Figure 3. B4ORM maturity model components and logic visualized.

The input from the expert panel was used to map each technology requirement to a suitable maturity stage. Level 0 (not present) and level 1 (ad-hoc) contain only process activities, since BPM technologies do not benefit these stages. Up from level 2, BPM technologies support improvements in process maturity on a recurring basis and it is formalized towards organization-wide integration.

The B4ORM maturity assessment artifact created in this research [79] was evaluated using a field study to examine the use of practical application regarding the maturity model artifact. The field study was composed of open interview questions for determining contextual information and perceptions that might influence the maturity model application and use. The interviews were transcribed and analyzed through coding and ranking. Additionally, structured assessments were performed using a programmed assessment instrument to instantiate the designed maturity model artifact for evaluation in practice.

4. Results: The Importance of ORM

Table 4 lists the sixteen organizations which provided usable information to answer the research questions. Per participating organization, at least one person was willing to participate in this research. Some organizations provided answers from multiple participants.

Table 4. Organizations participating in maturity model evaluation.

Organization & Industry	Primary Focus
Energy 1	Energy provider
Energy 2	Energy provider
Financial services 1	Insurance services
Financial services 2	Pension services
Financial services 3	Banking services
Financial services 4	Banking services
Financial services 5	Banking services
Financial services 6	Insurance services
Healthcare 1	Patient treatment
Healthcare 2	Patient treatment
Production & trade 1	Organic materials
Retail & consumer goods 1	Groceries
Retail & consumer goods 2	Health & beauty
Transport & Infrastructure 1	Airline services
Transport & Infrastructure 2	Airline services
Transport & Infrastructure 3	Infrastructure provider

The Importance of ORM was measured with the actual implementation of ERM related practices and perceived implementation or maturity level of ORM. The implementation of an enterprise wide approach towards risk management was measured trough the coordination central or de-centralized. A central approach towards risk is recognized by most of the participating organizations. About 88% indicated to have a central department coordinating risk management.

The presence of a Chief Risk Officer (CRO) role at the board level is another indicator of organization wide approach to risk management. Interestingly, 44% of the organizations delegate risk management to their Chief Financial Officer (CFO) compared to 44% appointing a dedicated CRO. In a few cases, even the Chief Executive Officer (CEO) or Chief Operations Officer (COO) was responsible for all risks. The CEO in most organizations (76%) just received reports or received reports and was brought up to speed regarding severe operational risk related incidents. ORM was given an overall importance of 7.6 (SD = 1.8) of 10. This indicates that most organizations find ORM quite important, but not the most important. Most implemented (100%) and most important process of ORM is risk assessment (8.8 of 10), including risk identification, analysis and evaluation.

Most organizations have a relatively small ORM department: 82% of the participating organizations dedicate between 1 and 15 Full Time Equivalent (FTE) to ORM, with some exceptions indicating higher numbers, mainly large international banks. On average, an ORM department is made up of 13 FTE, however a standard deviation of 14 indicates high fluctuations from this average in both ways (positive and negative). Not only the ORM department is involved with operational risks. On average about 5.7 (SD = 2.9) different roles are mentioned to be involved with ORM on a regular basis.

An enterprise wide risk management framework is often also described to structure the organization and its processes regarding risk management. COSO ERM appears to be the most popular by 56% of the participating organizations. While 25% of the participating organizations have no framework at all. The maturity of ORM processes overall was measured using perception of the participants and via calculation of the maturity scores. Most participants scored their current maturity level 3.7 of 5 (SD = 1.1) very similar to their calculated score of 3.4 (SD = 0.99). The initial results of the maturity model were considered to yield an accuracy of 75%, accurately reflecting their current status.

5. Results: Tooling Use for ORM

For most organizations tooling for risk management is just known as software. Although BPM technologies are not equal to all software features, the actual use and availability of all software features are first described to provide context of tooling use. Then the software features are reduced towards the scope of this research and related to BPM technologies.

Most organizations, 14 of 16 (87.5%) indicated they use dedicated software for ORM, while 2 of 16 (12.5%) organizations indicated they rely primarily on self-made excel solutions for risk assessment or reporting. All participating organizations were asked why software is needed for operational risk management. From interview analysis it appears that most, or 11 of 16 (69%) organizations, primarily need the software for efficiency; without the software more people are needed to perform the same tasks.

On average, 37 (55%) distinctive software features are used for operational risk management, from the 68 identified software features in the market analysis. Software features for describing the organizational environment, such as organogram and processes, are most used by all organizations. Qualitative scales for operational risk assessments are used by almost all organizations (88%) in this research. Risk assessment features (incl. the processes of identification, analysis and evaluation) appear to be used by most organizations, however around 12 percent indicate that these features are not actually available in the purchased software and therefore these organizations rely on spreadsheet solutions.

Interview transcript analysis showed that half of the participating organizations, 8 of 16 (50%), indicated the software for ORM leads to a better overview & insights regarding operational risks. Additionally, about one third, or 5 of 16 (31%), of the participating organizations indicated that the integration of all operational risk related data into one integrated tool enables efficient and effective communication and collaboration. Dashboards & Reporting are the most used software features as indicated by 9 of 16 (56%) of the participating organizations. Half of the participating organizations, 8 of 16 (50%), talk about risk assessment. Central storage or a central database, or data warehouse is described by 6 of 16 (38%). Process modelling is described to be used by one third or 5 of 16 (31%). Incident registration is reported to be used by 4 of 16 (25%). Workflow as a component of collaboration is used by 3 of 16 (18%). The use of a file manager for documents and reports is used by 3 of 16 (19%). The least used software features are Action Tracking—2 of 16 (13%)—and Filter & sort features for reports and data sets—2 of 16 (13%). Features that were only mentioned once include a rules engine for fraud detection, control monitoring (measuring mitigation effectiveness) and operational risk workshop support.

5.1. Satisfaction of ORM Software

Only 25% of the organizations indicated that they were fully satisfied with their software for ORM. While 44% indicated that they had small points for improvements. About one third (31%) are not satisfied on their most important points. When considering motivations for satisfaction, it appears most complaints (26%) relate to central integration into a central data repository for operational risks and resulting quality of reporting (18%). Usability in the sense of a user friendly interface is a fairly large (18%) reason for being dissatisfied.

5.2. Use & Availability of BPM Technologies

The previous sections described the use of software as a whole. This section describes the relation with Business Performance Management related technologies. From the 68 identified software features, 63 = 94% are related to Business Performance Management Technologies. Excluded BPM technologies are process modelling functionalities, process documentation and policy documents (used by 69%) via a file system, risk voting (used by 12.5%), process or scenario simulation (used by 12.5%) and rich text editor functionality (used by 6%).

On average. 2% of all used software features cannot be realized using business performance management technologies. Most notable features are process documentation & policy documents (used by 69%) via a file storage manager and process flow modelling (used by 75%). Currently the most used business performance management technologies from interviews are: dashboards & Reporting: 9 of 16 (56%), risk assessment 8 of 16 (50%), central storage or database 6 of 16 (37%), data entry for incident registration 4 of 16 (25%), workflow 5 of 16 (31%). Most of the participating organizations (62%) indicated falling back to using spreadsheet solutions for ORM, organizations utilizing more than 60% Business Performance Management Technologies available do not appear to have this fallback.

During interviews, the participants were asked about their future (5 year) perspective regarding the software for Operational Risk Management. 10 of 16 (63%) expect data integration to become more important. 8 of 16 (50%) describe improvements of dashboards & reporting functionalities. Insights related to risks and mitigating measures by 5 of 6 (31%). 6 of 16 (38%) indicated context aware solutions, adapting to a specific role in the organization (e.g., only information that is relevant for that specific person at a specific time) is an important improvement in the future. Additionally, usability, specifically user friendliness and easy-to-use interfaces, is required by 4 of 16 (25%). Collaboration, process automation & process monitoring functionalities are described by 3 of 16 (19%) of the participants.

5.3. BPM Technologies Related to ORM

The goal of this section is to describe how the maturity levels relate with actually used technologies in order to describe their qualities and suitability for measurement.

The overall average of calculated ORM maturity scores per organization were compared with overall average of BPM technologies regarding use and availability. On average, calculated ORM process maturity has a strong (0.78) Pearson correlation with overall BPM technology use. Note this correlation was performed on a relatively small sample (n = 16). However, such a strong correlation indicates that the level of ORM maturity is related to actual BPM technologies used.

When diving into more detail, the environment, risk identification, risk analysis, risk evaluation and mitigation steps are quite decently correlated with maturity and used technologies. Objective setting and monitoring functionalities appear to be available to organizations with higher maturity scores, but they are far from the most used. Risk assessment in general might be too general, because it does not appear to have any relationship with maturity and technologies. No relationship was found for maturity and technologies to aid communication, but this might be explained by the fact that communication is a human process and does not necessarily rely on technology to be successful.

5.4. Other Factors of Maturity

Since the maturity model context was also recorded for interpretation, these organization characteristics were also compared to maturity as measured with the developed maturity model. Pearson correlations were performed on a small sample (n = 16). Weaker correlations than 0.20 with alpha 0.05 are left out, because such correlations are so weak that considering the sample size they do not indicate anything at all.

Organization size, especially the amount of FTE appears to correlate moderately (0.50 alpha 0.05) with ORM process maturity. Additionally, technology maturity and BPMT use show a weak relationship. A similar relationship is not found when considering the yearly income where only a weak relationship exists with maturity. Being an international organization or not does not appear to indicate a difference for ORM.

The number of laws and regulations for an organization do not appear to influence the actual maturity, however they have a weak relationship (0.27 alpha 0.05) with the technology maturity. A perception of a higher competitive pressure interestingly seems to relate moderate (−0.41 alpha 0.05) negative to the actual use of technology.

When considering the structure of ORM, the presence of a framework for ORM does not appear to be meaningful. The same appears to be the case for a centralized or de-centralized approach towards ERM; these correlations are so weak that they do not really indicate anything. The number of FTE dedicated to ORM appears to have a weak relationship (0.27 alpha 0.05) with ORM maturity.

The appointment of a Chief Risk Officer appears to have a moderate relationship (0.49 alpha 0.05) with technology maturity and BPMT use (0.39 alpha 0.05). Cost of the tooling does not need to increase with more technologies, but the data shows that process maturity increases with higher software costs (0.42 alpha 0.05). There is a reasonably moderate to strong relationship with satisfaction and ORM maturity (0.45 alpha 0.05) and a very strong relation with higher tooling satisfaction when using more BPM technologies (0.88 alpha 0.05). Organizations scoring higher on maturity appear to have less expectations (−0.45 alpha 0.05) about changes in importance of ORM software. Additionally, these organizations use less spreadsheets for ORM (−0.60 alpha 0.05).

5.5. ORM Tooling in Different Sectors

The importance of software for operational risk management varies per industry. Table 5 illustrates that most industries find the use of dedicated software for ORM important or very important; in most cases the analysis from interviews corresponds with the given scores on a scale from 1 (not important) to 10 (very important).

Table 5. Importance of ORM tooling.

Sector	AVG BPM Technology Score	AVG ORM Maturity Score	Perceived Overall Importance
Energy	3.1	4.1	7.5
Financial services	3.7	3.6	7.2
Healthcare	3.2	3.4	8
Retail & consumer goods	2.8	3.6	8.5
Transport & Infrastructures	3.5	4.1	9

Table 6 shows that healthcare appears to be the industry with the highest BPM technology use and availability. ORM was found most important with an average of 9 out of 10 in the transport industry. Airline companies especially consider ORM to be of vital importance for the safety of their passengers. This sector is the only sector using exactly as many technologies as they have available. However, their ORM software appears incomplete, because 66% need solutions in Excel and the satisfaction with ORM software is only 50%. However, this sector achieved the highest ORM maturity scores. On average financial services organizations pay the highest yearly software fees. This is caused by a number of large banks with expensive and very complete ORM software. The BPM technologies used and available are much less by smaller financial services organizations. The retail and consumer industry appears to use more than actually available. This means these organizations rely heavily on non-integrated spreadsheet based solutions for ORM. The average 80k yearly fees in this case are skewed because one retail organization used expensive anti-fraud software. The energy industry appears to be average on almost all aspects. The entire sector indicated needing spreadsheet solutions while none were fully satisfied with their software solution for ORM. Interestingly, they achieved the highest ORM maturity level, but compared to their use of technology they lag the most of all industries.

Table 6. Business Performance Management technologies as used in different sectors.

Sector	BPMT Use	BPMT Availability	Delta	Manual Work in Excel	AVG Yearly Software Fees	AVG Satisfaction
Energy	49%	52%	+3	100%	75k	25%
Financial services	62%	69%	+7	50%	500k	58%
Healthcare	68%	77%	+9	0%	60k	75%
Retail & consumer goods	44%	32%	−12	100%	80k	25%
Transport & infrastructure	65%	65%	0	66%	50k	50%

6. Conclusions and Recommendations

Operational risks are seen as the root cause for many of the (large scale) financial failures in the past decades. Operational Risk is defined by the Basel Committee from the Bank of International Settlements as risks resulting from: Internal Processes, Humans, Systems and External events. In most organizations Operational Risk Management is part of Enterprise Risk Management (ERM). Business Performance Management (BPM) technologies are believed to provide a solution for effective Operational Risk Management by offering several combined technologies including: work flow, data warehousing, (advanced) analytics, reporting and dashboards. The combination of different BPM technologies appeared to match for 94% with requirements for ORM tooling.

Central in this research was the development and practical validation of a new maturity model: B4ORM. The model was developed using the Design Science method as described by Hevner [60]. The maturity model was constructed of a process part, related to operational risk management implementation and the technologies part, relating to BPM technologies used. The initial results of the maturity model were considered to yield an accuracy of 75% by the participating organizations. On average, calculated ORM process maturity has a strong (0.78) Pearson correlation with overall BPM technology use.

Operational Risk Management was first placed into context by measuring the importance of the organizational process, before measuring the actual implementation level of ORM and the use of BPM technologies. The importance of ORM—as scored by the participants—resulted in an overall score of 7.6 on a scale from 1 (not important) to 10 (very important). In conclusion, most organizations consider operational risks fairly important. ORM is most often (50%) used to prevent damage and other adverse effects, more than for learning, improvement or awareness (13%). Business Performance Management Technologies can be seen as a subset of software related technologies. Therefore, the measured software technologies were first analyzed and then scoped back to BPM technologies. Most organizations 87.5%) indicated using dedicated tooling for ORM, while 12.5% organizations indicated relying primarily on self-made Excel solutions for risk assessment or reporting. The importance of tooling for operational risk management varies by industry. Healthcare, Transport & Infrastructure and the Financial Services industries utilize most BPM technologies. Of these, the industries using more than 60% BPM technologies appear to be most satisfied with their software solutions for ORM. These same industries also have less need to fall back on using spreadsheet software.

From this research we can conclude that there are some clear relations with specific sets of BPM technologies found to influence the maturity of Operational Risk Management. Therefore, the maturity model as developed in this research could provide some useful guidelines on the applicability of certain technologies. The maturity model as developed in this research provides a suitable path with six stages for organizations seeking to improve their ORM processes. The six stages provide an instrument to match appropriate technologies to the current stage of maturity and enables organizations to grow in maturity towards enterprise integration and continuous improvement.

As this research provides some answers to unanswered questions, all research leads to new research possibilities. Therefore, this section provides some future research directions. As this research explored a novel domain in a qualitative manner, larger samples are needed for further validation of the maturity model. Additionally, there appears to be a difference between industries but the samples for each industry are too shallow for real conclusions.

ORM tooling in general is required for efficiency and structure. Only when using ORM tooling it will be possible to reach organization-wide integration. Especially BPM technologies support organization wide integration and collaboration via workflow. Some participants suggested that maintainability of tooling for ORM is an issue. This suggestion could be related to dissatisfaction, complaints about user-friendliness and mismatch between tooling and ORM as described in this research.

7. Discussion

There are some relations found with specific sets of BPM technologies to influence the maturity of Operational Risk Management. Therefore, the maturity model as developed in this research could provide some useful guidelines on the applicability of certain technologies, especially for non-mature industries. The maturity model as developed in this research provides a suitable path with six stages for organizations seeking to improve their ORM processes. The six stages provide an instrument to match appropriate technologies to the current stage of maturity and enables organizations to grow in maturity towards enterprise integration and continuous improvement.

This research provides substantial new insights into the actual use and availability of BPM technologies in different industries. These insights can be used for further empirical research projects and the results provide a kind of ranking about the feasibility or existence of the phenomena reported in this paper.

Considering the general research design it is important to note that the selection criteria were in part not based on indisputable and objective information, but also on qualitative interpretation. Although this is rather common and not necessarily problematic for this type of explorative and qualitative research, the results might be different when applying these criteria.

Only Dutch organizations participated in this research. Our findings might, therefore, differ somewhat in other countries. The financial services industry is mostly harmonized in Europe by the EU regulations, but especially other sectors might uncover severe differences among countries due to different laws, regulations and culture.

During the B4ORM maturity model development, the market analysis was limited to 65 products. However, we did not validate our sample for completeness and representativeness with respect to the entire ORM software market. As a matter of fact, the ORM software market size is currently unknown. Nevertheless, the results in this research are validated using an expert panel. The expert panel served the purpose of validation and ranking of identified software features.

The size of the expert panel was limited. Experts were mainly involved in financial services. Furthermore, five experts were considered sufficient, however eight or more experts would have been better [80]. During the expert panel, the range voting method was used. Although this method allowed for sufficient answers, this is not a Delphi method with full anonymity (e.g., [81]). There is no guarantee that the expert panel was unbiased regarding their answers. However, a Delphi expert panel would have consumed too much time [82,83]. Some bias was prevented via an anonymous voting system and a discussion afterwards.

An evident limitation of this research is its sample size. This situation puts limits on considering any generalizations. Therefore, at this moment no real generalizations can be made yet. As such, there is still room for further refining the reliability and validity of the scales of the maturity model. According to Hoyle [84], with respect to a relatively modest data sample as gathered and reported on in this research, a Pearson correlation coefficient does not have to pose problems for qualitative research (because you do not test a hypothesis), when being aware of the fact that small samples are less reliable and never reach a significance level lower than .05. In conclusion, the results in this research should not be seen as clear-cut evidence, but as providing clear directions for further empirical research.

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Abbreviations

The following abbreviations are used in this manuscript:

ORM	Operational Risk Management
DSS	Decision Support System
EIS	Executive Information System
DW	Data Warehouse
BI	Business Intelligence
BPM	Business Performance Management
CPM	Corporate Performance Management
EPM	Enterprise Performance Management
BPMT	Business Performance Management Technologies
ERM	Enterprise Risk Management
SEM	Strategic Enterprise Management
QMMG	Quality Management Maturity Grid
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
GRC	Governance, Risk and Compliance
HSEQ	Health, Safety, Environment and Quality
CRO	Chief Risk Officer
CFO	Chief Financial Officer
CEO	Chief Executive Officer
COO	Chief Operating Officer
FTE	Full Time Equivalent
COSO	Committee of Sponsoring Organizations of the Treadway Commission
OCEG	Open Compliance and Ethics Group
ISO	International Organization for Standardization
AS/NZS	Standards Australia and Standards New Zealand

References

1. Hoffman, D.G. *Managing Operational Risk: 20 Firmwide Best Practice Strategies*; John Wiley & Sons: Hoboken, NJ, USA, 2002.
2. Alexander, C. *Operational Risk: Regulation, Analysis and Management*; Pearson Education: London, UK, 2003.
3. Power, M. The invention of operational risk. *Rev. Int. Political Econ.* **2005**, *12*, 577–599.
4. Moosa, I.A. Operational risk: A survey. *Financ. Mark. Inst. Instrum.* **2007**, *16*, 167–200.
5. Chernobai, A.S.; Rachev, S.T.; Fabozzi, F.J. *Operational Risk: A Guide to Basel II Capital Requirements, Models, and Analysis*; John Wiley & Sons: Hoboken, NJ, USA, 2008.
6. Breden, D. Managing Operational Risk in a Continuously Changing Environment (Bank of Finland). Available online: http://www.webcitation.org/6tjvVI1pV (accessed on 25 September 2017).
7. Tarantino, A. *Governance, Risk, and Compliance Handbook: Technology, Finance, Environmental, and International Guidance and Best Practices*; John Wiley & Sons: Hoboken, NJ, USA, 2008.

8. Malik, S.A.; Holt, B. Factors that affect the adoption of Enterprise Risk Management (ERM). *OR Insight* **2013**, *26*, 253–269.
9. Fontnouvelle, P.; DeJesus-Rueff, V.; Jordan, J.; Rosengren, E. *Using Loss Data to Quantify Operational Risk*; Federal Reserve Bank of Boston: Boston, MA, USA.
10. Panjer, H.H. *Operational Risk: Modeling Analytics*; John Wiley & Sons: Hoboken, NJ, USA, 2006.
11. Kenett, R.S.; Raanan, Y. *Operational Risk Management: A Practical Approach to Intelligent Data Analysis*; John Wiley & Sons: Hoboken, NJ, USA, 2011.
12. Kavakr, F.; Spiegel, A.D. Risk management in health care institutions A strategic approach. *J. Healthc. Qual.* **2004**, *26*, 56–58.
13. Moseley, G.B., III. *Managing Legal Compliance in the Health Care Industry*; Jones and Bartlett Publishers: Burlington, MA, USA, 2013.
14. Marques, R.C.; Berg, S. Risks, contracts, and private-sector participation in infrastructure. *J. Constr. Eng. Manag.* **2011**, *137*, 925–932.
15. Cruz, C.O.; Marques, R.C. Risk-sharing in seaport terminal concessions. *Transp. Rev.* **2012**, *32*, 455–471.
16. Coca, D.; de Blas, R.; Gallejones, C.; Moral, R.; Calvo, J.; Álvarez, J.; del Canto, Á. Operational Risk Management in the Energy Industry, 2014. Available online: http://www.webcitation.org/6xA33zgEB (accessed on 11 February 2018).
17. Mitra, S.; Karathanasopoulos, A.; Sermpinis, G.; Dunis, C.; Hood, J. Operational risk: Emerging markets, sectors and measurement. *Eur. J. Oper. Res.* **2015**, *24*, 122–132.
18. Lam, J. *Enterprise Risk Management: From Incentives to Controls*; John Wiley & Sons: Hoboken, NJ, USA, 2014.
19. Arnold, V.; Benford, T.; Canada, J.; Sutton, S.G. Leveraging integrated information systems to enhance strategic flexibility and performance: The enabling role of enterprise risk management. *Int. J. Account. Inf. Syst.* **2015**, *19*, 1–16.
20. Operational Issues of Risk Management (PwC). Available online: http://www.webcitation.org/6xA3V6UXv (accessed on 11 February 2018).
21. Enterprise Risk Management A 'Risk-Intelligent' Approach (Deloitte). Available online: http://www.webcitation.org/6tqFniCol (accessed on 29 September 2017).
22. Tweede Nationaal Onderzoek Risicomanagement in Nederland (Nyenrode Business University). Available online: http://www.webcitation.org/6u4NMANUK (accessed on 8 October 2017).
23. Beasley, M.; Chen, A.; Nunez, K.; Wright, L. Working hand in hand: Balanced scorecards and enterprise risk management. *Strateg. Financ.* **2006**, *87*, 49–55.
24. Azvine, B.; Cui, Z.; Majeed, B.; Spott, M. Operational risk management with real-time business intelligence. *BT Technol. J.* **2007**, *25*, 154–167.
25. Hevner, A.; March, S.T.; Park, J.; Ram, S. Design science in information systems research. *MIS Q.* **2004**, *28*, 75–105.
26. Fraser, J.; Simkins, B.; Narvaez, K. *Implementing Enterprise Risk Management: Case Studies and Best Practices*; John Wiley & Sons: Hoboken, NJ, USA, 2014.
27. Miller, K.D. A framework for integrated risk management in international business. *J. Int. Bus. Stud.* **1992**, *23*, 311–331.
28. Meulbroek, L.K. A senior manager's guide to integrated risk management. *J. Appl. Corp. Financ.* **2002**, *14*, 56–70.
29. Rosenberg, J.V.; Schuermann, T. A general approach to integrated risk management with skewed, fat-tailed risks. *J. Financ. Econ.* **2006**, *79*, 569–614.
30. Simkins, B.; Ramirez, S.A. Enterprise-wide risk management and corporate governance. *Loyola Univ. Chic. Law J.* **2007**, *39*, 571.
31. Culp, C.L. The revolution in corporate risk management: A decade of innovations in process and products. *J. Appl. Corp. Financ.* **2002**, *14*, 8–26.
32. Olson, D.L.; Wu, D.D. *Enterprise Risk Management*; World Scientific Publishing Co., Inc.: Singapore, 2015.
33. Gordon, L.A.; Loeb, M.P.; Tseng, C.Y. Enterprise risk management and firm performance: A contingency perspective. *J. Account. Public Policy* **2009**, *28*, 301–327.
34. GRC Defined (OCEG). Available online: http://www.webcitation.org/6u4EFWKFn (accessed on 29 September 2017).

35. Racz, N.; Weippl, E.; Seufert, A. A frame of reference for research of integrated GRC. In *Communications and Multimedia Security*; Springer: Berlin, Germany, 2010; pp. 106–117.
36. Racz, N.; Weippl, E.; Seufert, A. Governance, risk & compliance (GRC) software-an exploratory study of software vendor and market research perspectives. In Proceedings of the 44th Hawaii International Conference of System Sciences (HICSS), Honolulu, HI, USA, 4–7 January 2011; pp. 1–10.
37. Enterprise Risk Management—Integrated Framework (COSO). Available online: http://www.webcitation.org/6tq28Hzzq (accessed on 29 September 2017).
38. Power, M. The risk management of nothing. *Account. Organ. Soc.* **2009**, *34*, 849–855.
39. The 2015 GRC Maturity Survey Report (OCEG). Available online: http://www.webcitation.org/6tq1Wnl8r (accessed on 29 September 2017).
40. Nissen, V.; Marekfia, W. Towards a research agenda for strategic governance, risk and compliance (GRC) management. In Proceedings of the Conference Business Informatics (CBI), Vienna, Austria, 15–18 July 2013; pp. 1–6.
41. Operational Risk (Bank of International Settlements). Available online: http://www.webcitation.org/6tjuXt27o (accessed on 25 September 2017).
42. Sound Practices for the Management and Supervision of Operational Risk (Bank of International Settlements). Available online: http://www.webcitation.org/6tjugPqoB (accessed on 25 September 2017).
43. Tattam, D. *A Short Guide to Operational Risk*; Gower Publishing: Farnham, UK, 2011.
44. Sadgrove, K. *The Complete Guide to Business Risk Management*; Routledge: Abingdon-on-Thames, UK, 2016.
45. Fraser, J.; Simkins, B.J. *Enterprise Risk Management*; John Wiley & Sons: Hoboken, NJ, USA, 2008; pp. 19–29.
46. Taxonomy-Based Risk Identification (Carnegie-Mellon University). Available online: http://www.webcitation.org/6tjvlXoXf (accessed on 25 September 2017).
47. Purdy, G. ISO 31000: 2009—Setting a new standard for risk management. *Risk Anal.* **2010**, *30*, 881–886.
48. ISO 31000 Risk management—Principles and Guidelines. Available online: http://www.webcitation.org/6u4GJyZ7w (accessed on 8 October 2017).
49. Lebas, M. Performance measurement and performance management. *Int. J. Prod. Econ.* **1995**, *41*, doi:10.1016/0925-5273(95)00081-X.
50. Simons, R. *Performance Measurement and Control Systems for Implementing Strategy*; Prentice Hall: Upper Saddle River, NJ, USA, 2002.
51. Frolick, M.N.; Ariyachandra, T.R. Business performance management: One truth. *IS Manag.* **2006**, *23*, 41–44.
52. Spruit, M.; Sacu, C. DWCMM: The Data Warehouse Capability Maturity Model. *J. Univ. Comput. Sci.* **2015**, *21*, 1508–1534.
53. Sharda, R.; Delen, D.; Turban, E. *Business Intelligence A Managerial Perspective on Analytics*; Pearson Education Limited: London, UK, 2014.
54. Melchert, F.; Winter, R.; Klesse, M. Aligning process automation and business intelligence to support corporate performance management. In Proceedings of the Tenth Americas Conference on Information Systems, New York, NY, USA, 6–8 August 2004; pp. 4053–4063.
55. Samsonowa, T. *Industrial Research Performance Management: Key Performance Indicators in the ICT Industry*; Springer: Berlin, Germany, 2011.
56. Wasmann, M.; Spruit, M. Performance Management within Social Network Sites: The Social Network Intelligence Process Method. *Int. J. Bus. Intell. Res.* **2012**, *3*, 49–63.
57. Spruit, M.; Jagesar, R. Power to the People! Meta-algorithmic modelling in applied data science. In Proceedings of the 8th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management, Porto, Portugal, 11–13 November 2016; pp. 400–406.
58. Lytras, M.; Raghavan, V.; Damiani, E. Big data and data analytics research: From metaphors to value space for collective wisdom in human decision making and smart machines. *Int. J. Sem. Web Inf. Sys.* **2017**, *13*, 1–10.
59. McCormack, K.; Willems, J.; Van den Bergh, J.; Deschoolmeester, D.; Willaert, P.; Štemberger, M.; Vlahovic, N. A global investigation of key turning points in business process maturity. *Bus. Process Manag. J.* **2009**, *15*, 792–815.
60. Hevner, A.R. A three cycle view of design science research. *Scand. J. Inf. Syst.* **2007**, *11*, 87–92.
61. Nolan, R.L. Managing the computer resource: A stage hypothesis. *Commun. ACM* **1973**, *16*, 399–405.

62. Fraser, P.; Moultrie, J.; Gregory, M. The use of maturity models/grids as a tool in assessing product development capability. In Proceedings of the Engineering Management Conference, Cambridge, UK, 18–20 August 2002; pp. 244–249.
63. Humphrey, W.S. Characterizing the software process: A maturity framework. *IEEE Softw.* **1988**, *5*, 73–79.
64. Paulk, M.C.; Curtis, B.; Chrissis, M.B.; Weber, C.V. Capability maturity model, version 1.1. *IEEE Softw.* **1993**, *10*, 18–27.
65. Spruit, M.; Roeling, M. ISFAM: The Information Security Focus Area Maturity model. In Proceedings of the 22nd European Conference on Information Systems, Tel Aviv, Israel, 9–14 June 2014.
66. Spruit, M.; Pietzka, K. MD3M: The Master Data Management Maturity Model. *Comput. Hum. Behav.* **2015**, *51*, 1068–1076.
67. Hillson, D.A. Towards a risk maturity model. *Int. J. Proj. Bus. Risk Manag.* **1997**, *1*, 35–45.
68. RIMS Risk Maturity Model (RMM) for Enterprise Risk Management. Available online: http://www.webcitation.org/6u4JnW9Vu (accessed on 8 October 2017).
69. BDO Operational Risk Management Maturity Model. Available online: http://www.webcitation.org/6tjv044RV (accessed on 25 September 2017).
70. Assessment Framework for Information Security. Available online: http://www.webcitation.org/6tqGVV1fF (accessed on 29 September 2017).
71. Cybersecurity Capability Maturity Model (C2M2). Available online: http://www.webcitation.org/6u4KJW1Pf (accessed on 8 October 2017).
72. Maturity Model for Operational Risk Management. Available online: http://www.webcitation.org/6u4KS5LSa (accessed on 8 October 2017).
73. Wettstein, T.; Kueng, P. A maturity model for performance measurement systems. *WIT Trans. Inf. Commun. Technol.* **2002**, *26*, 113–122.
74. AMR's Business Intelligence/Performance Management Maturity Model. Available online: http://www.webcitation.org/6tjsca0P4 (accessed on 25 September 2017).
75. Maturity Model for Business Intelligence and Performance Management. Available online: http://www.webcitation.org/6u4L6tRsm (accessed on 8 October 2017).
76. Aho's Capability Maturity Model for Corporate Performance Management. Available online: http://www.webcitation.org/6tjsFaUHz (accessed on 25 September 2017).
77. Big Data & Analytics Maturity Model. Available online: http://www.webcitation.org/6u4LXWzsH (accessed on 8 October 2017).
78. Sacu, C.; Spruit, M. BIDM: The Business Intelligence development model. In Proceedings of the 12th International Conference on Enterprise Information Systems, Funchal, Madeira, Portugal, 8–12 June 2010; pp. 288–293.
79. Pieket Weeserik, B.; Spruit, M. B4ORM assessment instrument. Available online: http://bit.ly/b4orm-assessment (accessed on 27 February 2018).
80. Ashton, R.H. Combining the judgment of experts: How many and which ones? *Organ. Behav. Hum. Decis. Process.* **1986**, *38*, 405–414.
81. Baars, T.; Spruit, M. Designing a Secure Cloud Architecture: The SeCA Model. *Int. J. Inf. Secur. Priv.* **2012**, *6*, 14–32.
82. Linstone, H.A.; Turoff, M. *The Delphi Method. Techniques and Applications*; Addison-Wesley: Reading, MA, USA, 2002.
83. Hsu, C.C.; Sandford, B.A. The Delphi technique: Making sense of consensus. *Pract. Assess. Res. Eval.* **2007**, *12*, 1–8.
84. Hoyle, R.H. *Statistical Strategies for Small Sample Research*; Sage: Newcastle upon Tyne, UK, 1999.

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Risk Management and Knowledge Management as Critical Success Factors of Sustainability Projects

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Abstract: The paper is focused on the analysis of the key aspects of sustainability projects, namely advanced risk management and project knowledge. These aspects are recommended to the attention of institutions and project managers when designing and executing new projects simultaneously with quality and project status management. The aim of the paper is to point out the critical factors that have recently affected the success of sustainability projects, which is also its contribution. Empirical research focused on the identification of the application level of the post-project phases in project management in the Czech Republic in 2016 and 2017 was performed. The research was performed as qualitative research employing observation and inquiry methods in the form of a controlled semistructured interview. The research identified 21 most common reasons for not executing post-project phases. Ensuring good and efficient progress of post-project phases, in particular by the means of post-implementation system analysis and compilation of a set of improvement suggestions for subsequent project management, forms the practical background for application of knowledge management and project management principles. A case study focused on the application of fuzzy logic in project risk assessment has been elaborated. In practice, current project management requires the application of advanced risk analysis methods that will replace the simple risk values estimated by calculations of separate risk components.

Keywords: project sustainability; project management; knowledge management; project risk; post-project phases; fuzzy logic; project management quality

1. Introduction

Sustainable development represents one of the key issues in preserving human society on our planet. A UNESCO study defined 17 sustainable development goals [1]. The execution of these goals cannot be left to chance and one cannot rely on the goals being achieved by unprompted development. Also, it is impossible to rely on an intervention by an extraordinary human being under whose management the goals would be successfully achieved and sustainable development would be set.

It is project management that seems to be the effective and efficient way to achieve sustainable development goals; therefore, it is very meritable and important that in the Special Issue, the Sustainability journal editorial board concentrated on the subject of sustainable development realization by means of quality project management, stating that the role of project management is essential for achieving sustainability goals.

The paper discusses two aspects in relation to sustainability projects. These aspects are recommended to the attention of institutions and project managers when designing and executing new projects. They are, namely:

- Advanced risk management of sustainability development projects.
- Utilization of knowledge management by employing post-project phases in the project life cycle.

The aim of the paper is to point out the critical factors that have recently affected the success of sustainability projects. Most sustainability development projects have ambitious goals that can be very beneficial to the sustainable development of human society. For this reason, it is important that the probability of their success is high. Their failures mean not only considerable financial losses of the project stakeholders, but also undermine the whole sustainable development movement, and what is more, may have adverse effects on any future attempts to raise money for sustainable development. Thus, the paper points out that continuous project design and management quality require attention through knowledge management in order to increase the probability of sustainability project success. Moreover, the paper aims to demonstrate the procedures and methods to manage these critical factors of sustainable development projects successfully.

2. Literature Review

Application of project management to sustainable development projects is not a new idea. A number of steps to achieve partial goals leading to sustainable development have already been implemented as projects [2,3]. However, the issue of improving efficiency and effectiveness of the projects in the new millennium needs to be addressed. Research and analyses show numerous errors and drawbacks of the current projects, including those related to sustainable development projects [4]. Therefore, certain groups of scientists have focused on research of advanced methods related to the issues of project success evaluation, project risk assessment, project status assessment [5], and future project development prediction [6,7], and so on. These are the key areas where many errors occur. A possible solution to minimize these problems are general efforts to apply risk management [8] and knowledge management [9] principles more effectively. Successful project execution absolutely requires continuous project status assessment, taking successful achievement of the target status into account. A comparison may be made to well-structured projects, for example, in construction or engineering, where well-structured methods of project status assessment can be used [10]. For this reason, soft methods are applied in sustainability projects to assess the project status in milestones which with unprofessional and superficial attitude, may result in inaccurate and unrealistic project status assessment [11].

The classic approach to project risks, “A Guide to the Project Management Body of Knowledge” (PMBOK® Guide), considers risk as a product of risk occurrence probability and the financial risk impact within the project [12]. Since in many cases, it is difficult to determine the risk probability value directly and to calculate the risk impact value, alternative methods of expressing the values are used [13,14].

A number of authors deal with research in project risk management in their works (see Table 1).

Table 1. Literature review of project risk (Source: processed by the author using quoted literature).

Author(s)	Main Findings
Rudnik, Deptula [15]	The probabilistic fuzzy risk assessment model for the innovative project. The linguistic risk variables are the inputs to the model. The shapes of fuzzy sets for linguistic values are identified using expert knowledge. Fuzzy rules (if–then), probability measures of fuzzy events, and conclusion of rules are the knowledge.
Nasirzadeh et al. [16]	The integrated dynamic fuzzy model for quantitative allocation of construction risks between owners and contractors. Fuzzy logic and system dynamics approach was used for modelling of all the factors affecting the risk allocation process. The values of key uncertainty factors were described using fuzzy numbers. The project cost is simulated at different percentages of risk allocation, thanks to the model.
Liu, Ye [17]	The procedure for multiple attribute decision making based on the trapezoid fuzzy linguistic weighted Bonferroni mean (TFLWBM) operator was developed. The procedure was verified for evaluating the investment project risk of the case study.

Table 1. *Cont.*

Author(s)	Main Findings
Rodriguez et al. [18]	The multicriteria risk assessment model based in the fuzzy inference system (FIS) and fuzzy analytic hierarchy process (FAHP). FIS was used for the integration of the areas of risk factors. FAHP was used for evaluation of the risk factors. The fuzzy model includes the different levels of uncertainty and the relationship among risk factor areas.
Zwikael et al. [19]	The research of the relationship between a project planning process and project success. The level of project success is measured in the form of project plan risks. They suggest the careful planning for high-risk projects.
Doskočil et al. [20]	The expert fuzzy model is used for project success evaluation. It is a hierarchical fuzzy model that evaluates project success in terms of project status, project risk, and project quality assessment. They recommend applying the model in particular in the implementation stage and then repeatedly after the completion of each project stage. Thanks to the model, the project manager and the project team members have a tool to support their decision making, which also enables them to implement the respective measures relatively in time, which contributes to more efficient project management.

The application of the RIPRAN™ method (RIsk PRoject Analysis) [21] extended by the fuzzy approach of the risk evaluation in both the components of "probability" and "impact on the project" and then the quantification of the overall risk value is the contribution of the paper in the area of sustainability risk management project.

A number of authors deal with managing project knowledge in their research works (see Table 2).

Table 2. Literature review of project knowledge models (Source: processed by the author using quoted literature).

Author(s)	Main Findings
Ginevičius et al. [22]	The project management knowledge model is used to analyse the economic, legal, technical, technological, organizational, social, cultural, political, ethical, and psychological factors in a comprehensive way. According to the authors, the above factors affect the project as such and their application contributes to increased competitiveness.
Matthies, Coners [23]	The semiautomated implementation approach for double-loop learning in project environments. A combined application of two complementary methods is suggested for this purpose: latent semantic analysis (LSA) and analytic network process (ANP). This way, the approach addresses two problems of the project management practice: Firstly, the information overload in project environments, where the LSA is used for the semiautomated extraction of lessons learned from large collections of textual project documentation. Secondly, the lack of procedures and methods for the practical implementation of available project knowledge, where the ANP is used for the systematic modelling of extracted lessons learned and their integration into the evaluation of project concepts and current project management routines
Zhang, Wang [24]	The study investigates the level of construction industry maturity in Shaanxi. The authors state that the maturity is in its early stage (level two of four) and faces several critical factors. As the main issue, they mention the low level of transformation and insufficient knowledge management within construction projects. Their recommendations include, for example, the need to increase the stress on company vision target realization in the development strategies of their enterprises, increased education, research and development budget, and implementation of standardized project management.

The emphasizing of the importance of post-project phase application in sustainability projects is the contribution of the paper in the area of knowledge management. One of the reasons is that sustainability projects are usually implemented in widely diversified project teams (not only in one company). The knowledge management principles play an important role in management of these projects.

3. Materials and Methods

The findings of general management theory and other managerial disciplines, in particular project and knowledge management, were used in the elaboration of the paper. Moreover, findings of system sciences and system applications were used [25].

In the stage of analysis of the current status of the discussed issues, the method of relevant data secondary analysis was employed, which represented the process of obtaining and processing secondary data, where new information was gained by analysing the original data and information.

The inputs included mostly the study of scientific articles published in scientific journals and conference collections (see Section 2).

The primary data were obtained by applying empirical research focused on identifying the level of post-project phase application in project management in the Czech Republic in 2016 and 2017. The respondents were the participants in project management courses from companies operating in the Czech Republic. These were both company courses and public courses open to business people from all over the country. The total number of respondents was 150. The courses on project design and management covered the knowledge defined in the International Project Management Association (IPMA) competence baseline for level D. The participants were members of staff of small and medium-size businesses from various industrial fields (most frequently construction, engineering, the electrical industry, the power industry, and IT), since large companies are usually owned by foreign parent companies that organize their own internal education courses of project management and usually do not send their employees to external courses. Two-thirds of the respondents were project team leaders (PTL), and the rest were members of staff participating in business projects as project team members. There were no heads of project management offices among the course participants.

The research was performed as qualitative research employing observation and inquiry methods in the form of a controlled semistructured interview. The controlled interviews took the form of targeted personal meetings with the respondents. They were experts from selected companies in the roles of project managers or project team members. The collected data were then processed and assessed using the comparative method and content analysis. It was applied to the analysis, classification, and study of primary data.

The following research questions were delineated:

- Is it possible that implementation of the principles of knowledge management through post-project phases contribute to improving the management of sustainability projects?
- What are the reasons for ignoring post-project phases?
- Is it possible that fuzzy approach application improves the risk evaluation process of sustainability projects?

The method of modelling was used in the case study for project risk assessment. Here, a model means a simplified depiction of reality used as a basis for modelling the characteristics significant in terms of the analysed phenomenon. The expert model of project risk evaluation was realized using the fuzzy sets and fuzzy logic apparatus.

A fuzzy set $\widetilde{A}$ (defined by Lotfi A. Zadeh in 1965 [26]) is usually expressed in terms of its membership function $\mu_{\widetilde{A}}$ which maps domain elements (x) with their respective degrees of belonging in the interval $[0;1]$ (see Figure 1).

$$\widetilde{A} = \{(x, \mu_{\widetilde{A}}(x)) : x \in X, \mu_{\widetilde{A}}(x) \in [0;1]\}, \tag{1}$$

A support of a fuzzy set $\widetilde{A}$ is the classical set

$$\text{supp } \widetilde{A} = \{x \in X : \mu_{\widetilde{A}}(x) > 0\}. \tag{2}$$

A core of a fuzzy set $\widetilde{A}$ is the classical set

$$\ker \widetilde{A} = \{x \in X : \mu_{\widetilde{A}}(x) = 1\}. \tag{3}$$

A height of a fuzzy set $\widetilde{A}$ is the number

$$\text{hgt } \widetilde{A} = \sup_x \mu_{\widetilde{A}}(x). \tag{4}$$

Example: If a fuzzy set $\widetilde{A}$ is "about 2" (see the triangular membership function in Figure 1), then supp $\widetilde{A} = (1;3)$, ker $\widetilde{A} = \{2\}$, and hgt $\widetilde{A} = 1$.

Fuzzy logic is an approach to computing based on the "degrees of truth" described using fuzzy set theory [27–29]. The computing of fuzzy logic [30] includes three basic processes [31]:

1. Fuzzification: translate input into truth values. Input variables are assigned degrees of membership in various classes.
2. Fuzzy inference: compute output truth values. Inputs are applied to a set of "if–then" control rules.
3. Defuzzification: transfer truth values into output. Fuzzy outputs are combined into discrete values needed to drive the control mechanism.

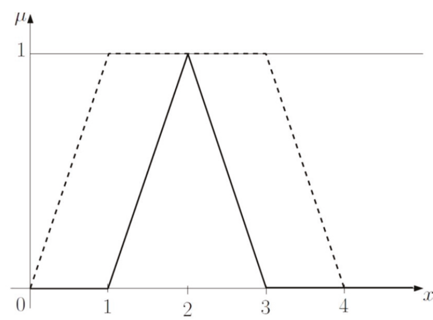

Figure 1. Trapezoidal and triangular membership function.

4. Results

4.1. Knowledge Management: Post-Project Phases

The empirical research results showed fatal drawbacks in the investigated area. Generally, the level of application of post-project phases is very low in the Czech environment. This phase is not performed at all in the majority of cases. The following table comprehensively presents the key reasons, according to the respondents (see Table 3).

Table 3. The most common reasons why companies fail to process post-project phases of projects (source: processed by the author).

Number	Reasons
1	Excited by the success of a completed project, the workers start to feel there is no need to analyse or improve anything.
2	Devastated by the project failure, the project participants and all the stakeholders try to forget the project as fast as possible.
3	Under the load of more and more new projects and everyday issues, there is no time for such an analysis.
4	Since any possible "easy and possible financial savings" are made in the already tight project budgets, the post-implementation analysis is usually one of them, so it is not even planned.
5	Such a thing is considered unnecessary pondering and obstruction to proper work.
6	There is a worry among the project team members that even well-intended, (self-) critical conclusions may turn against them (e.g., reduction of project remuneration).
7	People do not know how to perform it practically, so they prefer not to do it.
8	The analysis was done once but the recommendations were put aside ad acta, so the whole thing inevitably seemed to have been a waste of time and considerable efforts, and so nobody wants to risk needless work.
9	Unlike the project execution, it is often not explicitly required; so it is not done!
10	The project team does not want to point out mistakes they have made (why should they?), and pointing out success, on the other hand, is considered boasting.
11	Since the workers do it wrong, the results are not satisfactory, so after some time, the activity is discontinued due to "inefficiency".
12	The analytical teams are repeatedly comprised of incompetent staff members, so the results do not correspond to the expended resources or time and the analysis is cancelled.
13	Because its need and existence are essentially denied or ignored. (This belongs to "quality", not to "projects".)

Table 3. *Cont.*

Number	Reasons
14	Most companies lack a system of company experience accumulation, so it is not required for projects either. (Must be required by company top management.)
15	In the Czech Republic, many people consider themselves to be very smart and believe they do everything right and do not need to learn anything anymore.
16	There are still many people who remember a document titled "Lessons Learnt from Critical Development..." which did not bring success to its authors! (Generation-specific and Czech-specific reason.)
17	In the chaos and hurry of everyday work on the project, it simply gets forgotten.
18	A lot of people often refuse to look back, they only want to look ahead—a common attitude of many young people. (There is not so much time in their past, but a relatively long time in their future.)
19	There is no project documentation, and sometimes there are no project participants anymore, so the question is what in particular should be responsibly analysed.
20	A number of project management methodology materials still do not mention these phases, as well as pre-project phases, and focus solely on immediate project management, from start to completion.
21	The current time is VUCA (volatile, uncertain, complex, ambiguous). Therefore, it makes no sense to prepare for anything by analysing the past. Everything will be different and nothing can be predicted and no past experience can be used.

4.2. Risk Management: Fuzzy Risk Quantification

The advantage of the fuzzy set is its ability to work with vague terms which are typical for daily use in project management. The current approach, for example, in the field of risk engineering, applied either numerical values of probability and impact or worked with classical sharp jurisdiction of these values into certain sets. It was not appropriate for many applications and did not correspond to the actual perception of risk [32].

The case study is focused on the application of fuzzy logic for the evaluation of project risk based on the RIPRAN™ method. Branislav Lacko is the author of the RIPRAN™ method. He was a finalist of the 2016 Federation European Risk Manager Association award in innovation method categories. The RIPRAN™ method is a trade mark no. 283536 registered by the Industrial Property Office, Prague. It is recommended for project risk analysis according to the IPMA competence baseline (ICB) international standard in the Czech Republic.

The RIPRAN™ method does not represent a difficult approach to project risk analysis. It is the methodological arrangement of the individual activities in the risk analysis of the project systematically, so that nothing important is forgotten, and suitably documented for the needs of the project risk register. It is not necessary to start with a risk evaluation using the fuzzy approach in the current version of the method. This is possible to be postponed until the project team decides that the use of the fuzzy approach is suitable. The main contribution of this extended version of the RIPRAN™ method is the possibility to quantify the individual components of "probability" and "impact on the project" using vague fuzzy values and then the quantification of the overall risk value. The total benefit of this fuzzy approach compared with simple estimates of overall risk by the traditional approach is considerable. This "cheap or inexpensive" intuition (as shows practice) is, on the contrary, very expensive in the view of the impact of poor quality intuitive estimates and intuitive approaches to project risk analysis.

The fuzzy logic toolbox in Matlab was used for the fuzzy model creation. The fuzzy model of risk value evaluation (FM_RV) consists of two input variables (*P—Probability*, *IP—Impact on the Project*), one rule block, and one output variable (*RV—Risk Value*) (see Figure 2).

The fuzzy logic deduction method was used for obtaining outputs based on inputs (see fuzzy rules below). Mamdani's fuzzy inference method was used, because the system is described only roughly using the natural language: knowledge is unstructured or little structured. The fuzzy set defined by the membership function is the output of the inference process. This type of output is sufficient for interpretation of the risk value in project management.

Figure 3 shows the input variable P with five linguistic fuzzy values: VH—very high, H—high, M—middle, L—low, and VL—very low. The membership function of type Π (trapmf) and range [0; 1] was used to create the fuzzy model. The input variable IP has the same parameters.

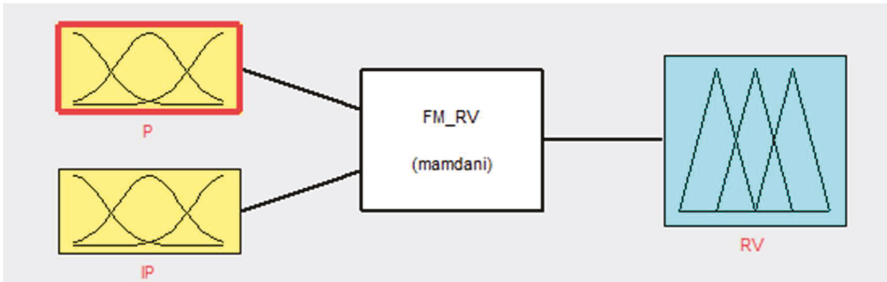

Figure 2. The fuzzy model diagram (FM_RV). P: probability, IP: impact on the project, RV: risk value.

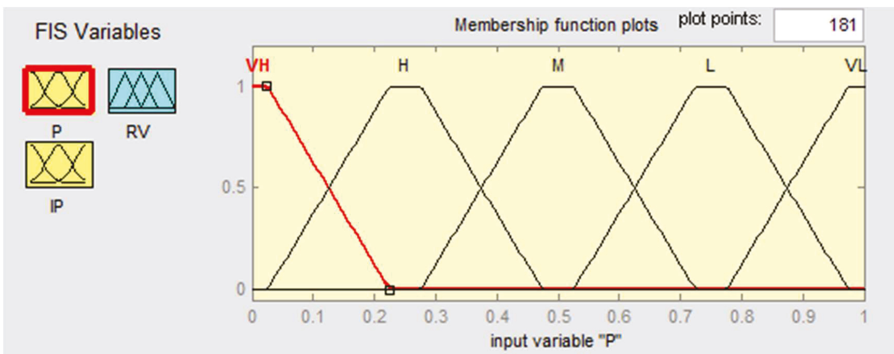

Figure 3. The linguistic input variable P with linguistic fuzzy values VH, H, M, L, and VL. FIS: fuzzy inference system.

Figure 4 shows the output variable *RV* with five linguistic fuzzy values: VH—very high, H—high, M—middle, L—low, and VL—very low. The membership function of type Π (trapmf) and range [0; 1] was used to create the fuzzy model.

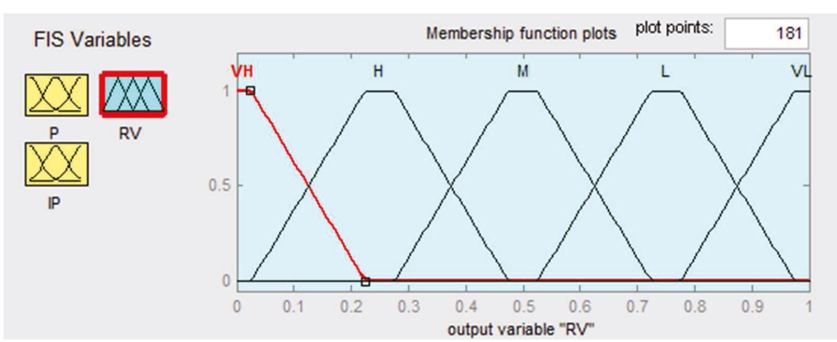

Figure 4. The linguistic output variable RV with linguistic fuzzy values VH, H, M, L, and V.

The expressing of the membership functions depends both on the subject (how deep is our experience) and on the context (where is the problem solution). That is the reason why the membership functions are expressed neutrally according to the generally applicable rules (metarules) in the first phase.

One rule, "if–then", expresses expert knowledge of the relationship existing between the basic components of the risk ("probability", "impact on the project") and the risk value. There are 25 rules in the fuzzy system. These rules represent the knowledge base, which describes the behaviour of the system. The antecedent includes all real combinations of linguistic values of input variables. The consequent includes evaluations for all combinations, that is, the assignment of the linguistic values to output variables. The listing of a combination of 25 rules of the system is based on the following distribution (see Table 4).

Table 4. The listing of a combination of fuzzy rules (source: processed by the author).

		Impact on the Project (IP)				
		VH	**H**	**M**	**L**	**VL**
Probability (P)	**VH**	RV = VH	RV = VH	RV = VH	RV = H	RV = M
	H	RV = VH	RV = VH	RV = H	RV = M	RV = L
	M	RV = VH	RV = H	RV = M	RV = L	RV = VL
	L	RV = H	RV = M	RV = L	RV = VL	RV = VL
	VL	RV = M	RV = L	RV = VL	RV = VL	RV = VL

Figure 5 presents an antecedent (column and row) and a consequent (intersection of a column and a row) of the fuzzy rule. There are 25 fuzzy rules (metarules). These rules can be changed or defined for a specific project.

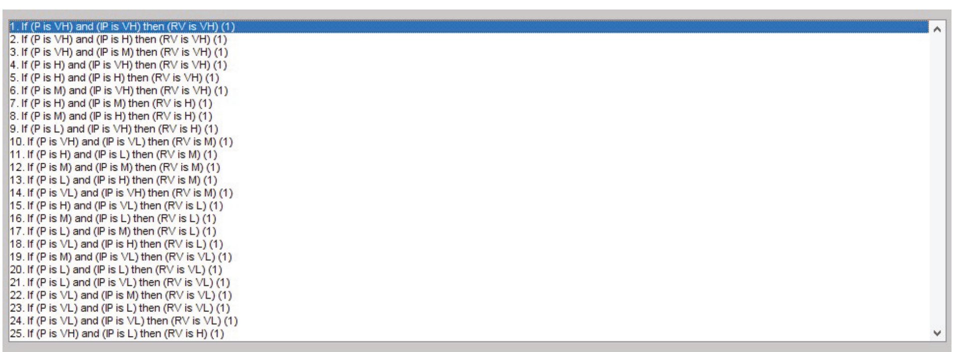

Figure 5. Rule block and rules.

Figure 6 shows the dependence between input and output variables. It is a function of RV = f (P, IP). The coordinates [0; 0] represent the following situation: If the input variables P and IP are very high, then the output variable RV is very high. The coordinates [1; 1] represent the following situation: If the input variables P and IP are very low, then the output variable RV is very low.

Figure 7 presents the project risk evaluation for a concrete project. The values of input variables P = 0 and IP = 0 give the value of output variable RV = 0.0729 (see the first rule in Figure 7). This situation interprets that the total risk of the project is very high. The fuzzy model was verified in this manner. The results match the requirement, so the fuzzy model can generally be regarded as functional.

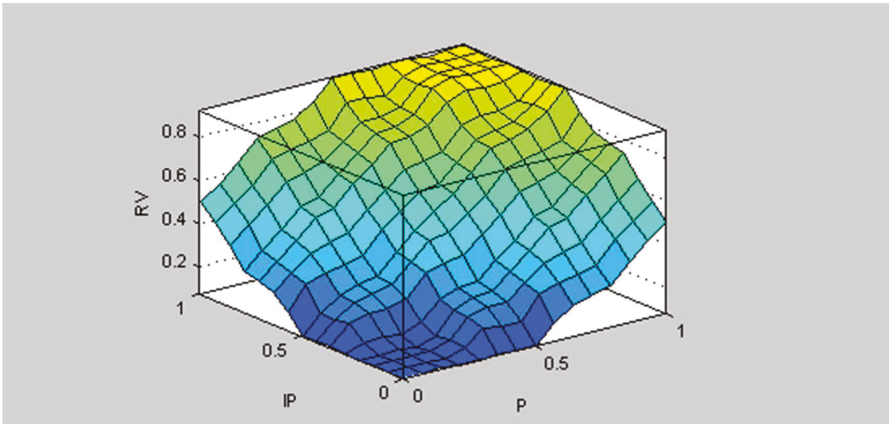

Figure 6. Surface - dependencies between input and output variables.

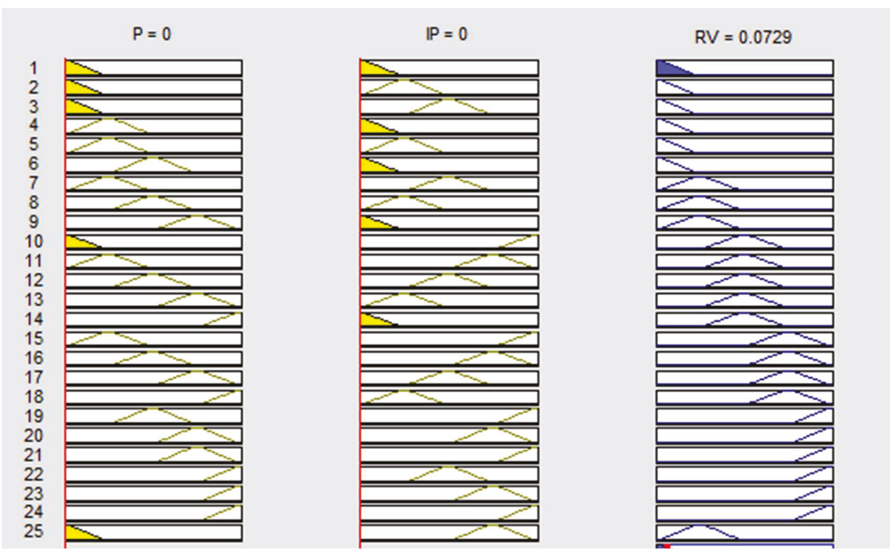

Figure 7. The evaluation of total project risk of a concrete project.

The created fuzzy model is necessarily tuned to set up the inputs to known values, evaluate the results, and change or add the rules. It is necessary to work with real data of the project for this process. Based on the real data, the parameters of the fuzzy model must be set. The model can be used in practice if the validation shows that the model provides accurate results.

This approach of risk management of the sustainability project is generally applicable and does not have any specific limitations. It assumes that the project team bases its work on past project experiences. These experiences must be applied methodologically according to the authors' described procedures. For use in a concrete company, it is necessary to prepare specific real data according to the results of the post-project analyses. These results reflect the experiences of already implemented projects and their documentation. This information serves as a reference for the risk analysis currently underway.

5. Discussion

The necessity to ensure sustainability project success in the current complicated times of a VUCA world [33] requires the project team members and project managers to improve continuously from one project to another. This can be realized if the principles of knowledge management are applied in project management. In practice, this requires ensuring good and efficient progress of post-project phases, in particular by means of post-implementation system analysis and compilation of a set of proposals for the improved management of subsequent projects. Through post-implementation analysis (post-project phase implementation), the necessary knowledge can be gained, which can be used later in correct knowledge management.

The paper shows to sustainability project managers and project team members what new and sophisticated methods should be used in order to achieve a high level of probability of successful project completion with the expected benefits. It lists particular advanced methods for areas crucial for success: RIPRAN™ for risk analysis, replacing a simple estimate of the total risk value by a calculation of gradually separated risk components (threat probability, scenario probability, sum of values of all partial impacts); post-project phases for accumulation of gained project knowledge; and fuzzy sets for improvement of quantitative assessment of not only risks, but also deadlines, costs, and the achieved project quality. The contribution of the paper lies in the fact that these procedures do not require any significant additional financing, but improvements can be achieved in particular by coherent technical and organizational processes applied to the work of the project teams, preparation, organization, and project execution. The original contribution of the paper is the list of the established causes impeding the quality performance of post-project phases, as targeted elimination of these causes may follow from these findings. An innovative contribution is the system concept of risk management and knowledge management in the project management of sustainability projects. Nowadays, the practice is usually such that these approaches are applied in isolation, without any interrelations; or even in some sustainability projects, are ignored.

Workers engaged in industry are confronted with the need to comply with high production quality on a daily basis, either by applying the total quality management (TQM) principles through the ISO 9000 Quality Management Systems set of standards or the Six Sigma movement. The requirements to conform to these high-quality principles have logically generated requirements to comply with the high-quality principles also in areas such as nonproduction and sustainability project management, referred to jointly as project management and quality of project.

Increased attention needs to be paid to the selection of members of the sustainability project teams. Very often, project managers are appointed to head the project teams as professionals in project management methodology who, however, do not understand and do not identify with the notion of sustainable development and their motivation to solve complex issues within these projects is low. On the other hand, enthusiastic advocates of sustainable development principles know nothing about professional project management, according to international standards. The international standard ISO 21500 (“Guidance on project management”) defines basic principles and basic concepts of project management and recommends structuring the project into individual phases. It defines the content for theses phases [34]. The international standard ISO 31000 (“Risk management”) unifies the terminology of risk management. It explains the basic principles, approaches, and procedures of risk management. It presents the risk analysis techniques [35]. The international standard ISO 10006 (“Quality management—Guidelines for quality management in projects”) defines and characterizes nine processes that are necessary to ensure project quality management according to TQM principles [36].

The approach described in the fuzzy set application enables the fuzzy approach to be applied not only to risks, but to put together a method of complex project status assessment in terms of deadlines, costs, risks, and quality, which would improve the quality and success of sustainability projects [13]. The fuzzy approach application creates conditions for building a knowledge base that would become the basis for creating an expert system of assessing the risks of sustainability projects.

It is a fact that the RIPRAN™ method is positively evaluated and successfully used by approximately 13 important companies in the Czech Republic. It is also taught at 10 universities (14 faculties) in the Czech Republic nowadays.

Future research will focus on elaborating procedures for risk evaluation through the fuzzy approach in the context of the RIPRAN™ method. The aim will be to apply the principal functionality of the fuzzy model for the use of a concrete company or selected sector (mechanical engineering, IT, etc.), including a methodology of implementation. The first phase of the research is planned to realise selected mechanical engineering projects at our university in cooperation with Industry Cluster 4.0.

A necessary prerequisite for the tuning of a fuzzy model is the experience and knowledge gained from realised projects in the past. These are possibly obtained using the post-project phases in the context of knowledge management. The obtained knowledge base will be also able to generate input data of the model (fuzzy rules, membership functions) using the adaptive neuro-fuzzy inference system (ANFIS).

6. Conclusions

To conclude, it needs to be emphasized that projects as complex as sustainable development projects require the application of a system approach and system dynamics as products of system thinking [37]. It seems astounding that the ISO 21500 international standard, although having been issued for international project management including the management of sustainable development projects to follow its respective principles, is not taken into account as needed and is not paid sufficient attention. Instead, sustainable development projects are executed intuitively and based on local and national customary procedures, which often impede efficient problem solving within the sustainable development projects [38].

The analysis of the behaviour of current project workers—both project managers and project team members [39]—shows that these workers fail to perform knowledge transfer and accumulation of their own accord in the course of the projects and within the companies and institutions where the projects take place and are managed. Therefore, all sustainable development project stakeholders need to be recommended to support and organize knowledge management explicitly.

To manage knowledge means not only to ensure its storage and accumulation, evaluation, and further utilization, but also to organize and require continuous education of those who propose the sustainability projects and manage their execution. In particular, the analysis of causes obstructing experience sharing and accumulation has to be recommended and the established causes need to be purposefully eliminated.

Both processes, that is, knowledge and education management, need to be recommended as processes for creating learning organizations [40].

It might be debatable whether all of the recommendations mentioned in the paper can be realised, when a wide range of companies and institutions usually participate in sustainable development projects. The authors believe that the sustainable development goals that all the project stakeholders should become aware of may act as the synergic effect that should unite the efforts of all to coordinate the required endeavours.

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References

1. Nilsson, M.; Griggs, D.; Visbeck, M. Policy: Map the interactions between Sustainable Development Goals. *Nat. News* **2016**, *534*, 320. [CrossRef] [PubMed]
2. Sustainability Projects for United States|Sustainable Measures. Available online: http://www.sustainablemeasures.com/projects/Sus/Sustainability/5 (accessed on 20 March 2018).
3. Yu, M.; Zhu, F.; Yang, X.; Wang, L.; Sun, X. Integrating Sustainability into Construction Engineering Projects: Perspective of Sustainable Project Planning. *Sustainability* **2018**, *10*, 784. [CrossRef]
4. Hardy-Vallee, B. The Cost of Bad Project Management. *Business Journals*, 7 February 2012.
5. Lacko, B. *Evaluation of Software Projects with Mta*; Vsb-Tech University Ostrava: Ostrava, Czech Republic, 2012; ISBN 978-80-248-2669-1.
6. Doležal, J. Prediction in Project Using Markov Chains. Available online: https://www.vutbr.cz/studenti/zav-prace?zp_id=34323 (accessed on 15 March 2018).
7. Šviráková, E. Methods for Project Tracking in Creative Environment. *Acta Inform. Pragensia* **2017**, *6*, 32–59. [CrossRef]
8. Rasheed, S.; Wang, C.; Lucena, B. Risk Leveling in Program Environments—A Structured Approach for Program Risk Management. *Sustainability* **2015**, *7*, 5896–5919. [CrossRef]
9. Nguyen, L.H.; Watanabe, T. The Impact of Project Organizational Culture on the Performance of Construction Projects. *Sustainability* **2017**, *9*, 781. [CrossRef]
10. Relich, M. A computational intelligence approach to predicting new product success. In Proceedings of the 11th International Conference on Strategic Management and Its Support by Information Systems, Uherske Hradiste, Czech Republic, 21–22 May 2015; pp. 142–150.
11. Naeni, L.M.; Shadrokh, S.; Salehipour, A. A fuzzy approach for the earned value management. *Int. J. Proj. Manag.* **2011**, *29*, 764–772. [CrossRef]
12. Schwalbe, K. *Řízení projektů v IT: Kompletní průvodce*; Vyd. 1; Computer Press: Brno, Czech Republic, 2011; ISBN 978-80-251-2882-4.
13. McManus, J. *Risk Management in Software Development Projects*; Routledge: Abingdon, UK, 2012; ISBN 978-1-136-36791-5.
14. Boehm, B.W. Software Risk Management: Principles and Practices. *Nasirzadeh* **1991**, *8*, 32–41. [CrossRef]
15. Rudnik, K.; Deptula, A.M. System with probabilistic fuzzy knowledge base and parametric inference operators in risk assessment of innovative projects. *Expert Syst. Appl.* **2015**, *42*, 6365–6379. [CrossRef]
16. Nasirzadeh, F.; Khanzadi, M.; Rezaie, M. Dynamic modeling of the quantitative risk allocation in construction projects. *Int. J. Proj. Manag.* **2014**, *32*, 442–451. [CrossRef]
17. Liu, Z.-C.; Ye, Y. Models for comprehensive evaluating modeling of investment project risk with trapezoid fuzzy linguistic information. *J. Intell. Fuzzy Syst.* **2015**, *28*, 151–156. [CrossRef]
18. Rodriguez, A.; Ortega, F.; Concepcion, R. A method for the evaluation of risk in IT projects. *Expert Syst. Appl.* **2016**, *45*, 273–285. [CrossRef]
19. Zwikael, O.; Pathak, R.D.; Singh, G.; Ahmed, S. The moderating effect of risk on the relationship between planning and success. *Int. J. Proj. Manag.* **2014**, *32*, 435–441. [CrossRef]
20. Doskocil, R.; Skapa, S.; Olsova, P. Success Evaluation Model for Project Management. *E M Ekon. Manag.* **2016**, *19*, 167–185. [CrossRef]
21. RIPRAN—Metoda pro analýzu projektových rizik. Available online: http://ripran.eu/ (accessed on 30 January 2018).
22. Ginevičius, T.; Kaklauskas, A.; Kazokaitis, P. Knowledge model for integrated construction project management. *Bus. Theory Pract.* **2011**, *12*, 162–174. [CrossRef]
23. Matthies, B.; Coners, A. Double-loop learning in project environments: An implementation approach. *Expert Syst. Appl.* **2018**, *96*, 330–346. [CrossRef]
24. Zhang, J.; Li, H.; Wang, S.H.-M. Analysis and Potential Application of the Maturity of Growth Management in the Developing Construction Industry of a Province of China: A Case Study. *Sustainability* **2017**, *9*, 143. [CrossRef]
25. Janicek, P. Systems Conception of Problem-Solving. In *Engineering Mechanics 2017*; Acad Sci Czech Republic, Inst Thermomechanics: Prague, Czech Republic, 2017; pp. 402–405, ISBN 978-80-214-5497-2.
26. Zadeh, L.A. Fuzzy sets. *Inf. Control* **1965**, *8*, 338–353. [CrossRef]

27. Chen, S.-H.; Kaboudan, M.; Du, Y.-R. *The Oxford Handbook of Computational Economics and Finance*; Oxford University Press: Oxford, UK, 2018; ISBN 978-0-19-984437-1.
28. Meyer, A.; Zimmermann, H.-J. Applications of Fuzzy Technology in Business Intelligence. *Int. J. Comput. Commun. Control* **2011**, *6*, 428–441. [CrossRef]
29. Tripathy, B.K.; Sooraj, T.R.; Mohanty, R.K. A New Approach to Fuzzy Soft Set Theory and Its Application in Decision Making. In *Computational Intelligence in Data Mining, Cidm, Vol 2*; Behera, H.S., Mohapatra, D.P., Eds.; Springer-Verlag Berlin: Berlin, Germany, 2016; Volume 411, pp. 305–313, ISBN 978-81-322-2731-1.
30. Zadeh, L.A. Fuzzy logic as the logic of natural languages. In *Analysis and Design of Intelligent Systems Using Soft Computing Techniques*; Melin, P., Castillo, O., Ramirez, E.G., Kacprzyk, J., Pedrycz, W., Eds.; Springer-Verlag Berlin: Berlin, Germany, 2007; Volume 41, pp. 1–2. ISBN 978-3-540-72431-5.
31. Dostál, P. *Advanced Decision Making in Business and Public Services*, 1st ed.; Akademické nakladatelství CERM: Brno, Czech Republic, 2011; ISBN 978-80-7204-747-5.
32. Doskočil, R. An evaluation of total project risk based on fuzzy logic. *Bus. Theory Pract.* **2016**, *15*, 23–31. [CrossRef]
33. Fassinger, R.E.; Shullman, S.L.; Buki, L.P. Future Shock: Counseling Psychology in a VUCA World. *Couns. Psychol.* **2017**, *45*, 1048–1058. [CrossRef]
34. Zandhuis, A. *ISO21500: Guidance on Project Management—A Pocket Guide*; Van Haren Publishing: Zaltbommel, The Netherlands, 2013; p. 51.
35. Cooper, D.; Bosnich, P.; Grey, S.; Purdy, G.; Raymond, G.; Walker, P.; Wood, M. *Project Risk Management Guidelines: Managing Risk with ISO 31000 and IEC 62198*; Wiley: Hoboken, NJ, USA, 2014.
36. ISO 10006:2017—Quality Management—Guidelines for Quality Management in Projects. Available online: https://www.iso.org/standard/70376.html (accessed on 20 April 2018).
37. Kerzner, H.R. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*; John Wiley & Sons: Hoboken, NJ, USA, 2017; ISBN 978-1-119-16535-4.
38. Ariely, D. *The Upside of Irrationality: The Unexpected Benefits of Defying Logic at Work and at Home*; HarperCollins: London, UK, 2010; ISBN 978-0-00-735479-5.
39. McCrindle, M.; Wolfinger, E. *The ABC of XYZ: Understanding the Global Generations*; University of New South Wales Press: Sydney, Australia; London, UK, 2010; ISBN 978-1-74223-035-1.
40. Simonin, B.L. The Importance of Collaborative Know-How: An Empirical Test of the Learning Organization. *Acad. Manag. J.* **1997**, *40*, 1150–1174. [CrossRef]

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Distance Diffusion of Home Bias for Crowdfunding Campaigns between Categories: Insights from Data Analytics

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Abstract: As the information communication and investment of crowdfunding campaigns are usually accomplished online, online crowdfunding theoretically breaks the limitation of space. However, investors' behaviors still show significant home bias; furthermore, from a dynamic view, the changes in home bias during the funding duration reflect the investment preference. This paper studies the dynamics of home bias in crowdfunding investment as well as the distance diffusion of home bias in the crowdfunding market through data mining and econometric models. The distance between investors and founders gradually increases from 3605 km to 4229 km as the funding progresses, and home bias shows different diffusion patterns between categories. For most of the campaigns, the distance between backers and founders of the successful campaigns is always greater than that of the failed ones; thus, the distance diffusion impacts the pledge results. However, the study also finds that for some categories, home bias does not play a positive role in investment or that it even shows negative impacts, among which food and technology are two extreme categories. The study provides a theoretical basis from the perspective of user behavior to analyze online investment and to improve the promotion of crowdfunding campaigns.

Keywords: entrepreneurship; crowdfunding; home bias; distance diffusion; pledge results; Kickstarter

1. Introduction

Taking the online crowdfunding market as an example, project exhibition and investment are conducted over the Internet without any geographical restrictions; it should therefore not show any obvious home bias (also known as the geographic effect or geographical preference). However, our preliminary study shows that investments in crowdfunding projects present significant home bias. It is of great significance to promote the development of Internet finance through an in-depth analysis of investor behavior and an understanding of users' investment preferences, especially in a dynamic way.

In the online peer-to-peer (P2P) lending market, investors' behaviors show a significant home bias trend [1]. That is, investors prefer to support projects launched by founders from the same nation, same province (state), or same city [2]. In other words, investors are inclined to support projects near the location where they live, when the distance between the founders and the backers is small. However, in the literatures we could find, few studies focused on the distance diffusion of home bias in a dynamic way in the field of crowdfunding. Specifically, the distance diffusion of home bias associated with dynamic behavior patterns in the Internet financial market may exist and influence pledge results. According to the theory of social networking [3], a reasonable but unverified assumption is that early investors are closer to the founders, and that the distance increases gradually and spreads to a wide geographical scope as time goes on. However, in the field of crowdfunding we find no literature to distinguish the differences between home bias and social relationships.

Crowdfunding can be classified into many models, among which the reward-based model has been the fastest growing one in recent years [4]. Instead of rewarding the backers with cash or equities, the reward-based model pays the backers in promise types involving products or virtual items (such as the artist's signed photos, films, TV shows, t-shirts, and pre-sale products) [5]. Due to the unforeseen nature of the investment, the rewards promised by the founders are the main motivation for many investors to participate in the campaigns [6]. Reward-based crowdfunding has been a hot spot in recent years, and it gave birth to the world's largest reward-based crowdfunding platform called Kickstarter. In addition to the rewards promised by founders, investors' home bias also impacts the investors' investment intention in the reward-based crowdfunding campaigns. As the investment is a continuous process, investors can participate in the campaign before its completion, which involves dynamic home bias, that is, distance diffusion. Dynamic home bias can characterize the investor behavior patterns in a more profound way than a static process. It is therefore a promising direction for studying the home bias of investors from a dynamic perspective.

As for real data, Figure 1 shows the average distance between investors and founders in different phases of funding for 17,024,837 investments in 136,234 crowdfunding projects from Kickstarter. The distance between investors and founders is calculated in kilometers. The duration of the investment is divided evenly into 20 phases. As seen in Figure 1, the average distance between the two sides is 3329 km in the first phase. As funding progresses, the distance between the two sides spreads gradually and reaches 3956 km in the 20th phase. Thus, in the face of this phenomenon, we are dedicated to exploiting the distance diffusion and the impact of crowdfunding campaigns on financial performance.

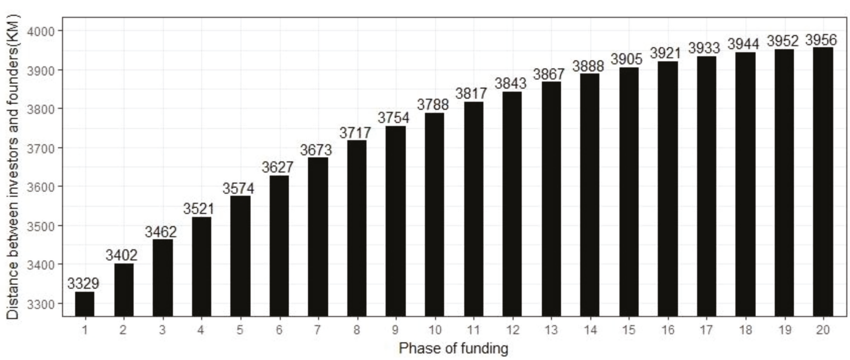

Figure 1. The average distance between investors and founders in different phases of funding.

The extensive statistical results in Figure 1 do not indicate the differences in the distance diffusion under project categories or the impact of distance diffusion on pledge results. While investors prefer to invest in campaigns with a relatively short distance, there are however theoretical differences between home bias and the distance diffusion itself. Home bias statically describes the investment habits of individual investors, while distance diffusion describes the dynamic investment pattern for the majority of investors at the level of groups. Therefore, this paper is devoted to resolving the questions of how distance is spread out in crowdfunding investment, and whether there are any differences between categories at the national, state, city, and distance levels. Additionally, how do distance diffusion and home bias affect the financial performance of the projects?

We employed data mining and econometrics models to carry out an empirical analysis on the data from Kickstarter and to study the home bias and the distance diffusion of investors at the national, state, city, and distance levels. This study has theoretical and practical values for guiding investing and financing practices.

2. Literature Review

2.1. Studies on Crowdfunding

Crowdfunding is the practice of funding a project or venture by raising monetary contributions from a large number of people. It is often performed via Internet-mediated registries, but the concept can also be executed through mail-order subscriptions or other channels [7]. In reward-based crowdfunding, capital-giving motivation is influenced by social relationships [3]. Some backers do not care about the physical return; instead, they are more concerned with a psychological return [8]. Those investors are often the founders' friends or family members. Some studies focus on the assessment of project qualities [9,10], showing that the success rate of crowdfunding is affected by external quality signals [11] including preparation, the attitude of other investors, the personality of the founders, credit rating, and social relationships [12,13].

Many researchers suggest that family and friends are the main source of money during the early stages of funding [14]; reciprocal giving is, for instance, significant in reward-based crowdfunding [15]. The importance of investment from friends and family was verified by data from SellaBand.com, which is consistent with other similar studies [16]. Successful projects can gain support from the founders' friends in social networks in the early funding phases, which is reflected in the number of Facebook followers or Twitter fans [17]. The success rate of crowdfunding was significantly and positively correlated with the number of followers on Facebook [18]. Social relationships show the quality of the creditworthiness of the founders; specifically, social networking increases the probability of successful funding while also lowering the interest rates and default rates on borrowings [19]. Social networking shows astonishing economic potential and has a positive impact on free financial markets and decentralized e-market design [20].

2.2. Studies on Home Bias

A study shows that lenders in the P2P lending market often ignore business characteristics and focus on personal characteristics instead, such as the gender of the borrowers or their location [21,22]. Although there exist some studies and explanations of gender bias, studying home bias is much more complicated. Home bias has already been studied in several areas, typically in business, economics, and finance [23–25]. Throughout current research, many studies mainly adopt offline data to confirm that home bias has a wide range of effects, in market transactions and venture capital for instance. Home bias affects many aspects of user behavior, including economics, geopolitics, culture, and consumer habits. Users tend to invest in projects that are culturally similar to their respective home countries [26].

Considering research and development (R&D) enterprises as an example, this can be completed in any geographical area, and the locations scattered in different addresses can make full use of the advantages of talent and culture from different areas. For example, Microsoft set up the Asian Institute. However, a significant proportion of R&D companies show a bias toward local resources [27]. Researchers have studied the impact of FDI on the flow of funds and on the trade integration of the European Union (EU), which does not adopt indicators such as tariffs or nontariff barriers but mainly adopts trade activities with a home bias. Using data from 1995 to 2009, they found that a country's trade integration and FDI activities were significantly positively correlated. However, the EU may be a special case because it is not possible to strictly distinguish between horizontal and vertical foreign direct investment [28].

A study of the Eurozone's debt crisis finds that home bias highlights the impact on domestic shocks and aggravates the debt crisis. The results support the prediction of the theoretical model; that is, that the consequences of the sovereign debt crisis depend on initial domestic instability and the influence of increasing home bias. They also suggest that increasing home bias reflects worsening fiscal conditions under sovereign debt pressures but could also reduce the possibility of default because local companies prefer local resources [29]. Since asset markets are incomplete, the results also show a significant home bias for transnational transactions in the financial market. Investors often trade a lot in foreign assets and hold so little of them in their portfolios, which increases the riskiness of foreign assets and facilitates risk-sharing across countries [30].

However, a study shows that the spillover effects of cultural and economic distances are more significant than the effects of geometric distance alone. Investors' familiarity with Asian countries seems to influence the fact that there is a similar extent of home bias across Asian financial markets, while this is not the case in developed countries [31]. In other words, different financial markets hold different attitudes toward economic distance and home bias.

2.3. Distance Diffusion and Interpretation

Existing studies on home bias have often focused on offline scenarios, and some researchers shifted their focus to online transactions with the rise of e-commerce. The earliest research on online trading notes that trading on eBay presents home bias. Researchers explain that some deals on eBay involve the sales of tickets, for a concert in New York for instance, in which merchants are likely from New York and consumers often live near New York as well. Thus, these transactions related to entity trading present typical geographic consistency. Another possible explanation is that distance proximity is beneficial for buyers and sellers as they can enter into a face-to-face contract [32].

Many researchers explain home bias from the perspective of the trading cost. For example, the current R&D of multinational enterprises is becoming common, and the preference for local resources is increasing with the scale effect, the scope economy, the coordination cost of international R&D, and the innovation system in the country in which the enterprises are located. Technology-leading is also associated with home bias and is often reflected in the strong intellectual property protection provided by the home country, along with potential foreign knowledge dissipation [27]. As measured by the speed of patent citations, knowledge spreads more slowly over international boundaries than within them, which is also known as home bias of knowledge spillovers [33].

Some explanation of home bias is focused on psychology [34]. Studies note that cultural and patriotic sentiments affect home bias, which affects bond portfolio investments. Most existing studies note that cultural and patriotic sentiments have a substantial impact on home bias in equity. The influence is often estimated from the following two perspectives: domestic preferences (overinvestment in domestic debt) and foreign preferences (underinvestment of the bonds issued by different countries). As a result of home bias, there is strong evidence that patriotism hampers foreign investment while overbilling domestic bonds. Due to home bias, investors from countries with higher uncertainties invest less in foreign bond markets [35]. Moreover, the trend of home bias for such investments has become more pronounced in recent years [36].

Some studies use cultural distance to explain the phenomenon of distance diffusion. Portfolios from culturally distant countries invest less abroad and under-weigh culturally distant target markets [37]. In the art auction market, the distance diffusion of home bias is especially obvious. With other conditions being the same, artwork for auctions tends to bid at a higher price in the artist's hometown, and the auction price declines with an increased distance from the city where the artist resides [38]. This indicates that the increase in distance leads bidders to lower the psychological price of the art; thus, distance diffusion causes bidders to lower the valuation of artwork. As funding is a dynamic process, the time factor would also impact the pledge [39].

3. Research Gap and Research Questions

3.1. Research Gaps

The existence of home bias in offline transactions as well as in e-commerce has been widely confirmed. In a similar study, researchers analyzed the home bias in P2P lending markets [1]. However, in new business models such as crowdfunding, we could find no systemic research on the home bias of investment behavior in the literature. Therefore, theoretical support as well as managerial insights for this new Internet financial model cannot be provided. Most existing research on crowdfunding is related to the impact of social relationships on pledge results or to investment factors analyses; thus, there is a lack of in-depth analysis on home bias. We can understand the investment preferences of investors and provide a basis for research and application on crowdfunding with an in-depth analysis of investment home bias.

Using the reward-based crowdfunding model as an example, founders often promise the investors a return; however, in a virtual platform, transactions and agreements among the founders, investors, and crowdfunding platforms are not signed face-to-face. There is therefore rarely face-to-face accountability, even in the case of default. In addition, because of the nature of crowdfunding, each investor invests only a small portion of money, as required by the project. For investors, there is therefore little incentive to enter into a direct agreement with founders and regulate the campaigns. In this context, home bias should not play a role in crowdfunding investment. However, almost no studies attempt to answer this question and the mechanism of home bias has not yet been discussed in the crowdfunding field, and neither has the distance diffusion of home bias.

Furthermore, most existing related research considers home bias to be a static variable and ignores the dynamic aspect of its distance diffusion. We can obtain the home bias spread by considering the time factor in the model. From the initial stage to the end of financing, there is a gap in the question of how the distance changes between the founders and backers, as well as in the question of how the distance diffusion impacts the success rate of the crowdfunding projects. We cannot find similar research on crowdfunding that combines both home bias and distance diffusion; therefore, there is a theoretical gap in crowdfunding practice.

3.2. Research Question Definition

Existing studies are almost solely focused on static behavior analysis; they do not consider the time factor in home bias and thus do not incorporate either distance diffusion analysis in the online financial market or the impact of distance diffusion on the pledge results of crowdfunding campaigns. Due to differences in the evaluation criteria for different categories, distance diffusion of home bias should present differences among categories correspondingly. Analyzing the differences is helpful to understand investment standards among investors in different categories as well as helping recognize behavior patterns that provide a new channel for mining the value of user behavior for online finance.

According to gaps in existing research and applications, we propose the following research questions.

(1) How is the distance of home bias spread out for investors? Are there differences in the distance diffusion between categories? What are the differences if the answer to the previous question is yes? Does distance diffusion of home bias show user dependence, that is, is it caused by some extreme users, or is it the common behavior of most investors?

(2) What is the difference between levels? Namely, what are the differences in the distance diffusion of home bias at the national, state, city, and distance levels? What is the impact of distance diffusion on the pledge results of the campaigns, that is, if the investors are dispersed in a wide geographical location in the early phase of funding, is this favorable or unfavorable to the success of the project?

4. Materials and Methods

4.1. Data Summary

Experimental data came from Kickstarter, the world's largest reward-based crowdfunding platform for creative ideas. Kickstarter was launched in 2009, with a current Alexa ranking of 544th. Anonymity is allowed when accessing Kickstarter for free, and Kickstarter keeps track of information on all projects including both successful and failed campaigns, which provides a channel to extract the data.

Table 1 shows the category statistics for the sample. Kickstarter's campaigns fall into 15 categories; overall, film & video as well as music projects are major parts of the sample. In terms of the success rate, dance is the highest (74%) among all categories, while fashion is the lowest (35%). The average success ratio is approximately 48.49%, which coincides with prior data collection [5].

Table 1. The category statistics for the sample.

Category	Number	Percentage	Avg. Goal	Avg. Backer	Avg. Pledged	Progress	Success Ratio
Art	10,965	8.05%	20,466.67	45	3533.75	204.48%	53.75%
Comics	3995	2.93%	8583.20	93	7337.16	287.36%	52.59%
Crafts	1170	0.86%	5316.83	39	2626.00	152.02%	44.96%
Dance	1854	1.36%	5623.66	49	3678.75	110.00%	73.84%
Design	7900	5.80%	24,948.62	113	23,135.55	203.55%	41.19%
Fashion	5462	4.01%	12,861.86	54	6802.46	211.50%	34.77%
Film & Video	31,979	23.47%	32,336.32	56	6962.71	150.45%	45.80%
Food	6137	4.50%	17,945.84	75	7827.61	176.45%	42.11%
Games	9926	7.29%	37,809.45	115	25,296.71	1041.18%	38.71%
Journalism	879	0.65%	37,660.54	51	4674.01	63.25%	42.43%
Music	26,855	19.71%	9044.09	57	4318.43	121.96%	61.75%
Photography	4037	2.96%	10,405.18	45	3475.19	67.78%	41.52%
Publishing	14,581	10.70%	9473.44	49	3524.34	241.95%	38.17%
Technology	4645	3.41%	58,519.93	104	37,504.03	168.95%	37.03%
Theater	5849	4.29%	11,207.05	51	4343.29	88.31%	68.85%
Sum	136,234		20,961.79		8843.46		48.49%

For pledge goals, technology is the highest with an average of $58,520, while craft is the lowest with $5316 on average. Accordingly, the highest pledged category is technology, with $37,504, while the lowest is crafts with $2626. The average duration ranges from 33 to 37 days. In terms of the number of backers, games attract the largest number of backers, while art is the lowest on average. This indicates that cyber-users are more concerned with games than with art; however, art ranks much higher than games in terms of the success rate (45% vs. 39%).

4.2. Measurements and Distance Calculation

As the location details for the projects and the investors are provided for the campaigns and backers, following this, we needed to convert the geographical location into latitude and longitude, which was a complicated and time-consuming job.

In the campaign's homepage, we can obtain the address, such as "San Diego, CA," before calling the Google Maps API (*Geocoding API*, https://developers.google.com/maps/documentation/geocoding/) to retrieve the latitude and longitude of the address. For example, the latitude and longitude of "San Diego, CA" are 32.7157380 and −117.1610840, respectively. After obtaining the latitude and longitude of the location, the earth sphere distance calculation approach was adopted to calculate the distance between any two points. In the calculation, the distance between investors and founders was calculated by a straight line rather than pavement distance; this should not impact the results because the distance between cities is usually closer than that between countries.

Equations (1) and (2) show the distance calculation approach, in which the latitude and longitude of the first point A is ($LngA$, $LatA$) and the latitude and longitude of the second point B is ($LngB$, $LatB$):

$$c = sin(LatA)^* sin(LatB)^* cos(LonA - LonB) + cos(LatA)^* cos(LatB) \tag{1}$$

$$Distance = Arccos(c)^* R^* Pi/180 \tag{2}$$

In Equations (1) and (2), $Distance()$ is the distance between A and B, $Arccos()$ represents the arccosine function, R is the radius of the Earth, and the value of R is set to 6371.004 km. Accordingly, the distances are represented in km.

4.3. Methodology

The data we collected stems from projects all over the world. However, being a US-based website, the vast majority of founders and investors are from the United States. Approximately 87.08% of projects are launched by US founders; these projects have significantly higher success rates than those from other countries, with 48.83% and 42.45% respectively. As a matter of fact, approximately 54.4% of the traffic comes from US, according to Alexa data. Therefore, to a certain extent, being a website from the US, investors will be more inclined to fund US projects.

However, it is not fair to consider only home bias at the national level. On the Kickstarter page, both investors and founders can choose to display their detail location, which provides a proxy to calculate the distance between founders and backers. Home bias involves different levels, including national markets, regional markets, and micro markets [1,40]. We therefore try to measure home bias and influences at different levels: (1) National-level home bias, which means the ratio of the investors who invest in projects from the same country. Investors prefer to invest in projects from their home country if national-level home bias exists and plays a role; (2) State-level home bias: similar to national-level home bias, state-level home bias indicates the ratio of backers from the same state (province) as the founders. State-level home bias measures the investor's geographical preference at a finer level; (3) City-level home bias, which presents the ratio of backers from the same city as founders; (4) Distance, for which in this study we adopted kilometers to measure the distance between backers and founders. Distance measures the investor's home bias in a way that can be quantified and compared and shows the distance diffusion for crowdfunding investors.

We estimated the financial impact of distance diffusion of home bias on pledge results and created a model as shown in Equation (3):

$$Status(Project_i) = \beta^* SamePlace_{ij} + f(FounderInfo_i, ProjectInfo_i) + \varepsilon_{ij} \tag{3}$$

where $Status(Project_i)$ means the pledge results, as Kickstarter adopts the "All-or-Nothing" mode, and the status of a project means the campaign has been funded successfully or has failed. The reason this model works is that there will be significantly more local investors than remote backers if home bias works for the cross-sectional data; therefore, projects involving more local investors will be more likely to succeed. In other words, pledge results are significantly impacted by local investors; that is, β should be significantly and positively correlated. Since the status of the project in Equation (3) has only two statuses, 1 for success and 0 for failure, a logit model is adopted to estimate the effect.

To explain the coefficients of the econometric model in detail, marginal effects are adopted. As the model we employ is the logit model, where the dependent variable is a dummy, the marginal effects refer to the probability of a dependent variable from 0 to 1 for a 1% change in independent variables, and a logit model can be presented as Equation (4):

$$p = Pr[y = 1|x, z] = \frac{exp(\alpha + \beta \cdot lnx + \gamma z)}{1 + exp(\alpha + \beta \cdot lnx + \gamma z)} \tag{4}$$

After some tedious calculus and simplification, the partial of that with respect to x becomes a simplified formula, as shown in Equation (5):

$$\frac{\Delta p}{100 \cdot \frac{\Delta x}{x}} = \frac{\beta \cdot p \cdot (1 - p)}{100} \tag{5}$$

The equation is in a semi-elasticity formation and can be interpreted as the change in probability of success funding for a 1% change in x. The greater the marginal effects, the greater the impact on funding results once the value of the variable is changed to the same degree.

Some crowdfunding projects attract very few investors, and these campaigns with small numbers of investors make it difficult to estimate the impact of distance diffusion. Therefore, in the financial impact of home bias testing model, we only employed the projects that are supported by more than 200 backers. The reasons for choosing these projects include the following: (1) these projects often maintain a stable trend and demonstrate the distance diffusion of home bias more obviously; (2) these projects reflect the patterns and trends of investments comprehensively and enduringly; and (3) these projects are able to demonstrate the diffusion process of home bias, which helps to evaluate the effect of distance diffusion on crowdfunding markets. The appendix shows the data summary of the campaigns with 200 plus investors.

5. Results

5.1. Difference between Distance Diffusion of Home Bias

The duration is uniformly divided into 20 phases, and the differences between successful projects and failed campaigns in the distance diffusion are compared. Figure 2 shows the distance diffusion at national-level, state-level, and city-level home biases in the pool data. We can see that national-level home bias is the most intense, followed by state-level, and finally city-level. The home bias declines over time, which is confirmed at all levels.

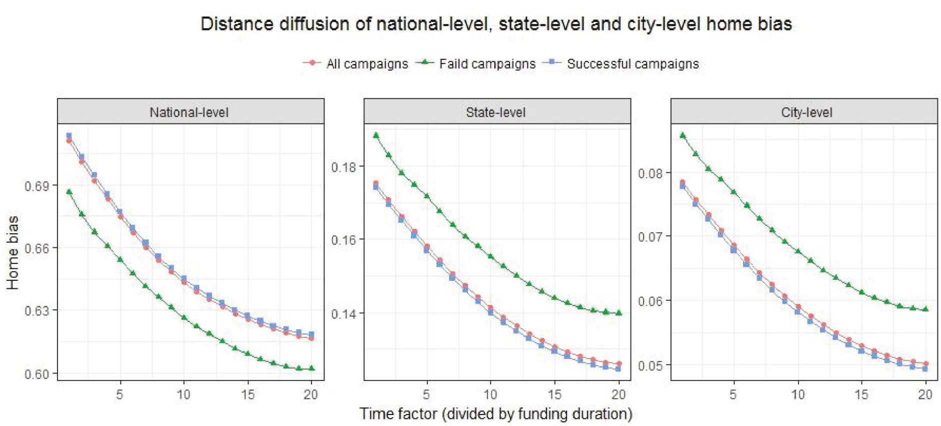

Figure 2. Distance diffusion at national-level, state-level, and city-level home biases.

National-level home bias refers to the ratio of investors and founders from the same country. The larger the ratio, the more investors like investing in the campaigns from their own country, which means that national-level home bias is more significant. Overall, the investment on Kickstarter shows significant national-level home bias. Successful projects show different trends from failed ones, i.e., national-level home bias for successful projects is weaker than that for failed projects. That is, successful projects can gain more support from foreign investors than from local backers.

Figure 3 shows the home bias diffusion between categories. Different categories show significant differences. For example, the home bias curve for technology projects is very steep, while the home bias curve for theater projects is very flat; this means that technology projects have gained more money from domestic investors, and as the financing progresses, investors will quickly expand into the global scope. In fact, at the 20th phase, the national-level home bias for technology projects is 0.54; namely, approximately 46% of investors come from different nationalities than the founders. In contrast, there is almost no change for the theater between phases, with a national level of 0.84 in the 1st phase and of 0.86 in the 20th phase, which indicates that the vast majority of theater investors come from the same country as the founders.

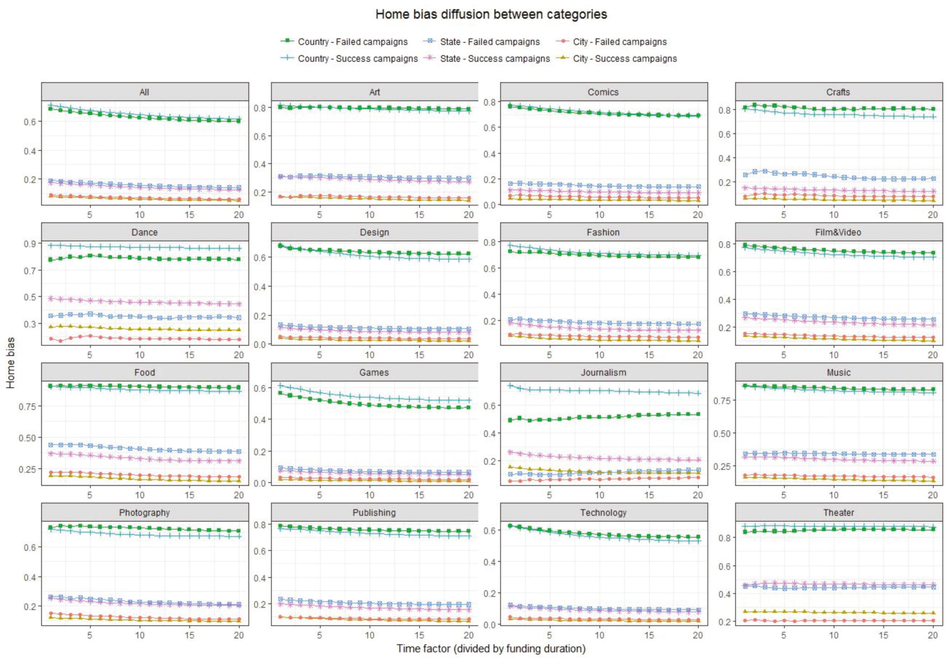

Figure 3. Home bias diffusion between categories.

Another noteworthy phenomenon is the discrimination against other countries in the food category; approximately 90% of investors only invest in campaigns from their own country. In contrast, games are the most international category, with approximately 50% of investors in game projects coming from countries different than that of the founders.

However, we must admit that the analysis at the national level is unfair because Kickstarter is a website based in the US with most of its investors and founders based in the US as well; in detail, about 87% of crowdfunding projects originate in the US, so there is an issue with imbalanced data. To overcome this bias, we remove all investors and founders outside the US from the data, leaving only investors and founders from the US for the state-level home bias analysis.

We can obtain results of state-level home bias that differ from national-level home bias: (1) Differences are shown in state-level distance-diffusion curves between successful and failed projects, with no coincidence between these curves; (2) In some categories, the state-level distance-diffusion curve of failed projects is above successful ones, such as comics, fashion, and crafts, while in other categories such as dance, publishing, and theater, the trend is the opposite. This shows the different distance diffusion patterns between categories; (3) Overall, the state-level distance-diffusion curve is flat in most categories, while in other categories such as photography, publishing, and film & video projects, it declines very rapidly, indicating that state-level distance spreads quickly in these campaigns.

If we subdivide and examine whether investors and founders are from the same city, city-level distance diffusion can be obtained. Overall, city-level home bias shows a declining trend and presents apparent differences between successful and failed campaigns. The distance-diffusion trend curve of failed projects is located above successful ones for art, comics, crafts, design, and fashion; that is, investors with a weaker home bias need to be involved if these project categories are to be funded successfully. In contrast, the distance-diffusion trend curve of successful projects is located above failed ones for the categories of dance, journalism, and theater, which indicates that the support of investors from far distances is a factor helps the project be successfully funded.

There are a number of categories in which the distance-diffusion curve of successful projects differs greatly from failed ones, such as dance, crafts and theater, which shows an obvious difference in the behavior patterns of backers between successful and failed campaigns. These investors are more influenced by the distance factor when they evaluate the campaigns. In contrast, in other projects, the distance-diffusion curve of successful projects is close to that of failed ones, such as games, technology and publishing, which indicates that the distance factor will have a much smaller influence on investors. Furthermore, some categories present a steep distance-diffusion curve. Examples include food and journalism; this indicates that distance is expanding faster in such projects than in any other campaigns. Other categories, such as games and theater, show relatively smooth distance-diffusion curves, which indicates that the speed of distance diffusion for such projects is slow.

The great differences between categories may be caused by the nature of the projects themselves and the preferences of the investors, among which technology projects and theater projects are two opposite examples. Transnational investment on technology projects is a common investment phenomenon, therefore the home bias for technology projects on the national level is not obvious. On the contrary, culture shows a significant impact on theater projects because investors tend to invest in the projects with similar culture [26,27]. The difference in the nature of such projects directly leads to differences in the behavioral pattern of the investors. Investors of theater projects prefer to invest in the projects in the same country as the fundraisers. This phenomenon is particularly evident in the state level and city level. That is, investors prefer theater projects from the same state or city. Another possible reason is the offline market's impact on online finance. In general, campaigns such as food and theater rely strongly on geographical position. Investors prefer projects with the similar culture and habits as themselves, therefore the offline preference affects the behavior patterns of online investment of the crowdfunding pitch.

However, we have to pay attention that in some categories, home bias does not seem to be evident, such as technology, design, and comics projects. Such projects have generally objective evaluation criteria which do not change with differences in the culture, education, social status, and geographical location of the investors. Therefore, for such campaigns, investors inspected the campaigns from the perspective of project quality rather than the geographical factors. Thus, social relationship factors have a much smaller impact on the project investment. This has important implications for the fundraiser of the crowdfunding campaigns, because the extant research and application almost do not discriminate between the differences in the categories. Most of the extant research conclusions are made from the pool data of all campaigns without attempting to distinguish between categories.

Taking the game campaign as an example, the evaluation standards of investors for these projects are more focused on quality than the geographical location of the founders. In the game category, only 0.91% of the investors came from the same city as the fundraisers in the anaphase of the funding duration (last 1/3). That is, in the investment of game projects, investors will not support the crowdfunding projects because of the geographical position of the founders. On the contrary, since investors are distributed in a wide area, these investors care more about the quality of the project itself rather than the location which determines whether the project is worth investing. Founders of such projects should improve the quality of the project in order to attract investors. At the same time, there should be a larger scope for the promotion of the project, and a wide range of promotion is more effective than small-scale promotion. The opposite example includes the food category where fundraisers should pay close attention to the investors who are geographically close.

The study provides a preliminary analysis to compare the difference between categories in fine-grained home bias in a dynamic way.

5.2. Financial Impact of Distance Diffusion of Home Bias

Table 2 shows the financial impact of home bias for projects with over 200 investors through a logit model. It shows that the impact at the national, state, and city levels on pledge results increases in turn with 2.031 ***, 3.715 ***, and 5.016 ***, respectively. In other words, the project will more likely be funded successfully if it attracts more investments from local investors.

Table 2. Financial impact of home bias for projects with over 200 investors (logit).

Variable	National Level	State Level	City Level	Distance
logNumUpdates	1.359 *** (0.0702)	1.342 *** (0.0703)	1.335 *** (0.0696)	1.353 *** (0.0705)
logNumComment	0.1743 *** (0.0383)	0.252 *** (0.0394)	0.2054 *** (0.0391)	0.243 *** (0.0401)
logGoal	−2.696 *** (0.081)	−2.786 *** (0.0831)	−2.749 *** (0.082)	−2.693 *** (0.0813)
logLastdays	−0.1479 (0.1781)	−0.1209 (0.1826)	−0.1043 (0.1794)	−0.1448 (0.181)
logNumPledgeLevel	−0.3241 *** (0.1046)	−0.2952 *** (0.105)	−0.2761 *** (0.1042)	−0.3711 *** (0.1054)
Video	0.8863 *** (0.2143)	0.8219 *** (0.2134)	0.7855 *** (0.2107)	0.8555 *** (0.2148)
logNumPreceding	−0.1901 *** (0.0426)	−0.1565 *** (0.0424)	−0.1626 *** (0.0421)	−0.1379 *** (0.0425)
logNumFollowers	0.0221 (0.0143)	0.0208 (0.0144)	0.0231 (0.0143)	0.023 (0.0143)
logMaxPledge	0.1155 *** (0.0313)	0.1244 *** (0.0316)	0.1242 *** (0.0314)	0.1085 *** (0.0314)
logMinPledge	0.068 *** (0.0252)	0.064 ** (0.0252)	0.0673 *** (0.0251)	0.063 ** (0.0251)
logAvgPledge	0.876 *** (0.0577)	0.8378 *** (0.0578)	0.85 *** (0.0575)	0.8709 *** (0.0576)
logPopulationDensity	−0.0263 (0.0575)	−0.092 (0.057)	−0.1518 *** (0.0582)	−0.0565 (0.0609)
CountryBias	2.031 *** (0.1806)			
StateBias		3.715 *** (0.303)		
CityBias			5.016 *** (0.5215)	
logDistance				−1.004 *** (0.0878)
constant	19.39 *** (0.9417)	21.12 *** (0.9403)	21.24 *** (0.9309)	28.77 *** (1.158)
Pseudo R2	0.5045	0.5136	0.5048	0.5083
Observations	10,160	10,160	10,160	10,159

** $p < 0.01$; *** $p < 0.001$, Standard errors in parentheses.

For the distance between investors and founders, the closer the two sides are, the more likely it will be that the project is successful; the coefficient is −1.004 ***. The negative coefficient means that the farther the distance is, the less likely it is to be successful in funding. This is consistent with the financial impact of home bias at the national, state, and city levels.

In the model, we control the population density because we believe that both home bias and distance diffusion are affected by the population density of the project location. For example, 100 km in Canada is a significantly different proposition than 100 km in the Netherlands. In terms of the regression coefficient, although the impact is negative in other models, population density only has a significant effect at the city level. This shows that at the city level, population density will affect the financing results of the crowdfunding projects, that is, launching crowdfunding projects in densely populated cities will reduce the possibility of successful funding. However, this conclusion does not hold at the national and state levels, as well as in the distance-level model.

The marginal effect of distance is the change in the success ratio for projects based on the discrete change of the dummy variable (from 0 to 1), as shown in the Table 3; it shows that all the marginal effects are significant for national-, state-, city-, and distance-level home bias. In detail, the marginal effects are significantly positively correlated for national-, state-, and city-level home bias, with 0.0354 ***, 0.061 ***, and 0.0855 ***, respectively. The city-level home bias shows the maximum energy with regards to successful campaigns, which is to say that while the other conditions are equal (proportionally equal changes from investors in the same city with respect to the same country and the same state), the pledge results are impacted most significantly. Meanwhile, the marginal effect is significantly negatively correlated with the distance level with −0.0172 ***, which means that for each additional unit of distance between the investor and the founders, the project's success rate will decrease by 1.72%.

Table 3. Marginal effects based on the discrete change of the dummy variable from 0 to 1 for projects with over 200 investors (logit).

Variable	National-Level dy/dx	State-Level dy/dx	City-Level dy/dx	Distance dy/dx
logNumUpdates	0.0237 *** (0.0019)	0.0221 *** (0.0018)	0.0227 *** (0.0018)	0.0232 *** (0.0018)
logNumComment	0.003 *** (6.7×10^{-4})	0.0041 *** (6.7×10^{-4})	0.0035 *** (6.7×10^{-4})	0.0042 *** (7.0×10^{-4})
logGoal	−0.0469 *** (0.0029)	−0.0458 *** (0.0029)	−0.0468 *** (0.003)	−0.0462 *** (0.0029)
logLastdays	−0.0026 (0.0031)	−0.002 (0.003)	−0.0018 (0.0031)	−0.0025 (0.0031)
logNumPledgeLevel	−0.0056 *** (0.0018)	−0.0049 *** (0.0017)	−0.0047 *** (0.0018)	−0.0064 *** (0.0018)
Video	0.0232 *** (0.008)	0.0197 *** (0.0072)	0.0192 *** (0.0071)	0.0217 *** (0.0078)
logNumPreceding	−0.0033 *** (7.7×10^{-4})	−0.0026 *** (7.1×10^{-4})	−0.0028 *** (7.4×10^{-4})	−0.0024 *** (7.4×10^{-4})
logNumFollowers	3.9×10^{-4} (2.5×10^{-4})	3.4×10^{-4} (2.4×10^{-4})	3.9×10^{-4} (2.5×10^{-4})	3.9×10^{-4} (2.5×10^{-4})
logMaxPledge	0.002 *** (5.6×10^{-4})	0.002 *** (5.3×10^{-4})	0.0021 *** (5.5×10^{-4})	0.0019 *** (5.5×10^{-4})
logMinPledge	0.0012 *** (4.4×10^{-4})	0.0011 ** (4.2×10^{-4})	0.0011 *** (4.3×10^{-4})	0.0011 ** (4.4×10^{-4})
logAvgPledge	0.0153 *** (0.0013)	0.0138 *** (0.0012)	0.0145 *** (0.0013)	0.0149 *** (0.0013)

Table 3. *Cont.*

Variable	National-Level dy/dx	State-Level dy/dx	City-Level dy/dx	Distance dy/dx
logPopulationDensity	-4.6×10^{-4} (0.001)	-0.0015 (9.4×10^{-4})	-0.0026 *** (0.001)	-9.7×10^{-4} (0.001)
CountryBias	0.0354 *** (0.0038)			
StateBias		0.061 *** (0.0061)		
CityBias			0.0855 *** (0.01)	
logDistance				-0.0172 *** (0.0018)
Observations	10,160	10,160	10,160	10,160

** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses; dy/dx for discrete change of dummy variable from 0 to 1.

5.3. Distance Versus Social Relationships

Although we have demonstrated the diffusion trends of investors' distance, we do not discuss the impact of home bias and social relationships on the funding results. Some extant studies show that home bias and social relationships are significantly correlated [16], thus distance effects may be a likely proxy of social relationships.

As it is difficult to exclude founders' social relationships from the analysis, it is impossible to identify whether the backers truly were strangers or simply friends living in another city or state. This could potentially be done by using the founders' social networks as a proxy, because the more extensive the social network is, the more friends there are in the corresponding node. It is also likely that these friends already have built social relationships offline [41]. The Pearson correlation coefficient between the number of backers and distance is 0.493 *** ($p < 0.001$), that is, the closer the investor and financier, the more backers of the campaigns are. This indicates, from the geographical distance, that a part of social friends should be closer to the investor. Therefore, nodes with extensive social relationships may be more affected by distance.

In order to analyze distance versus social relationships for funding results, we attempted to examine the moderated effect of distance and social relationships, as shown in Table 4, where *logNumFollowers* indicates the number followers on online social platforms (including facebook.com, twitter.com, flickr.com, etc.).

The results of distance versus social relationships show that the social relationships weaken the effect of distance on the funding results (0.0031); meanwhile, the distance weakens the impact of social relationships on the funding results (-0.4023 ***). The moderate effect of social relationships on funding results is negatively impacted by the distance, that is, the distance between founders and backers weakens the impact of social relationships. The results indicate that some investors are acquaintances of the founders. Therefore, home bias, to some extent, is influenced by the social relationships of founders.

At the same time, the moderate effect of distance on funding results is negatively impacted by social relationships (-0.3036 ***). In other words, the distance factor and social relationships show certain substitution effects, which is to say that some investors are friends or family members of founders, which leads to the negative influence.

Table 4. Results of distance versus social relationships.

Variable	Model					
	(1)	(2)	(3)	(4)	(5)	(6)
logNumUpdates	1.363 *** (0.069)	1.357 *** (0.0704)	1.353 *** (0.0705)	1.355 *** (0.0705)	1.417 *** (0.0707)	1.396 *** (0.0717)
logNumComment	0.0467 (0.0362)	0.2357 *** (0.0399)	0.243 *** (0.0401)	0.2376 *** (0.0401)	0.1245 *** (0.0375)	0.2663 *** (0.0406)
logGoal	−2.716 *** (0.0799)	−2.698 *** (0.0813)	−2.693 *** (0.0813)	−2.696 *** (0.0814)	−2.716 *** (0.0809)	−2.695 *** (0.0818)
logLastdays	−0.1745 (0.1733)	−0.1482 (0.1811)	−0.1448 (0.181)	−0.1471 (0.1811)	−0.1772 (0.1763)	−0.1577 (0.1821)
logNumPledgeLevel	−0.2142 ** (0.1016)	−0.3638 *** (0.1053)	−0.3711 *** (0.1054)	−0.3654 *** (0.1053)	−0.3223 *** (0.1043)	−0.4267 *** (0.1068)
Video	0.8167 *** (0.2091)	0.869 *** (0.2142)	0.8555 *** (0.2148)	0.865 *** (0.2144)	0.8545 *** (0.212)	0.8623 *** (0.2164)
logNumPreceding	−0.1524 *** (0.0416)	−0.1224 *** (0.0414)	−0.1379 *** (0.0425)	−0.1268 *** (0.0424)	−0.1626 *** (0.0426)	−0.1476 *** (0.0431)
logMaxPledge	0.1306 *** (0.0308)	0.1097 *** (0.0314)	0.1085 *** (0.0314)	0.1094 *** (0.0314)	0.1205 *** (0.0312)	0.1042 *** (0.0317)
logMinPledge	0.0641 *** (0.0249)	0.0624 ** (0.0251)	0.063 ** (0.0251)	0.0626 ** (0.0251)	0.0626 ** (0.0252)	0.0627 ** (0.0253)
logAvgPledge	0.8777 *** (0.0566)	0.8732 *** (0.0576)	0.8709 *** (0.0576)	0.8728 *** (0.0576)	0.8487 *** (0.0572)	0.8487 *** (0.0579)
logPopulationDensity	−0.2171 *** (0.0602)	−0.0562 (0.061)	−0.0565 (0.0609)	−0.0564 (0.061)	−0.1666 *** (0.0606)	−0.0461 (0.0612)
logNumFollowers	0.0286 ** (0.014)		0.023 (0.0143)		0.9018 *** (0.0864)	0.6871 *** (0.0922)
logDistance		−1.009 *** (0.0878)	−1.004 *** (0.0878)	−1.009 *** (0.0878)		−.8342 *** (0.0904)
logNumFollowers logDistance*				0.0031 (0.0065)	−0.4023 *** (0.0389)	−0.3036 *** (0.0414)
constant	21.8 *** (0.917)	28.89 *** (1.156)	28.77 *** (1.158)	28.87 *** (1.157)	21.85 *** (0.9316)	27.64 *** (1.169)
Pseudo R2	0.4872	0.5080	0.5083	0.5080	0.5026	0.5159
Observations	10,160	10,159	10,159	10,159	10,159	10,159

** $p < 0.01$ *** $p < 0.001$, Standard errors in parentheses.

6. Discussion and Conclusions

This study investigates the dynamics of home bias in crowdfunding investment and the distance diffusion of home bias in the crowdfunding market, as well as the financial impact of the distance diffusion of home bias on pledge results. Through data mining and econometric models, we validate the existence of distance diffusion of home bias in crowdfunding and find that the investor's behavior pattern regarding dynamic home bias affects the success rate of campaigns in the crowdfunding pitch. In particular, we try to answer two key questions in this study: (1) How is distance spread out in crowdfunding investment, and are there any differences between categories? (2) What is the economic value of home bias and distance diffusion? Additionally, how do distance diffusion and home bias affect the financial performance of the projects?

In the extant literature, there is little research on home bias under reward-based crowdfunding, but there are some studies on other crowdfunding modes, such as P2P lending [1] and equity crowdfunding [42]. The P2P lending study uncovers home bias and validates the influence of home bias on online investments [1], while in the equity study the relationship between equity home bias and financial integration is found to be U-shaped [42]. Another equity crowdfunding platform, ASSOB, presents evidence of the influence of geographic distance among retail, accredited, and overseas investors and venture locations in an equity crowdfunding context. Geographic distance is negatively correlated with investment probability for home country investors; however, investment decisions differ by investor type [43]. However, in the reward-based crowdfunding mode, few relevant theoretical explorations and practical implications exist.

In the few studies we can find, there is little research on home bias, especially for the research on Internet finance. In the most relevant study, P2P lending is adopted as the research object. There, the authors mainly discussed two questions: (1) Is there home bias in online debt-based crowdfunding market? (2) If so, what is the mechanism that drives home bias in this market? Results from a series of tests consistently refuted a purely economic explanation of home bias—including variance-based statistical discrimination—and supported the argument that behavioral factors at least partially drive home bias behaviors. The paper documents empirical evidence of home bias in online crowdfunding and tries to tease out the mechanism behind it [20]. In this paper, we employ the reward-based crowdfunding as the study object which compensates for the lack of existing research on reward-based model. Further, we provide solid evidence for the existence of home bias in the reward-based crowdfunding. The conclusion of this study also provides improvement for the extant works and provides creative solutions for practice.

Many extant studies explains the home bias according to the influence of offline social relationships on online behavior. They often conclude that the influence of offline social networks extends to online business. Therefore, investors from closer distances have significant home bias trends. However, in this paper, we have shown that in addition to the influence of social network, home bias does exist and works in the reward-based crowdfunding pitch.

Many studies consider the home bias as a static variable, in which user behavior tends to occur in a certain area, rather than breaking the regional restrictions. For example, transactions within a province are always more than that of between provinces. Researchers generally believe that this is due to transaction costs and cultural dependence. However, the extant studies almost does not consider the changes in home bias of the investors in the funding time window. Since crowd-funding investment behavior is completed within a certain time window, investors can continue to invest within this time window. Therefore, investors' home bias can be expressed as a dynamic behavior, that is, the investors' preference can be split into early stage, middle stage, and late stage. The study shows that in the early stage of financing, investors from relatively close distances occupy a large proportion, and as financing proceeds, many remote financers gradually participate in investment, and therefore, it shows a typical distance diffusion of home bias. This phenomenon has not been studied in extant studies and practice.

Extant studies mainly discuss the source of crowdfunding investors from the perspective of social relationships. Due to the social relationships of the fundraisers, the crowdfunding campaigns often attract seminal investors in the early stage of funding, among which, most of the backers in the early stage are the friends or family members of the founders. Therefore, in the early stage of financing, the distance between investors and backers is close. However, these studies ignore the economic value of home bias. That is, when backers from closer distances participate in investment, are crowdfunding projects more likely to succeed or fail? This study shows that the farther the distance between investors and financiers is, the less likely it is for the project to succeed. In other words, a near-distance investment is conducive to the successful financing of the projects. It is similar to the influence of offline financing. In offline investments, a closer distance means that investors have a better understanding of the capabilities and credits of the founders.

Our study adds new insights to the literature by theorizing and empirically testing the effects of distance diffusion of home bias on performance predictors such as the pledge results of crowdfunding campaigns [1] and the moderated effect of distance and social relationships [16]. Insights from this study yield both theoretical and practical implications.

6.1. Contribution to Theory

As a common behavioral pattern, home bias is heavily discussed in offline markets, as the offline market is often impacted by factors related to geographical location (communication cost, contract cost, supervision cost, etc.). Many studies have therefore proven the existence of home bias in offline transactions and presented various theories to explain home bias in offline markets [44]. However, there is much less research on online markets. As an emerging Internet financial model, crowdfunding is the subject of only very few systemic studies, especially with regards to the distance diffusion of home bias. Relevant research results are rare, as can be seen in the reward-based crowdfunding mode.

Although social relationships play an important role in the financing of crowdfunding, they cannot fully explain the influence of home bias in reward-based crowdfunding. After controlling social factors, investors' home bias still significantly affects the success rate of crowdfunding campaigns. In previous studies, it was widely believed that early investors were friends or family members of financiers; therefore, the geographic distance between investors and financiers is smaller. But in theory, the explanation has two shortcomings: (1) the explanation considers home bias and its impacts from a static perspective, without a dynamic perspective to examine the relationship between investors and financiers; and (2) in the early stage of financing, due to the existence of social relationships, it is easy to attract friends of the financier to participate in the investment. However, this explanation almost ignores the influence of nonsocial relationships on investment. In fact, in addition to financiers' friends and family members, there must be a large number of strangers involved in the investment. This group of investors has affected the pledge results of campaigns and cannot be confused with social relationships. The paper's theoretical contribution is based on answers to these two questions.

Through empirical studies on 136,234 crowdfunding projects from Kickstarter, the study confirms the existence of distance diffusion in crowdfunding investment. However, distance diffusion is complicated and extremely uneven across categories. For instance, for food campaigns, significant discriminations exist in other countries; investors are more willing to invest in food projects from their own regions or from the same location [45]. In contrast, home bias shows less impact on technology projects, i.e., investors in technology projects will rapidly spread to a broad area. The differences in distance diffusion between categories reflect the inconsistency in investors' evaluation criteria. Previous studies have shown that the specialization of food crowdfunding projects, such as environment and food security [46], along with the description relating to environmental protection and food safety, are very useful in pinpointing fund raising success [47]. However, previous studies did not pay attention to the differences among the sources of investors. Investors in food crowdfunding projects demonstrate strong home bias. Investors prefer to invest in projects that are geographically closer to financiers, which may be due to the convergence of culture and eating habits. Geographic proximity often means a similarity in living habits. In terms of dynamic investment behavior, it is not easy for investors in food crowdfunding to spread farther, which was not noted in previous studies. For technology projects, the impact of geographical location is much smaller than it is for food. In other words, backers can spread quickly across a wide geographical range as long as the project is of high quality; similar examples include games. In reality, because of the quality rather than the location of the projects, many games or technology projects can quickly gain support from the global market once they are listed. Thus, investors' evaluation standards for such projects are not related to their geographic location. Instead of the office location, the founders of such projects therefore need to focus on project ideas and improve project quality.

In terms of the speed of distance spread, the distance-diffusion curves are steeper for some categories, such as game and theater, which shows that the distance between investors and founders in these campaigns can spread rapidly and expand to long-distance investors quickly, thus generating considerable long-distance investment. In contrast, in other categories, such as food and journalism, the distance-diffusion curve is relatively flat, which indicates that the distance between investors and founders of such projects spreads slowly. However, this does not mean that long-distance investors are reluctant to participate in the investment. Instead, it is likely that the number of long-distance investors backing the campaigns is lower than the number of local-distance investors, especially during the first phase of financing. The opposite example includes games, where long-distance investors are dominant from the first phase to the last phase.

In terms of the difference between successful and failed projects, the distance-diffusion trend curve of successful projects differs greatly from that of failed ones for dance, crafts, and theater. This indicates that there is a huge difference in behavioral patterns for investors of successful and of failed campaigns. These investors are more concerned about the distance factor when investing, and therefore home bias shows a greater impact. In contrast, the distance-diffusion trend curve of successful projects is close to that of failed ones in other projects, such as games, technology, and publishing, which indicates that the influence of the distance factor will be much smaller. In the economic sense, the difference reflects the economic value of home bias.

Existing studies on the economic value of home bias are almost all from the financial field rather than the crowdfunding pitch. A typical study is the influence of home bias on portfolio holdings, not only for equity, but also for bonds [48]. However, this type of studies lacks an examination of home bias behavior from the perspective of investor behavior. In fact, due to the particularity of the reward-based crowdfunding model, some crowdfunding projects promise to give investors a return in kind of the product. For example, the reward of a food campaign is likely to be food. Under these circumstances, it is impossible to explain the investment intention through a return on investment, such as a capital assets pricing model (CAPM), which is widely adopted in the financial field.

The study shows that the distance between investors and founders gradually increases over time, and there is very little systematic research on the distance diffusion of investment behavior. In the case of dividing the funding duration into three phases, the average distance between investors and founders in the prophase is 3605 km, the average distance in the metaphase is 4154 km, and the average distance in the anaphase is 4299 km. Using another measurement, the average distance between investors and founders in the first phase is 3329 km, while that during the last phase is 4131 km when the investment duration is divided evenly into 20 phases, which shows a significant distance-diffusion trend. The econometric model still shows the significant impact of distance factors on pledge results, even when the population density and social relationships are controlled. Discovering and proving the existence of distance diffusion of home bias for crowdfunding investment constitutes another theoretical contribution of this study.

At the same time, distance diffusion of home bias affects the pledge results of the projects. Viewed as collective behavior [49], whether a crowdfunding campaign will succeed or not is affected by various factors; home bias is one of these factors, but there are few systematic discussions that focus on it. Taking national-level home bias as an example, the overall investment on Kickstarter shows significant home bias at the national level, and the difference between successful projects and failed campaigns exhibits significant differences between categories. In particular, successful projects are often less affected by national-level home bias; that is, they can get more support from foreign investors.

Financial globalization that encourages optimal international portfolio investments should improve the investor protection standards (IPS) of a country, and the quality of IPS improves when the optimal international equity portfolio allocation of domestic and foreign investors is higher; in other words, biases play a role in international portfolio allocation [50]. But this does not explain the impact of home bias on pledge results in the crowdfunding pitch. That is, a successful crowdfunding project is, on the one hand, affected by the quality of the project [11], while on the other hand it is influenced by the investor's preference. However, few studies exist on the influence of investors' preferences.

Categories also show significant differences. For example, the home bias curve for technology projects is very steep, which indicates that they can gain more support from domestic investors during the early stages. With financing in place, investors gradually expanded to the global scale. In fact, the national-level home bias of technology projects is 0.54 in the 20th phase; namely, approximately 46% of investors come from different nationalities than the founders'. In contrast, theater projects do show significant differences in national-level home bias. The national-level home bias of theater projects is 0.84 in the 1st phase and 0.86 in the 20th phase, which demonstrates that most investors of theater projects come from the same country as the founders. In short, investors in theater projects prefer local resources. Among all campaigns, food projects exhibit the most significant discrimination in other countries; that is, approximately 90% of investors only invest in food projects from their own country. In contrast, game projects are the most international category, with approximately 50% of investors coming from different countries than the founders', which provides both theoretical and practical implications. Regarding the theoretical aspect, this is a future direction that should be deeply studied according to the category and characteristics of projects. In extant studies, the investor's behavior was rarely discussed according to the category and characteristics of the project.

6.2. Managerial Implications

This study provides rich implications and suggestions for founders in terms of effectively promoting the project. Most previous research did not focus on the impact of home bias on pledge results, thus many founders do not know how to promote their projects during the duration of funding, for instance, how and when to recommend their projects to potential backers. This study provides guidance that founders need in order to focus on backers in a small geographical range during the early stages of funding. To meet the requirements of investors' behavioral patterns, the recommended sequence should start in the same city, same state (province), and same country, and then expand to other areas, and this provides the basis for raising the success rate of crowdfunding campaigns.

At the same time, the proximity of geographical location often means a similarity in language and culture [51]. The study concludes that investors are more inclined to invest in projects with the same language and culture; therefore, founders should consider investors from the same language or culture [52]. However, some categories, like crafts, are not only subject to national-level home bias, but can easily obtain support from investors from different countries than the founders'. That is, for these categories, investors prefer exotic projects. Thus, founders should ignore home bias in promoting such projects and focus on a broader pool of investors during the early phase.

This paper provides evidence that home bias is one of the most important factors for investors to take part in crowdfunding campaigns. The differences in investors' evaluation standards is the main reason for the difference in the distance diffusion of home bias between categories. This difference provides a theoretical basis for founders and crowdfunding platforms on the basis of which to recommend suitable projects to investors. However, we should note that for some categories, home bias does not work, even showing a counterproductive influence.

6.3. Limitations and Future Directions

Although we studied the distance diffusion of home bias and its financial impact in the crowdfunding market, we admit that there exist some limitations. Directions for a future in-depth study are as follows: (1) The paper studies the distance diffusion and diffusion speed and their impacts on pledge results in reward-based crowdfunding without any in-depth analysis on other crowdfunding modes. Furthermore, as Kickstarter adopts the "All-or-Nothing" financing mode, the conclusion of this study may not be applicable to other modes, such as the "All-and-More" mode. In fact, in addition to reward-based crowdfunding, there are many other business models, such as equity-based, donation-based, and scientific crowdfunding. Thus, in future research, we plan to analyze the difference in distance diffusion of home bias under different financing modes; (2) An important theoretical basis for this study is that early investors are often the founders' friends or family members, so that the distance between the two sides is closer at an earlier stage than it is at a later point in time. However, this theory only explains the behavior of early investors but cannot explain the difference between investors' behavior patterns in the middle and late phases. The behavioral difference between the middle and late phase is significant, as shown in the results, and a theoretical improvement regarding this phenomenon is therefore a direction for future research; (3) The econometric model ignores the possible endogenous problem. This study adopts the explanation that home bias in investments leads to pledge results; however, another possible explanation is that investments impact home bias and then determine pledge results. Thus, we plan to employ "difference in difference" in order to solve the problem in the future; (4) The data we adopted is biased itself. As Kickstarter is a US-based website, and accordingly, the vast majority of founders and investors are from the United States. Therefore, to a certain extent, we just analyzed the home bias of American investors earlier but lacked the analysis of other countries. In the future, we plan to analyze the data from other countries, especially from different cultures and regions, and try to distinguish the differences of home bias between cultures.

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Appendix A

Figure A1 shows the average distance between investors and founders in different phases of funding (200 plus investors). The distance between investors and founders is calculated in kilometers. The duration of the investment is divided evenly into 20 phases. As seen in Figure 1, the average distance between the two sides is 2877 km in the first phase. As funding progresses, the distance between the two sides spreads gradually and reaches 3217 km in the 8th phase before gradually decreasing to 2894 km in the last phase. The distance between investors and founders for the campaigns with 200 plus investors shows an n-shape trend.

Some crowdfunding projects attract very few investors, and these campaigns with small numbers of investors make it difficult to estimate the impact of distance diffusion. Therefore, in the financial impact of a home-bias testing model, we only employ the projects that are supported by more than 200 backers. The reasons for choosing these projects include the following: (1) these projects often maintain a stable trend and demonstrate the distance diffusion of home bias more obviously; (2) these projects reflect the patterns and trends of investments comprehensively and enduringly; and (3) these projects are able to demonstrate the diffusion process of home bias, which helps to evaluate the distance diffusion of home bias in crowdfunding markets. The appendix shows the data summary of the campaigns with 200 plus investors.

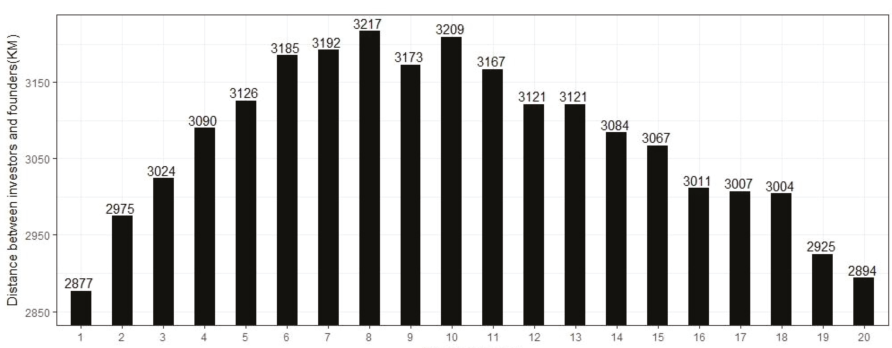

Figure A1. The average distance between investors and founders in different phases of funding (200 plus investors).

Table A1 shows the category statistics for the sample (200 plus investors). Kickstarter's campaigns fall into 15 categories; overall, film & video games, along with design projects, are the major parts of the sample. In terms of the success rate, the success ratio of the sub-data financing is high with average success ratio of 89.22%.

Table A1. The category statistics for the sample (200 plus investors).

Category	Number	Percentage	Avg. Goal	Avg. Backer	Avg. Pledged	Progress	Success Ratio	Distance
Art	356	3.49%	21,888.46	353.50	23,157.73	316.97%	95.51%	2476.36
Comics	554	5.43%	11,500.02	391.90	18,673.82	255.12%	97.65%	3478.17
Crafts	40	0.39%	12,378.88	359.33	22,304.15	802.12%	97.50%	3118.63
Dance	32	0.31%	16,293.75	271.72	18,968.12	130.97%	96.88%	1650.44
Design	1396	13.69%	28,682.70	435.19	36,804.81	511.05%	83.52%	4099.68
Fashion	346	3.39%	20,163.22	395.25	32,475.33	312.30%	94.80%	3398.03
Film & Video	1903	18.67%	45,453.17	374.66	35,703.44	122.60%	90.91%	2716.93
Food	604	5.93%	23,475.12	338.89	27,262.23	191.30%	94.87%	1529.75
Games	1848	18.13%	34,320.70	444.34	24,762.37	1560.57%	78.84%	3962.92
Journalism	53	0.52%	20,662.52	381.23	24,620.11	153.82%	94.34%	2909.79
Music	1179	11.57%	21,497.92	342.78	22,284.63	158.88%	97.79%	2232.54
Photography	183	1.80%	17,379.56	343.53	24,525.91	196.41%	96.72%	3581.74
Publishing	782	7.67%	14,993.38	366.41	20,312.96	218.27%	95.78%	2872.05
Technology	738	7.24%	61,292.66	444.30	59,810.99	304.71%	80.22%	4407.06
Theater	180	1.77%	33,626.23	350.40	34,574.03	118.22%	93.89%	1411.15
Sum	10,194		31,286.20	393.74	30,526.85	489.79%	89.22%	3187.84

For pledge goals, technology is the highest with an average of $61,292.66, while craft is the lowest with $12,378.88 on average. Accordingly, the highest pledged category is technology, with $59,810.99, while the lowest is comics, with $18,673.82. In terms of the number of backers, games attract the largest number of backers, while dance is the lowest on average. This indicates that cyber-users are more concerned with games than with dance; however, dance is much higher than games in term of the success rate (96.88% vs. 78.84%).

References

1. Lin, M.; Viswanathan, S. Home bias in online investments: An empirical study of an online crowdfunding market. *Manag. Sci.* **2015**, *62*, 1393–1414. [CrossRef]
2. Chen, W.J.; Liaw, S.C. What is the value of eco-tourism? An evaluation of forested trails for community residents and visitors. *Tour. Econ.* **2012**, *18*, 871–885. [CrossRef]
3. Zhao, Q.; Chen, C.-D.; Wang, J.-L.; Chen, P.-C. Determinants of backers' funding intention in crowdfunding: Social exchange theory and regulatory focus. *Telemat. Inform.* **2017**, *34*, 370–384. [CrossRef]
4. Kim, T.; Por, M.H.; Yang, S.-B. Winning the crowd in online fundraising platforms: The roles of founder and project features. *Electron. Commer. Res. Appl.* **2017**, *25*, 86–94. [CrossRef]
5. Kuppuswamy, V.; Bayus, B.L. Does my contribution to your crowdfunding project matter? *J. Bus. Ventur.* **2017**, *32*, 72–89. [CrossRef]
6. Belleflamme, P.; Lambert, T.; Schwienbacher, A. Crowdfunding: Tapping the right crowd. *J. Bus. Ventur.* **2014**, *29*, 585–609. [CrossRef]
7. Gleasure, R.; Feller, J. Emerging technologies and the democratisation of financial services: A metatriangulation of crowdfunding research. *Inf. Organ.* **2016**, *26*, 101–115. [CrossRef]
8. Gerber, E.M.; Hui, J. Crowdfunding: Motivations and deterrents for participation. *ACM Trans. Comput. Hum. Interact.* **2013**, *20*, 34. [CrossRef]
9. Giudici, G.; Guerini, M.; Rossi-Lamastra, C. Reward-based crowdfunding of entrepreneurial projects: The effect of local altruism and localized social capital on proponents' success. *Small Bus. Econ.* **2018**, *50*, 307–324. [CrossRef]
10. Davis, B.C.; Hmieleski, K.M.; Webb, J.W.; Coombs, J.E. Funders' positive affective reactions to entrepreneurs' crowdfunding pitches: The influence of perceived product creativity and entrepreneurial passion. *J. Bus. Ventur.* **2017**, *32*, 90–106. [CrossRef]

11. Xu, A.; Yang, X.; Rao, H.; Fu, W.-T.; Huang, S.-W.; Bailey, B.P. Show me the money!: An analysis of project updates during crowdfunding campaigns. In Proceedings of the 32nd Annual ACM Conference on Human Factors in Computing Systems, Toronto, ON, Canada, 26 April–1 May 2014; Association for Computing Machinery: New York, NY, USA; pp. 591–600.
12. Bi, S.; Liu, Z.; Usman, K. The influence of online information on investing decisions of reward-based crowdfunding. *J. Bus. Res.* **2017**, *71*, 10–18. [CrossRef]
13. Snyder, J.; Crooks, V.A.; Mathers, A.; Chow-White, P. Appealing to the crowd: Ethical justifications in canadian medical crowdfunding campaigns. *J. Med. Ethics* **2017**. [CrossRef] [PubMed]
14. Cumming, D.J.; Johan, S.A. *Venture Capital and Private Equity Contracting: An International Perspective*; Academic Press: Cambridge, MA, USA, 2013.
15. André, K.; Bureau, S.; Gautier, A.; Rubel, O. Beyond the opposition between altruism and self-interest: Reciprocal giving in reward-based crowdfunding. *J. Bus. Ethics* **2017**, *146*, 313–332. [CrossRef]
16. Agrawal, A.; Catalini, C.; Goldfarb, A. Crowdfunding: Geography, social networks, and the timing of investment decisions. *J. Econ. Manag. Strategy* **2015**, *24*, 253–274. [CrossRef]
17. Zeng, X.; Li, Y.; Leung, S.C.; Lin, Z.; Liu, X. Investment behavior prediction in heterogeneous information network. *Neurocomputing* **2016**, *217*, 125–132. [CrossRef]
18. Mollick, E. The dynamics of crowdfunding: An exploratory study. *J. Bus. Ventur.* **2014**, *29*, 1–16. [CrossRef]
19. Zheng, H.; Xu, B.; Wang, T.; Chen, D. Project implementation success in reward-based crowdfunding: An empirical study. *Int. J. Electron. Commer.* **2017**, *21*, 424–448. [CrossRef]
20. Lin, M.; Prabhala, N.R.; Viswanathan, S. Judging borrowers by the company they keep: Friendship networks and information asymmetry in online peer-to-peer lending. *Manag. Sci.* **2013**, *59*, 17–35. [CrossRef]
21. Kgoroeadira, R.; Burke, A.; van Stel, A. Small business online loan crowdfunding: Who gets funded and what determines the rate of interest? *Small Bus. Econ.* **2018**. [CrossRef]
22. Li, C.S.J.; Henley, J.; Ansell, J.; Dong, T.P. Location-specific factors, localisation strategy, and firm performance: A case study of taiwanese manufacturing mne subsidiaries investing in China. *Tijdschr. Econ. Soc. Geogr.* **2011**, *102*, 426–440. [CrossRef]
23. Forman, C.; Ghose, A.; Goldfarb, A. Competition between local and electronic markets: How the benefit of buying online depends on where you live. *Manag. Sci.* **2009**, *55*, 47–57. [CrossRef]
24. Graham, J.R.; Harvey, C.R.; Huang, H. Investor competence, trading frequency, and home bias. *Manag. Sci.* **2009**, *55*, 1094–1106. [CrossRef]
25. Forman, C.; Goldfarb, A.; Greenstein, S. The internet and local wages: A puzzle. *Am. Econ. Rev.* **2012**, *102*, 556–575. [CrossRef]
26. Fuchs, A.; Gehring, K. The home bias in sovereign ratings. *J. Eur. Econ. Assoc.* **2017**, *15*, 1386–1423. [CrossRef]
27. Belderbos, R.; Leten, B.; Suzuki, S. How global is R&D? Firm-level determinants of home-country bias in R.&D. *J. Int. Bus. Stud.* **2013**, *44*, 765–786.
28. Martínez-San Román, V.; Bengoa, M.; Sánchez-Robles, B. Foreign direct investment, trade integration and the home bias: Evidence from the european union. *Empir. Econ.* **2016**, *50*, 197–229. [CrossRef]
29. Cornand, C.; Gandré, P.; Gimet, C. Increase in home bias in the eurozone debt crisis: The role of domestic shocks. *Econ. Model.* **2016**, *53*, 445–469. [CrossRef]
30. Hnatkovska, V. Home bias and high turnover: Dynamic portfolio choice with incomplete markets. *J. Int. Econ.* **2010**, *80*, 113–128. [CrossRef]
31. Kim, H. The spatial impact of cultural distances on home bias across asian emerging markets. *Atl. Econ. J.* **2017**, *45*, 81–101. [CrossRef]
32. Hortaçsu, A.; Martínez-Jerez, F.; Douglas, J. The geography of trade in online transactions: Evidence from ebay and mercadolibre. *Am. Econ. J. Microecon.* **2009**, *1*, 53–74. [CrossRef]
33. Griffith, R.; Lee, S.; Van Reenen, J. Is distance dying at last? Falling home bias in fixed-effects models of patent citations. *Quant. Econ.* **2011**, *2*, 211–249. [CrossRef]
34. Teng, C.I.; Tseng, F.C.; Chen, Y.S.; Wu, S. Online gaming misbehaviours and their adverse impact on other gamers. *Online Inf. Rev.* **2012**, *36*, 342–358. [CrossRef]
35. Pradkhan, E. Impact of culture and patriotism on home bias in bond portfolios. *Rev. Manag. Sci.* **2016**, *10*, 265–301. [CrossRef]
36. Levy, H. What is the economic cost of the investment home bias? *J. Money Credit Bank.* **2017**, *49*, 897–929. [CrossRef]

37. Anderson, C.W.; Fedenia, M.; Hirschey, M.; Skiba, H. Cultural influences on home bias and international diversification by institutional investors. *J. Bank. Finance* **2011**, *35*, 916–934. [CrossRef]
38. Shi, Y.; Xu, H.; Wang, M.; Conroy, P. Home bias in domestic art markets: Evidence from China. *Econ. Lett.* **2017**, *159*, 201–203. [CrossRef]
39. Mountantonakis, M.; Minadakis, N.; Marketakis, Y.; Fafalios, P.; Tzitzikas, Y. Quantifying the connectivity of a semantic warehouse and understanding its evolution over time. *Int. J. Semant. Web Inf. Syst.* **2016**, *12*, 27–78. [CrossRef]
40. Torelli, C.J.; Ahluwalia, R.; Cheng, S.Y.; Olson, N.J.; Stoner, J.L. Redefining home: How cultural distinctiveness affects the malleability of in-group boundaries and brand preferences. *J. Consum. Res.* **2017**, *44*, 44–61. [CrossRef]
41. Subrahmanyam, K.; Reich, S.M.; Waechter, N.; Espinoza, G. Online and offline social networks: Use of social networking sites by emerging adults. *J. Appl. Dev. Psychol.* **2008**, *29*, 420–433. [CrossRef]
42. Mukherjee, R.; Paul, S.; Shankar, S. Equity home bias—A global perspective from the shrunk frontier. *Econ. Anal. Policy* **2018**, *57*, 9–21. [CrossRef]
43. Günther, C.; Johan, S.; Schweizer, D. Is the crowd sensitive to distance?—How investment decisions differ by investor type. *Small Bus. Econ.* **2018**, *50*, 289–305. [CrossRef]
44. Baschieri, G.; Carosi, A.; Mengoli, S. Family firm local involvement and the local home bias phenomenon. *Long Range Plan.* **2017**, *50*, 93–107. [CrossRef]
45. Brunori, G.; Barjolle, D.; Van Broekhuizen, R.; Colombo, L.; Giampietro, M.; Kirwan, J.; Lang, T.; Mathijs, E.; Maye, D.; De Roest, K.; et al. Are local food chains more sustainable than global food chains? Considerations for assessment. *Sustainability* **2016**, *8*, 449. [CrossRef]
46. Arcese, G.; Flammini, S.; Lucchetti, M.C.; Martucci, O. Evidence and experience of open sustainability innovation practices in the food sector. *Sustainability* **2015**, *7*, 8067–8090. [CrossRef]
47. Yuan, H.; Lau, R.Y.; Xu, W. The determinants of crowdfunding success: A semantic text analytics approach. *Decis. Support Syst.* **2016**, *91*, 67–76. [CrossRef]
48. Solnik, B.; Zuo, L. Relative optimism and the home bias puzzle. *Rev. Finance* **2016**, *21*, 2045–2074. [CrossRef]
49. Lytras, M.D.; Raghavan, V.; Damiani, E. Big data and data analytics research: From metaphors to value space for collective wisdom in human decision making and smart machines. *Int. J. Semant. Web Inf. Syst.* **2017**, *13*, 1–10. [CrossRef]
50. Kwabi, F.O.; Thapa, C.; Paudyal, K.; Adegbite, E. Biases in international portfolio allocation and investor protection standards. *Int. Rev. Finance Anal.* **2017**, *53*, 66–79. [CrossRef]
51. Beugelsdijk, S.; Frijns, B. A cultural explanation of the foreign bias in international asset allocation. *J. Bank. Finance* **2010**, *34*, 2121–2131. [CrossRef]
52. Dollani, A.; Lerario, A.; Maiellaro, N. Sustaining cultural and natural heritage in Albania. *Sustainability* **2016**, *8*, 792. [CrossRef]

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Article

Dynamic Evaluation of the Energy Efficiency of Environments in Brazilian University Classrooms Using DEA

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Abstract: This paper presents an experience applied to a public university campus using Data Envelopment Analysis (DEA) to evaluate and improve the energy efficiency of the indoor spaces of the buildings within the limits of the Federal University of Piauí, considering the lighting (installed power and luminous flux) and air conditioning (absorbed electric power and cooling capacity) input/output variables. Using Brazilian energy efficiency evaluation methods, a comparison was made between DEA and Brazilian standards, with the goal of examining DEA's performance and feasibility in efficiency improvement. The results revealed that all of the analyzed university classrooms were inefficient, which is coherent with the classification obtained by applying Brazilian standards; the calculated efficiency scores for these rooms varied from 0.7182 to 0.8477, a 0.7848 average. The DEA model, while operating in lighting and air conditioning systems, achieved a reduction of installed power of 43.5% and 22.7%, respectively, totaling a decrease of 25.6%, being able to maintain the standard characteristics of the systems mentioned. According to the DEA models, it was found that the generated targets effectively improved the efficiency of lighting and air-conditioning systems, reducing excessive inputs such as air conditioners' consumption and increasing deficient outputs such as luminous flux. It is possible to expand this successful application in the layout of the building in the whole campus area to concept small smart city projects; both have been achieved in the public buildings of the administrative body. Results from this paper revealed DEA's potential in assessing and optimizing the energy efficiency of buildings, improving their sustainability indexes, acting as a tool to support decision-making and benchmarking.

Keywords: data envelopment analysis; optimization; energy efficiency; lighting; air conditioning

1. Introduction

Since the 19th century, with the Second Industrial Revolution, the development of society has been directly linked to increasing electricity dependence, in such a way that it is difficult to imagine life without electrical energy nowadays. Its applications in industry, hospitals, electric appliances, lighting, air conditioning, etc. show that electric energy is indispensable to the functioning of virtually everything in modern society. The growth of the population and consequently, energy consumption, combined with this resource's limited availability, show that its adequate management is necessary. In Brazil, it is estimated that consumption could grow from 525 TWh, registered in 2014, to 786 TWh in 2024, a 4.1% percent growth per year [1].

In the 1970s, the world oil crisis stimulated energy conservation discussions [2], which resulted in growing environmental awareness towards energy conservation and efficient use in the following years. As the term "efficiency" has a broad meaning, energy efficiency can be defined as the ability of a building to provide inner comfort conditions with minimum energy [3].

In December 1985, a major advance in Brazilian public policies associated with energy conservation was achieved: the program PROCEL was created by Eletrobrás (Centrais Elétricas Brasileiras S.A. Rio de Janeiro, Brazil), saving 70.1 billion of kWh between 1986 and 2013 [4]. The program encompasses several measures, adopting energy efficiency standards, spreading energy conservation awareness and combating electricity losses [5]. Another interesting aspect of PROCEL is the subprogram PROCEL Edifica, created to rationalize energy consumption in residential, commercial and public buildings, by evaluating energy efficiency and assigning a label the edification. Energy conservation in buildings is an important goal, since commercial, residential and public buildings are responsible for about 50% of the energy consumed in Brazil [6].

In Brazilian public buildings, which are the main study object of this paper, Lamberts, Dutra, and Pereira [7] concluded that is possible to reduce 30% to 50% energy consumption by adopting low cost technical and management measures. In these buildings, energy efficiency evaluation is made by following the steps described on the Quality Technical Report for the Energy Efficiency Level of Commercial, Services and Public Buildings (RTQ-C), which specifies criteria for the building's illumination, air conditioning and envelope systems.

Figure 1 shows the distribution of energy consumption for Brazilian public buildings.

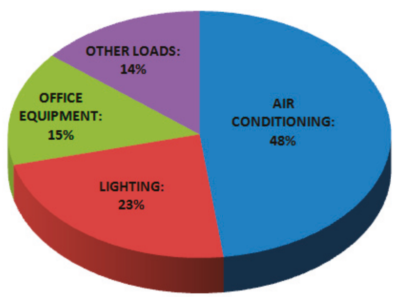

Figure 1. Distribution of energy consumption in public buildings. Source: [8].

It is evident that the maximum contribution to the energy consumption is 48% from air conditioning, followed by 23% from lighting, which are responsible for 71% of the energy consumed. Very close to the consumption profile of a residence in the tropical region where the university campus is located. Therefore, efficient lighting and air conditioning are mandatory to obtain high energy efficiency in public buildings, which makes energy efficiency and environmental performance evaluation crucial [9]. Efficient use of electrical energy brings various benefits, such as environmental conservation, visual and thermal comfort, and reduction of public spending with energy bills.

The optimization models only aim to reduce the energy consumption and reduce the final cost. However, this disregards the needs of the consumer. Therefore, proposals which appear excellent in theory are usually impracticable and non-commercial. Considering the different home appliance categories and level of consumer satisfaction for the new load scheduling of the appliances would be much more comprehensive than the other models analyzed. Moreover, it can be applied in any energy scenario.

There is a need for efficiency evaluation methods in Brazil and in other countries. In this way, the development of advanced computational techniques has opened new possibilities to evaluate and improve buildings' energy efficiency. Data Envelopment Analysis (DEA), has attracted much attention in the energy sector [10] and has been accepted as a benchmarking technique in many countries [11]. DEA uses linear programming models to compare, calculate and evaluate the efficiency of productive entities, known as Decision Making Units (DMUs), in addition, to establish a set of targets for inefficient

DMUs [12–14]. The nature of the DMUs will differ from one application to another, which might be companies, equipment, industries, etc. Therefore, DEA could work as a support tool to handle what has to be changed to reach efficiency while keeping adherent with RTQ-C, providing a preliminary overview of the building's energy efficiency situation.

In this study, DEA was applied to evaluate and improve energy efficiency of indoor spaces (classrooms) from the Federal University of Piauí, focusing the analysis especially on lighting and air conditioning—the main consumption plots. The university campus is composed of several buildings with more than 60 undergraduate courses and more than 15,000 active students. This campus resembles a small Brazilian city. In order to assess DEA's performance and feasibility in efficiency improvement, Brazilian energy efficiency standards were used to compare the efficiency levels before and after the application of DEA's suggestions. Ultimately, one can extend the proposal so that all the buildings in a small city presents scores that reflect their level of energy efficiency.

In addition to this introduction, this paper has five other sections, structured as follows. Section 2 presents an evaluation of energy efficiency method by applying RTQ-C. Moreover, in Section 3, an overview of the DEA technique is presented. Sections 4 and 5 present the case study in which the proposed methodological tool is applied. Finally, Section 6 presents the conclusions of this study.

2. Energy Efficiency Evaluation Using RTQ-C

As previously stated, energy efficiency evaluation in Brazilian public and commercial buildings are made by evaluating lighting, air conditioning and envelopment systems, following the criteria described in the RTQ-C. For residential applications, RTQ-R is used. RTQ-C was approved in 2009 by decree no. 163 of National Institute of Metrology, Quality and Technology [15] and was developed by the Energy Efficiency Laboratory (LabEEE) team of the Federal University of Santa Catarina (UFSC) in collaboration with Eletrobrás, under the program PROCEL Edifica [7].

The evaluation can be made by the prescriptive method, which uses equations and tables with established values or by computational simulation, which uses software to calculate the indoor spaces' performance. Usually, the first method is faster and simpler, and will be covered in the next sections. In the prescriptive method, the building's general efficiency score is composed by the sum of the illumination, air conditioning and envelope scores; illumination score composes 30% of the global score, envelope 30% and air conditioning 40%. It is important to mention that the "envelope" system (the building's physical part formed by the external surfaces, such as walls, roofs, openings and facades) must not be mistaken for the "envelopment" in DEA, as it is not related. Each system is ranked from "A" (most efficient) to "E" (least efficient), and receives a score matching its rank in Table 1.

Table 1. Efficiency levels and corresponding scores.

System Efficiency	Equivalent Score
A	5
B	4
C	3
D	2
E	1

Source: [15].

After obtaining each individual score, the system's efficiencies are combined in a single equation, which determines the building's global score (GS). Although the building's envelope is used in the global score calculation, its evaluation is more complex, and it is not included in this paper's objectives. This study focuses on lighting and air conditioning efficiencies.

In Sections 2.1 and 2.2, the evaluation of illumination and air conditioning systems will be detailed, according to the prescriptive method.

2.1. Lighting System Evaluation

The artificial lighting system, composed basically by lamps, luminaires and reactors, is indispensable to perform activities in public buildings; however, lighting energy costs represent 22% of the country's energy consumption [8] and 23% of the public buildings' consumption (Figure 1). The results of efficient lighting are savings in energy and numerous environmental benefits [16] while maintaining the visual comfort levels. An efficient design is not merely a matter of adequate equipment choices, but it also considers taking advantage of the building's natural illumination.

RTQ-C defines two methods for lighting system evaluation, both based on installed power limits. The first is known as "area method", and it is applied for buildings with a maximum of three main activities, which is the case of the subject studied in this paper. For this method, RTQ-C establishes the maximum levels of Illumination Power Density (DPI) allowed for each classification based on the activity performed on the building. Table 2 presents some of the limits defined in the RTQ-C.

Table 2. Maximum Illumination Power Density (DPI) values based on the building's main activity for the desired classification level.

Building Type	Maximum DPI for Rank A (W/m^2)	Maximum DPI for Rank B (W/m^2)	Maximum DPI for Rank C (W/m^2)	Maximum DPI for Rank D (W/m^2)
Universities	10.7	12.3	13.9	15.5
Libraries	12.7	14.6	16.5	18.4
Hospitals	13.0	15.0	16.9	18.9

Source: [15].

DPI can be defined as the ratio between the Total Lighting Installed Power (TLP) and the room area A:

$$\text{DPI} = \text{TLP}/\text{A}\left(\text{W}/\text{m}^2\right). \tag{1}$$

A university classroom with a 9.00 W/m^2 DPI, for example, is classified as "A", following Table 3. Another important parameter in lighting systems is the luminous efficiency η, defined as the ratio between the luminous flux ϕ emitted by the light source and the lighting power LP it has absorbed [17]:

$$\eta = \phi/\text{LP}\ (\text{lm}/\text{W}). \tag{2}$$

In order to obtain "A" classification, the lighting system is subject to other requisites (besides an adequate DPI) described in the RTQ-C, such as circuit division and automatic shutdown for rooms bigger than 250 m^2 [15], which will not be considered in this study, since these requisites are not quantities and cannot be computed by DEA.

Table 3. Minimum Energy Efficiency Coefficient (CEE) values for window units.

	CEE—Energy Efficiency Coefficient (W/W)				
Class	Category 1	Category 2	Category 3	Category 4	Total Devices
	≤9000 BTU/h	≥9000 BTU/h ≤13,999 BTU/h	≥14,000 BTU/h ≤19,999 BTU/h	≥20,000 BTU/h	
A	≥2.93	≥3.03	≥2.88	≥2.82	39
B	≥2.84	≥2.94	≥2.71	≥2.65	30
C	≥2.76	≥2.86	≥2.59	≥2.48	5
D	≥2.68	≥2.78	≥2.45	≥2.30	5

Source: [18].

2.2. Air Conditioning System Evaluation

Much like the illumination system, air conditioning is indispensable in the majority of buildings, as it generates comfort and improves the workplace productivity. Air conditioners with adequate capacity and power and high energy efficiency greatly increase energy savings, as the air conditioning system is the biggest responsible for energy consumption. In addition to equipment, adequate projects consider also the building's conditions, such as radiation, localization and materials used in the construction.

RTQ-C treats the air conditioning system in two manners, depending on whether the equipment is regulated by INMETRO or not. For equipment regulated by INMETRO, air condition system efficiency is obtained by verifying the device's label [15], which features classification results from laboratory tests and evaluation. This is a simple procedure because it depends on the Cooling Capacity (CC) and the mean power absorbed by the device, as follows:

$$\mathrm{CEE} = \mathrm{CC}/\mathrm{P}\ (\mathrm{W}/\mathrm{W}) \tag{3}$$

where CEE is the device's Energy Efficiency Coefficient, usually given in W/W or BTU/h/W. INMETRO provides tables containing minimum CEEs based on the device type and desired classification. For window units, for example, INMETRO supplies the values shown in Table 3.

Brazilian air conditioners are behind other countries' devices in energy efficiency, as Brazilian least efficient devices' mean CEE is around 2.08 W/W, while most of the least efficient devices in the world have CEEs around 2.80 W/W [19]. In addition, Brazilian's most efficient equipment has a 4.79 W/W CEE, while many other air conditioners in China and Japan have more than 6.0 W/W [20].

To obtain an "A" classification, besides from an INMETRO "A" labelling, there are other requisites: the window unit or the split's condensing unit should be shadowed, entirely or partly, and the ducts' isolation should have a 2.5 cm minimum width. If these requirements are not met, the device's maximum classification will be limited to "B". For devices not regulated by INMETRO, ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) establishes minimum CEE values according to the refrigerating type, capacity and desired efficiency.

3. Data Envelopment Analysis Overview

Data Envelopment Analysis (DEA) was developed by Charnes et al. [21], based upon earlier works of Farrell [22]. By using linear programming models, DEA evaluates and optimizes the performance/efficiency of the so-called Decision-Making Units (DMUs), which perform the same activity and generate multiple outputs while consuming multiple inputs [23]. Like other linear programming models, DEA has three elements [24]: (i) objective-function, which is the function involving the decision variables that will be maximized or minimized; (ii) restrictions, which are the conditions that need to be met and express the interdependence relationship between the variables; and (iii) decision variables, which are the characteristics that will be studied.

DEA has many advantages, which consolidated this relatively new approach inefficiency evaluation. Firstly, as a non-parametric technique, DEA does not require knowing a function that relates input and outputs [25]; secondly, it combines many characteristics with different units in a single efficiency measure. Finally, DEA analysis and DMU comparing are easier, as the results are presented more clearly [12].

A DEA-based application has the following basic elements [21]: (i) DMU, which is the subject that will be evaluated; (ii) inputs, which are the resources used by a DMU to perform an activity; (iii) outputs, which are the products generated by a DMU; (iv) efficiency frontier, which is the set composed by the most efficient DMUs; and (v) relative efficiency, which is the efficiency score of the DMUs regarding the efficiency frontier.

The linear combination of outputs multiplied by their respective weights is called virtual output, and the weighted combination of inputs is called virtual input. A DMU's efficiency ranges between zero and one, and can be calculated as follows [21]:

$$\mathrm{EFF_j} = \frac{\text{virtual output}}{\text{virtual input}} = \frac{u_1 y_{1j} + u_2 y_{2j} + \ldots u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \ldots v_n x_{nj}} \tag{4}$$

where EFF_j is DMU j' score, u_1, u_2, ..., u_n, are the output weights, v_1, v_2, ..., v_n, are the input weights, y_{1j} is the output 1 value for DMU j and x_{1j} is the input 1 value for DMU *j*. An efficient DMU receives the unitary score (100%): none of its inputs or outputs can be improved without worsening other inputs or outputs; the set of the efficient DMUs form the efficiency frontier of the program. An inefficient DMU, in turn, receives a score that reflects its improvement potential: a 0.7 score, for example, means that DMU *j* needs to reduce its inputs by 30% in order to reach the efficiency frontier. Equation (4) can be optimized either by reducing the virtual input while maintaining the output or increasing the virtual output while maintaining the inputs; the first approach is called input-oriented model, and the second is called output-oriented model [26].

The main objectives of DEA can be resumed as [24–28] (i) compare DMUs that perform the same activity and differ in inputs and outputs quantity; (ii) identify efficient DMUs, which will become benchmarks for inefficient DMUs; (iii) calculate the relative efficiency of all DMUs; (iv) provide strategies to improve the score of inefficient DMUs, optimizing their inputs/outputs. These strategies should not be taken as rigid objectives, but as suggestions of how the DMUs' inputs and outputs can be optimized [29].

The first DEA model, called CCR (Charnes, Cooper & Rhodes) or CRS (Constant Returns to Scale), was developed by Charnes et al. and was deemed more appropriate for this study. Its Dual formulations are presented as follows [21]:

Input-oriented

$$\begin{gathered} \text{Min } \theta_0 \\ \text{subject to:} \\ \theta_0 x_{i0} - \sum_{k=0}^{n} x_{ik}\lambda_k \geq 0,\ \forall i \\ -y_{j0} + \sum_{k=0}^{n} y_{jk}\lambda_k \geq 0,\ \forall j \\ \lambda_k \geq 0,\ \forall k \end{gathered} \tag{5}$$

Output-oriented

$$\begin{gathered} \text{Max } (1/\theta_0) \\ \text{subject to:} \\ x_{i0} - \sum_{k=0}^{n} x_{ik}\lambda_k \geq 0,\ \forall i \\ -y_{j0}/\theta_0 + \sum_{k=0}^{n} y_{jk}\lambda_k \geq 0,\ \forall j \\ \lambda_k \geq 0,\ \forall k \end{gathered} \tag{6}$$

where θ_0 is DMU 0's efficiency score, is DMU k's contribution on the targets of DMU 0, y_{j0} is output j quantity for DMU 0, x_{i0} is output i quantity for DMU 0 and n is the quantity of DMUs used on the model. Decision variables are θ and λ; in the input-oriented Dual Model (5), the program attempts to minimize DMU 0's inputs while maintaining the same output levels. If DMU 0 is considered efficient, θ_0 and λ_0 are equal to 1 and the other DMUs equal to 0, which means DMU 0's resources cannot be reduced without altering its outputs. In turn, if DMU 0 is deemed inefficient, its inputs can be reduced from x_{i0} to x_{ik} while maintaining the same outputs. Thus, the input-oriented Dual model provides a set of x_{ik} targets for each inefficient DMU's inputs, in order to maximize its score. On the other hand, the output-oriented Dual Model (6) increases DMU 0's outputs while maintaining the same input levels, providing a set of y_{jk} targets for inefficient DMUs' outputs. Aside from the input/output Dual CCR models, there are many other DEA models by Oliveira and Pinheiro [14] which use different returns to scale, operating characteristics and formulations.

4. Methods

To evaluate the indoor spaces' energy efficiency using DEA, the steps described in the systematic methodology proposed by Golany and Roll [30] were followed. A DEA-based efficiency study comprises three main phases [30]: (i) definition and selection of DMUs to enter the analysis; (ii) determination of relevant inputs and outputs to assess the relative efficiency of the selected DMUs; (iii) application of the DEA models and analysis of outcomes. Based on this methodology, five steps were defined to apply DEA, described through this section:

- Definition and selection of DMUs;
- Data collection;
- Selection of variables;
- DEA model choice;
- Software choice and model application.

In this paper, the DMUs were defined as indoor spaces (classrooms and laboratories) from the Federal University of Piauí, more specifically from the Civil Engineering Department (Building 5) of the Technology Center, campus Petrônio Portela. In this two-floor building, electrical engineering students of the University's Energy Efficiency Laboratory had collected the data about lighting and air conditioning systems. Each one of Building 5's ten rooms was considered a DMU.

As DEA calculates only relative efficiencies, comparing Building 5 rooms would not make sense because they have "B" or lower classification; as this paper's purpose is to improve the rooms' energy efficiencies to make them closer to an "A" classification, several real "A" rooms were added to the DMU set. With this addition, only "A" rooms would compose the efficiency frontier, thus the set of goals generated by the DEA model could bring the inefficient DMUs closer to an "A" classification. It is important to mention that even if the inefficient DMUs reach the frontier, they still are subject to the requisites mentioned in the RTQ-C.

Most of the "A" rooms added to the program are virtual, i.e., created rooms with "A" lighting and air conditioning systems, while the other part was collected from RTQ-C –based studies. In the creation process, different areas, lamps and air conditioners were used to avoid biasing the DEA model to an ideal "A" characteristic. The lamps selected had a luminous efficiency ranging from 100 to 120 lm/W and air conditioners with CEEs ranging from 3.33 to 3.48 W/W. Therefore, the DMU set is composed by 19 DMUs, which from this point on will be referred as 'classrooms'. In Table 4, the data obtained for lighting systems is presented.

According to Brazilian technical standards, the mean illuminance level E_M (ratio between the emitted luminous flux and the area) adequate to classrooms is 500 lx, therefore, almost all Building 5 rooms are inadequate (except 552-1), which means that the luminous flux must be increased to provide adequate visual comfort. The air conditioning systems data is presented on Table 5.

Table 4. Lighting systems data.

Room	Total Lighting Installed Power TLP (W)	Luminous Flux (lm)	Mean Illuminance E_M (lx)	Area (m^2)	DPI (W/m^2)	Lighting Classification
550-1	495	30,000	287.5	42.26	11.71	B
550-2	297	18,000	172.5	42.26	7.02	A
550-3	297	18,000	172.5	42.26	7.02	A
551	990	60,000	415.31	62.02	15.96	E
552-1	1188	72,000	537.81	53.55	22.18	E
552-2	990	60,000	448.18	53.55	18.48	E
553	990	60,000	380	63.04	15.7	E
554	990	60,000	345.12	69.54	14.23	D
555	990	60,000	449.43	66.75	14.83	D
556	1188	72,000	298.81	113.2	10.49	A
A1	140	15,960	513	14	10	A
A2	230	25,360	518.72	22	10.45	A
A3	160	19,200	569.17	15.18	10.54	A
A4	80	9600	508.23	8.5	9.41	A
A5	240	27,360	502.53	24.5	9.79	A
A6	425	42,500	508.28	40	10.62	A
A7	578	66,120	504.31	59	9.79	A
A8	300	34,200	501.95	30.66	9.78	A
A9	500	57,000	510.95	50.2	9.96	A

Table 5. Air conditioning systems data.

Room	Unit Power (W)	Unit CC (BTU/h)	Number of Devices	Total Air Conditioning Power (W)	Total CC (BTU/h)	CEE	Air Conditioning Classification
550-1	1938	18,000	2	3876	36,000	2.72	B
550-2	1228	12,000	1	1228	12,000	2.88	C
550-3	1228	12,000	1	1228	12,000	2.88	C
551	1938	18,000	1			2.72	
	2650	21,000	1	4588	39,000	2.32	C
552-1	3150	30,000	2	6300	60,000	2.79	B
552-2	3150	30,000	2	6300	60,000	2.79	B
553	2370	21,000	1			2.59	
	2650	21,000	1	5020	42,000	2.32	D
554	3230	30,000	1			2.72	
	1815	18,000	1	5045	48,000	2.9	B
555	3150	30,000	1			2.79	
	2650	21,000	1	5800	51,000	2.32	C
556	1938	18,000	1			2.72	
	2650	21,000	2			2.32	
	2180	21,000	1			2.82	
	3150	30,000	1	12,568	11,1000	2.79	C
A1	1580	18,000	1	1580	18,000	3.34	A
A2	660	30,000	4	2640	30,000	3.33	A
A3	1040	12,000	1	1040	12,000	3.38	A
A4	785	9000	1	785	9000	3.35	A
A5	1040	12,000	2	2080	24,000	3.37	A
A6	1887	22,000	2	3774	44,000	3.42	A
A7	2530	29,000	2			3.36	
	1010	1200	1	6070	70,000	3.48	A
A8	3110	36,000	1	3110	36,000	3.38	A
A9	2270	27,000	2	4540	54,000	3.47	A

Due to Building 5 being the oldest department of the University's Technology Center, all air conditioning devices were window units. Following the next step of DEA application, the selection of variables was made. Golany and Roll assert that the initial variables' list must be the greatest possible, and then a refinement of the more relevant ones should be made in three stages [30]: (i) judgmental screening; (ii) non-DEA quantitative analysis; and (iii) DEA based analysis. In this study, the selected variables were TLP and ACP as inputs and TLF and TCC as outputs, following the description below:

- TLP, Total Lighting Power (W)—indicates the classroom's total lighting installed power. Also affects directly the lighting energy efficiency.
- ACP, Air Conditioning Power (W)—indicates the classroom's total mean demanded power by the air conditioning devices. Affects directly the device's CEE, as shown by Equation (5), consequently the classification.
- TLF, Total Luminous Flux (lm)—indicates the total luminous flux emitted by the classroom's light sources. Affects directly the lighting energy efficiency.
- TCC, Total Cooling Capacity (BTU/h)—indicates the classroom's devices total cooling capacity. As with the variable ACP, affects directly the device's CEE.

After the variables were selected, the DEA model was chosen. As stated before, Building 5 classrooms' lighting systems were inadequate, and the output TLF needed to be increased, thus output orientation was deemed more appropriate to this case. On the other hand, all the air conditioners were adequate but inefficient, implying the use of an input-oriented model to maintain the outputs and reduce ACP. Therefore, the application of both CCR models was necessary in order to analyze DEA's performance in each particular situation.

To solve the model, DEA computation was carried out using Microsoft Excel spreadsheet. The results obtained from the DEA application are presented and discussed on Section 5.

5. Results and Discussion

The scores obtained by the application of the CCR models (5) and (6) are presented on Table 6 and Figure 2.

Table 6. Efficiency scores (θ).

Room	Score	Room	Score
550-1	0.7807	A1	1.0000
550-2	0.8477	A2	1.0000
550-3	0.8477	A3	1.0000
551	0.7342	A4	1.0000
552-1	0.8072	A5	0.9810
552-2	0.8007	A6	0.9802
553	0.7182	A7	1.0000
554	0.8087	A8	1.0000
555	0.7443	A9	1.0000
556	0.7588		

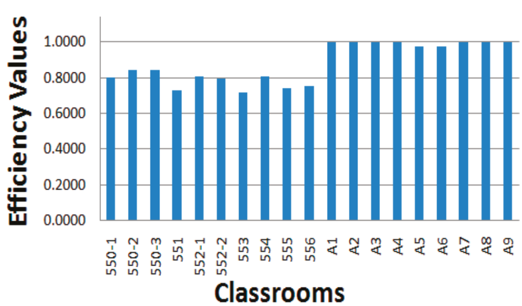

Figure 2. Comparative graphic with the obtained scores.

The results demonstrated in Table 6 and Figure 2 revealed that all "A" classrooms were considered near or full efficient (47.36% of the sample) and Building 5 classrooms received lower scores, which was expected and suggests coherence with the RTQ-C classification. Interestingly, Building 5 classrooms obtained relatively close scores, ranging from 0.7182 to 0.8477; from Tables 4 and 5, it can be noted that all rooms have the same luminous efficiency (60.60 lm/W) and relatively close CEEs, varying from 2.45 to 2.88 W/W. These similar systems' efficiencies explain the narrow distribution of efficiency values.

Classrooms 554 (0.8087), 550-2 (0.8477) and 550-3 (0.8477) were recognized as the most efficient from Building 5. Checking Table 5, it can be noticed that these rooms have the highest CEEs in the Building 5 DMU set, while maintaining the same luminous efficiency as the others. Also, classroom 553 obtained the worst score (0.7182) and has the same luminous efficiency, but worst CEE in the set. Therefore, it can be concluded that the DMU's score is directly related to the luminous and air conditioners efficiency, especially the latter. Considering that air conditioning consumes the greatest part of the energy in public buildings (Figure 1), it is reasonable to assume that its efficiency should be more relevant to the classroom's final score. The targets generated by the DEA models are presented on Tables 7 and 8, as follows.

Tables 7 and 8 reveal that the input model also generated output augmentations and the output model also generated input reduction: these values are known as output slacks and input slacks, respectively. Slacks generation are not abnormal, in fact, some DEA models apply slacks-based measures.

The slacks can be explained as additional reductions/augmentations that can be applied to the DMU without affecting its performance. Taking classroom 550-1 as an example, reducing its TLP to 333.33 and its ACP to 3026.66 would maximize its score, according to Table 7. However, with these same inputs, it is possible to increase its TLF to 38,000 without affecting negatively another input or output. The same conclusion can be applied to the Output model: increasing TLF to 48,663.66 and TRC 46,102.20 would take the DMU to the efficiency frontier, but with these same outputs it is possible to reduce the TLP input to 426.87 without any prejudice. It is important to mention that slacks values are not directly related with the score generated to the DMU. According to Table 7, no slacks were generated for TCC, which is coherent, as the classrooms' already have the adequate refrigerating capacity.

Both models can generate input and output slacks for the same DMU. Classroom 550-1, for example, obtained a 0.7808 (or 78.08%) score, meaning it will have to reduce its inputs by 21.91% to reach maximum relative efficiency. From Table 7, ACP reduction is −21.91%, but TLP reduction is −32.66%, indicating an additional reduction due to the generated input slacks, which won't affect the DMU's performance. Therefore, due to slacks, some of the targets goals won't reflect directly on the score given to each DMU. Classroom 553, for example, had the highest inefficiency, implying it should need greater inputs' reduction or greater outputs' augmentation than other DMUs. According to Table 7, classrooms 3's APC reduction is −28.17% (greatest APC reduction) and it also should have the greatest TLP reduction, which is not observed, as classroom 551's TLP reduction is even greater due to slacks generated to this variable (−9.9% versus room 3's −48.88%).

After applying the measures suggested by DEA, the performance of the input/output models is summarized on Table 9.

Table 9 points out important operating characteristics of input and output oriented models. Regarding lighting, the input-oriented model was more effective for improving the classification: from Table 9, it can be noted that every classroom except 552-1 was improved to "A" level. Input-oriented models can impose a greater reduction in the inputs, as this is the model's objective. On the other hand, the model did not improve the classrooms' lighting systems, and they still have an EM below the value allowed by the standards. The output model, in contrast, corrected the EM of most classrooms (except 550-2 and 550-3), but fewer classrooms were improved to "A": some were improved to "B" and room-1 went just from "E" to "D". Since the output orientation's main objective is to increase outputs and hold the input level, it is justifiable the inferior performance of the model. In addition, classroom 552-1 had a 990 TLP, more than twice of the power it should have to reach level "A"; this excessively high power may explain why both models could not improve its lighting to "A" level. Regarding air conditioning, both models improved efficiency to "A" level in all classrooms, but as these rooms already have the adequate cooling capacity, applying the output-oriented model's targets will lead to an overrated TCC.

Table 7. Decision Making Units' (DMUs') targets/goals—Input model.

Room	TLP Current (W)	Total Lighting Power (TLP) Goal (W)	%	Air Conditioning Power (ACP) Curr. (W)	Air Conditioning Power (ACP) Goal (W)	(%)	Total Luminous Flux (TLF) Current (lm)	Total Luminous Flux (TLF) Goal (lm)	(%)	Total Cooling Capacity (TCC) Goal (BTU/h)
550-1	495	333.33	−32.66	3876	3026.67	−21.91	30,000	38,000	26.66	36,000
550-2	297	151.02	−49.15	1220	1034.28	−15.22	18,000	18,000	0	12,000
550-3	297	151.02	−49.15	1220	1034.28	−15.22	18,000	18,000	0	12,000
551	990	502.04	−49.29	4588	3368.57	−26.58	60,000	60,000	0	39,000
552-1	1188	620.41	−47.78	6300	5085.71	−19.27	72,000	72,000	0	60,000
552-2	990	555.55	−43.88	6300	5044.44	−19.93	60,000	63,333	5.55	60,000
553	990	506.12	−48.88	5020	3605.71	−28.17	60,000	60,000	0	42,000
554	990	514.28	−48.05	5045	4080	−19.13	60,000	60,000	0	48,000
555	990	518.36	−47.64	5800	4317.14	−25.57	60,000	60,000	0	51,000
556	1188	901.46	−24.12	12,568	9536.7	−24.12	72,000	100,659	38.8	110,000

Table 8. DMUs' targets/goals—Output model.

Room	TLP Current (W)	TLP Goal (W)	(%)	ACP Goal (W)	TLF Curr. (lm)	TLF Goal (lm)	(%)	TCC Curr. (BTU/h)	TCC Goal (BTU/h)	(%)
550-1	495	426.87	−13.76	3876	30,000	48,663.66	62.21	36,000	46,102.20	28.06
550-2	297	178.13	−40.02	1220	18,000	21,232.04	17.95	12,000	14,154.69	17.95
550-3	297	178.13	−40.02	1220	18,000	21,232.04	17.95	12,000	14,154.69	17.95
551	990	683.78	−30.93	4588	60,000	81,720.10	36.2	39,000	53,118.06	36.2
552-1	1188	768.53	−35.3	6300	72,000	89,191.01	23.87	60,000	74,325.84	23.87
552-2	990	693.83	−29.91	6300	60,000	79,096.91	31.82	60,000	74,933.92	24.88
553	990	704.66	−28.82	5020	60,000	83,534.08	39.22	42,000	58,473.85	39.22
554	990	635.92	−35.76	5045	60,000	74,191.17	23.65	48,000	59,352.94	23.65
555	990	696.41	−34.34	5800	60,000	80,608.86	34.34	51,000	68,517.53	34.34
556	1188	1188	0	12,568	72,000	132,655.30	84.25	110,000	144,964.17	31.78

Table 9. Input and Output model's performances comparison.

Room	Class A Limit TLP (W)	Lighting Classification					Air Conditioning Classification	
		Current	Input Model		Output Model		Current	Input/Output Models
			New	E_M (lx)	New	E_M (lx)		
550-1	452.18	B	A	359.67	A	575.76	B	A
550-2	452.18	A	A	170.37	A	251.2	C	A
550-3	452.18	A	A	170.37	A	251.2	C	A
551	663.61	E	A	386.97	B	658.82	C	A
552-1	572.99	E	B	537.81	D	832.78	B	A
552-2	572.99	E	A	473.07	C	738.53	B	A
553	674.53	E	A	380.71	B	662.54	D	A
554	744.08	D	A	345.12	A	533.44	B	A
555	714.23	D	A	359.55	A	603.81	C	A
556	1211.24	A	A	355.68	A	585.93	C	A

As expected, applying an Input model to modify the lighting variables provides an adequate solution, because it will not increase the luminous flux accordingly. On the other hand, the Output model also generated infeasible solutions for air conditioning, because the classrooms already have the adequate capacity and the goals will increase the TCC even further. Also, the targets provided by the Output model will not increase energy savings considerably, as air conditioning consumes the most energy and no ACP reduction was generated. Thus, it can be concluded that the Input Model goals should be applied only to air conditioning variables (ACP and TCC) and Output Model goals should be applied only to lighting variables (TLP and TLF), in the current situation of Building 5 classrooms.

Using the information from Table 7, APC reduction suggests the exchange of the current inefficient devices for more efficient ones, maintaining the TRC and increasing their CEEs to at least 3.33 to achieve a performance similarly to the "A" classrooms' benchmarks. Moreover, these classrooms need a lighting redesign, as the standards and Table 9 suggests; by exchanging the current lamps for efficient ones with a least 100 lm/W, the TLP can be reduced a bit while increasing the TLF at the same time. In addition, classrooms 550-2 and 550-3 should have a complete lighting system redesign, in order to increase their illuminances to at least 500 lx. This can be achieved by increasing their TLP and TLF values to the same ones suggested for classroom 500-1 because they have the same areas. The discussion above can be adequately adapted for residential applications by simply using the RTQ-R indices rather than the RTQ-C indices. Thus, the methodology can cover cases of public, commercial and residential buildings, making up the whole of a small city profile. Ultimately, it can even extend to larger applications. The findings presented here can be an important step forward for the concept of the smart city.

6. Conclusions

This paper presented a new approach to evaluating public buildings' energy efficiency, applying DEA models to generate optimum targets for the classrooms' lighting and air conditioning systems' undesirable inputs/outputs. The use of DEA evaluation gave a quick overview of the analyzed DMUs, allowing the identification of which need more attention, and which are closer to the ideal classification. It can be concluded that this proposed DEA method has great potential in energy efficiency evaluation and can be used as a decision-making aided support tool to help administrators to improve energy efficiency while attending the RTW-C requirements.

Calculated scores showed inefficiency in all Building 5 classrooms, which confirms the low efficiency classification obtained by applying RTQ-C standards. The presented results confirmed that most of the set of targets and goals generated by the DEA model were effective, as all of the inefficient Building 5 classrooms had air conditioning efficiency improved to "A" level and most of them had the lighting efficiency improved to "A" or at least "C" level. The analysis of the solutions generated by the

DEA models show that both input and output-oriented models are applicable, each one to a particular situation whether the lighting/air conditioning system is adequate or not.

Considering the best performance of the DEA model—the input-oriented model, as shown in Table 7—it is possible to achieve a reduction of installed power in the lighting system of the rooms studied from 8415 kW to 4735.59 kW, which means a decrease of 43.5%. Regarding the air conditioning system, the reduction achieved is from 51,937 kW to 40,133.5 kW, or 22.7%. It is worth mentioning that there is a guarantee that all minimum limits dictated by the current lighting and air conditioning standards for this type of building are being respected. Even with this effort, the installed capacity reduction for the entire installation is 25.6%.

As an extension of this study, due to the characteristics of the campus where this proposal was executed, it is possible to further this discussion and apply its successful results in projects that involve concepts of small smart cities, for example, contributing to optimize the sustainability indexes wanted in the context of these projects.

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References

1. Empresa de Pesquisa Energética (EPE). *Projeção da Demanda de Energia Elétrica para os Próximos 10 Anos (2015–2024)*; Ministério de Minas e Energia: Brasilia, Brazil, 2015. (In Portuguese)
2. Sorrell, S. Reducing energy demand: A review of issues, challenges and approaches. *Renew. Sustain. Energy Rev.* **2015**, *47*, 74–82. [CrossRef]
3. Ekici, B.B.; Aksoy, U.T. Prediction of building energy needs in early stage of design by using ANFIS. *Expert Syst. Appl.* **2011**, *38*, 5352–5358. [CrossRef]
4. PROCEL. Apresentação do Programa. 2016. Available online: http://www.eletrobras.com/pci/main.asp?View=\protect\T1\textbraceleft89E211C6-61C2-499A-A791-DACD33A348F3\protect\T1\textbraceright (accessed on 26 March 2016).
5. Geller, H.; Schaeffer, R.; Szklo, A.; Tolmasquim, M. Policies for advancing energy efficiency and renewable energy use in Brazil. *Energy Policy* **2004**, *32*, 1437–1450. [CrossRef]
6. PROCEL. Edificações. 2016. Available online: http://www.procelinfo.com.br/main.asp?TeamID=\protect\T1\textbraceleft82BBD82C-FB89-48CA-98A9-620D5F9DBD04\protect\T1\textbraceright (accessed on 27 March 2016).
7. Lamberts, R.; Dutra, L.; Pereira, F.O.R. *Eficiência Energética na Arquitetura*; ELETROBRÁS/PROCEL: Rio de Janeiro, Brazil, 2014. (In Portuguese)
8. ELETROBRÁS—Centrais Elétricas Brasileiras. *Avaliação do Mercado de Eficiência Energética do Brasil—Ano Base 2005*; ELETROBRÁS/PROCEL: Rio de Janeiro, Brazil, 2009.
9. Zhou, G.; Chung, B.; Zhang, Y. Measuring energy efficiency performance of China's transport sector: A data envelopment analysis approach. *Expert Syst. Appl.* **2014**, *41*, 709–722. [CrossRef]
10. Heidari, M.D.; Omid, M.; Mohammadi, A. Measuring productive efficiency of horticultural greenhouses in Iran: A data envelopment analysis approach. *Expert Syst. Appl.* **2012**, *39*, 1040–1045. [CrossRef]
11. Zhou, P.; Ang, B.W.; Poh, K.L. A survey of Data Envelopment Analysis in energy and environmental studies. *Eur. J. Oper. Res.* **2008**, *189*, 1–18. [CrossRef]
12. Lins, M.E.; Oliveira, L.B.; Silva, A.C.M.; Rosa, L.P.; Pereira, A.O.P., Jr. Performance assessment of Alternative Energy Resources in Brazilian power sector using Data Envelopment Analysis. *Renew. Sustain. Energy Rev.* **2012**, *16*, 898–903. [CrossRef]

13. Mohammadi, A.; Rafiee, S.; Mohtasebi, S.S.; Avval, S.H.M.; Rafiee, H. Energy efficiency improvement and input cost saving in Kiwi production using Data Envelopment Analysis approach. *Renew. Energy* **2011**, *36*, 2573–2579. [CrossRef]
14. Oliveira, A.E.; Pinheiro, P.R. Analysis of the model DEA-CCR in the Selection of Investments of the Pension Funds Entities. In Proceedings of the Information Science and Industrial Applications (ISI), Cebu, Philippines, 29–31 may 2012; pp. 151–156.
15. BRASIL/INMETRO—Instituto Nacional de Metrologia, Normalização e Qualidade Industrial. *Regulamento Técnico da Qualidade para Eficiência Energética deEdifícios Comerciais, de Serviços e Públicos—RTQ-C*; PROCEL: Brasília, Brazil, 2014. (In Portuguese)
16. Schubert, E.F.; Kim, J.K.; Luo, H.; Xi, J.Q. Solid state lighting—A benevolent technology. *Rep. Prog. Phys.* **2006**, *69*, 3069–3099. [CrossRef]
17. Lobão, J.A.; Devezas, T.; Catalão, J.P.S. Energy efficiency of lighting installation: Software application and experimental validation. *Energy Rep.* **2015**, *1*, 110–115. [CrossRef]
18. INMETRO—Instituto Nacional de Metrologia, Normalização e Qualidade Industrial. INMETRO. 2016. Available online: http://www.inmetro.gov.br/consumidor/pbe/condicionadores.asp/ (accessed on 23 March 2016).
19. Moraes, C.S. Análise de Medidas Para Eficientização e Uso Racional da Energia Elétrica em Condicionadores de Ar. Master's Thesis, Universidade Federal do Mato Grosso, Cuiabá, Brazil, 2013. (In Portuguese)
20. CB3E—Centro Brasileiro de Eficiência Energética em Edificações. Nota Técnica Referente aos Níveis Mínimos de Eficiência Energética de Condicionadores de ar do Brasil. 2013. Available online: http://cb3e.ufsc.br/sites/default/files/projetos/etiquetagem/notatecnica-niveis-minimos-ar-condicionado.pdf (accessed on 15 April 2016).
21. Cooper, W.W.; Seiford, L.M.; Tone, T. *Data Envelopment Analysis: A Comprehensive Test with Models, Applications, References and DEA-Solver Software*; Kluwer Academic Publishers: Boston, MA, USA, 2000.
22. Farrell, M.J. The measurement of productive efficiency. *J. R. Stat. Soc. Ser. A (Gen.)* **1957**, *120*, 253–281. [CrossRef]
23. La Rovere, E.L.; Soares, J.B.; Oliveira, L.B.; Lauria, T. Sustainable expansion of electricity sector: Sustainability indicators as instruments to support decision making. *Renew. Sustain. Energy Rev.* **2010**, *14*, 422–429. [CrossRef]
24. Jubran, A.J. Modelo de Análise de Eficiência na Administração Pública: Estudo Aplicado às Prefeituras Brasileiras Usando a Análise Envoltória de Dados. Ph.D. Thesis, Escola Politécnica/USP, São Paulo, Brazil, 2006.
25. Song, M.; An, Q.; Zhiang, W.; Wang, Z.; Wu, J. Environmental efficiency evaluation based on data envelopment analysis: A review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 4465–4469. [CrossRef]
26. Mousavi-Avval, S.H.; Rafiee, S.; Jafari, A.; Mohammadi, A. Improving energy use efficiency of canola production using data envelopment analysis (DEA) approach. *Energy* **2011**, *36*, 2765–2772. [CrossRef]
27. Iribarren, D.; Vázquez-Rowe, I.; Rugani, B.; Benetto, E. On the feasibility of using emergy analysis as a source of benchmarking criteria through data envelopment analysis: A case study for wind energy. *Energy* **2014**, *67*, 527–537. [CrossRef]
28. Mardani, A.; Zavadskas, E.K.; Streimikiene, D.; Jusoh, A.; Khoshnoudi, M. A comprehensive review of data envelopment analysis (DEA) approach in energy efficiency. *Renew. Sustain. Energy Rev.* **2017**, *70*, 1298–1322. [CrossRef]
29. Bandeira, D.M.; Becker, J.L.; Borenstein, D. *Eficiência Relativa dos Departamentos da UFRGS Utilizando DEA*; Revista de Ciência e Tecnologia Política e Gestão para a Periferia: Recife, Brazil, 2001; Volume 5, pp. 116–143.
30. Golany, B.; Roll, Y. An application procedure for DEA. *Omega Int. J. Manag. Sci.* **1989**, *17*, 237–250. [CrossRef]

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Towards the Handling Demand Response Optimization Model for Home Appliances

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Abstract: The Demand Response (DR) is used by public electric utilities to encourage consumers to change their consumption profiles to improve the reliability and efficiency of the electric power system (EPS) and at the same time to minimize the electricity costs for the final consumers. Normally, DR optimization models only aim to reduce the energy consumption and reduce the final cost. However, this disregards the needs of the consumer. Therefore, proposals which appear excellent in theory are usually impracticable and non-commercial. This paper proposes a real-time Demand Response (DR) optimization model to minimize the electricity costs associated with consumption without compromising the satisfaction or comfort of residential consumers. The proposed DR here considered the different home appliance categories and level of consumer satisfaction for the new load scheduling of the appliances and is much more comprehensive than the other models analyzed. Moreover, it can be applied in any country, under any energy scenario. This model was developed as a nonlinear programming problem subject to a set of constraints. An energy consumption analysis of 10 families for 2015 from five geographic and climatic regions of Brazil was carried out. A computational validation of the model was performed using a genetic algorithm (GA) to determine the programming of residential devices for the time horizon. The computational simulations showed a decrease in the cost of the electricity. Moreover, the results showed that there was no impairment to consumer satisfaction and comfort due to the scheduling of appliances.

Keywords: demand response; genetic algorithm; load scheduling

1. Introduction

Demand response (DR) is a program that balances the supply and demand of electric power to maximize the reliability and efficiency of the electric power system (EPS). DR programs encourage residential, industrial and commercial consumers to change their way of consuming electricity in line with changes in electricity prices over the time horizon and at times of EPS overload [1–3].

Chanana and Kumar [4] related that utilities are normally only concerned with industrial and commercial consumers when it comes to DR programs. Setlhaolo et al. [5] explained that this is because DR is successful with such consumers, as it reduces the cost and consumption of electricity significantly. However, this does not happen so easily with residential consumers, who usually have specific needs for different spaces, which requires making several consumption profiles for one resident.

One of the obstacles to set up a DR in a residential environment is the need for manual intervention by the consumer for programming residential appliances along the time horizon [5]. However, due to lack of time, knowledge and commitment, the consumers are not usually willing to participate actively in such programs linked to the EPS, and therefore to set up a DR program in a residential scenario is more complex.

However, Chanana and Kumar [4] emphasized that, due to the technological advances that have taken place in the last decades that have improved the Advanced Metering Infrastructures (AMIs), the Home Area Networks (HANs) and the Grid Automation and Distributed Intelligence (GADI), it has become possible to include residential consumers in DR programs.

Considering these advances, other research groups have taken up the challenge to make DR programs a viable alternative for residential customers. Pop et al. [6] proposed a blockchain based architecture for distributed management, control, and validation of DR programs in low/medium voltage smart grids, thus assuring high reliability and decentralized operations by implementing trackable and tamper-proof energy flexibility transactions as well as near real time DR validation. To validate the proposal, a simulation based prototype was implemented using the Ethereum platform. The results showed that their blockchain based distributed demand side management can be used to match energy demand and production at a smart grid level, and the demand response signal is followed with high accuracy, while the amount of energy flexibility needed for convergence is reduced. However, the proposal does not consider multi-stakeholder markets (DSOs, TSOs, retailers as competitors or cooperators for the same energy flexibility).

Brusco et al. [7] proposed a new energy box (EB) to solve the problem of communication between the consumer and the aggregator in the face of the interaction challenges of interaction between an EB and an energy management system (HEMS). In this sense, the article presents two prototype, the low-EB that uses Arduino MEGA 2560, and the second (high-EB) that uses Raspberry Pi3. The results of the simulations showed that the two prototypes are relevantly cost-effective and effectively are able to serve attend demand response programs in cloud-based architectures. However, the authors restricts themselves to only evaluating one residential unit and nine types of apparatuses: internal and external lightings, a personal computer, a TV set, a refrigerator, an air-conditioning system, a washing machine, a tumble dryer, a dishwasher and an electric vehicle.

Wang and Paranjape [8] presented a multiagent system to manage residential DR to reduce the peak-to-average ratio (PAR) and the cost of electricity associated with consumption. The optimal control of electricity consumption is developed into a convex programming problem to minimize the cost of electricity under real-time pricing. However, the proposal only considered the level of satisfaction and comfort of the consumers for the recharging schedules of electric vehicles.

Ashabani and Gooi [9] proposed a multi-objective autonomous intelligent load control using a power electronic interface and a hybrid DC/AC grid concept. The objective is to introduce voltage hopper technology to provide autonomous and automated grid ancillary services and load control without the need of a supervisory/centralized controller. To validate the effectiveness of the proposed control and management strategy the building system was implemented and simulated in an interfaced dSPACE/OPAL-RT real-time simulator. The proposal has many advantages such as autonomous and automatic load control and grid frequency regulation; centralized regulation signal-based demand control; grid support; continuous/adaptive power control of critical and non-critical AC loads, DC loads, and HVAC systems; battery energy storage systems (BESSs); and Plug-in Electric Vehicles (PEVs). However, the results of the computational simulations showed that the proposal did not consider the simultaneous use of different categories of residential appliances nor the level of satisfaction and comfort of the consumers faced with this new optimized scheduling.

Guerrero-Martinez et al. [10] presented a smart multi-converter system for smart grid applications with a Hybrid Energy Storage System (HESS). The overall aim is to globally optimize the energy billing of the whole community, minimize losses and obtain the highest efficiency possible from the generation and storage units available in the community. The proposed multi-converter topology was simulated using the library components of the Simscape Power SystemsTM MATLAB/Simulink. The simulation and experimental tests demonstrated that this multi-converter presents several improvements compared with traditional converters: simultaneously it is able to track an active power set-point with high power quality; operate PV modules with a MPPT algorithm; and manage energy storage based on a hybrid configuration, composed of batteries and supercapacitors; this latter ability enables it to improve the efficiency and lifetime of the storage elements.

Croce et al. [11] proposed Overgrid, a fully distributed peer-to-peer (P2P) architecture designed to automatically control and implement distributed demand response (DR) schemes in a community of smart buildings with energy generation and storage capabilities. Thus, to implement the Overgrid service architecture, the authors developed, in Java, the software modules responsible for the distributed signaling mechanisms between the nodes by exploiting the open source library for gossip protocols called JavaGossip, which works on UDP transport packets. The results showed that the system is quite robust in terms of topological changes and message losses, while the adaption times are compatible with the typical times expected for DR mechanisms. In addition, adaptation to larger or smaller scale systems is possible. However, the proposal does not contemplate some aspects, such as aggregate buildings with complementary behaviors, capable of operating power consumption modulation all year round; prioritization mechanisms for power reduction; and energy storage to improve the integration of renewable source production.

Javaid et al. [12] proposed a hybrid scheme named GAPSO for residential load scheduling, to optimize the desired objective function of minimizing the electricity cost and user discomfort while taking into account the peak energy consumption. To alleviate the complexity of the problem, a multi-dimensional knapsack is used to ensure that the electricity load will not escalate during peak hours. Thus, the GAPSO scheme was implemented and its performance compared against a traditional dynamic programming (DP) technique and two heuristic optimization techniques: genetic algorithm (GA) and binary particle swarm optimization (BPSO) for residential load management. The authors formulated the binary optimization problem through a multiple knapsack problem (MKP). The results of the simulation showed that the proposed hybrid scheme, GAPSO, performed better in terms of cost and occupant discomfort minimization along with reduction of peak power consumption compared to its counterpart schemes GA and BPSO. However, the authors did not take into account, in the performance analysis for the management of residential loads, the category that includes heating, ventilation, and air conditioning (HVAC) appliances. Thus, the devices with high load consumption were not analyzed.

Roh and Lee [13] presented an algorithm for residential load scheduling to control the operational time and electric energy consumption of each device. The proposal was developed as a mixed integer nonlinear programming (MINLP) problem. The authors used the Benders decomposition approach to solve the problem with low computational complexity. However, the proposal restricts only one single residence.

Ma et al. [14] presented a minimization of electricity consumption cost and user discomfort are considered as objective functions. Time flexible and power flexible appliances are considered for the efficient use of energy. The scheduling problem is formulated as convex optimization and electricity price is defined by the utility on a day-ahead basis. The results of the simulations showed that the proposed technique achieved a desired trade-off between both parameters of the objective functions. However, by increasing the size of the problem, the computational complexity also increases.

Jovanovic et al. [15] proposed a new demand response scheduling framework for an array of households, which are grouped into different categories based on socio-economic factors, such as the number of occupants, family decomposition and employment status. The proposal takes the preferences of participating households into account and aims to minimize the overall production cost and, in parallel, to lower the individual electricity bills. The proposal was mathematically designed as a mixed integer programming problem. The model was implemented using IBM ILOG CPLEX and executed using the default solver settings. The computational simulations showed that coupling the preference levels of the consumers with the associated job descriptions can be beneficial, for both the customer and the utility company. The results also showed that the reduction in the operations of the utility company can also be reflected in customer bills by means of incentives. A significant level of savings in production costs can be achieved while maintaining a high degree of satisfaction for the participating households. In addition, further savings can be achieved by allowing a higher level of maximal dissatisfaction for households. However, the work presented does not consider the different categories (interruptible and deferrable, uninterruptible and deferrable, uninterruptible and non-deferrable) of home appliances.

Vivekananthan et al. [16] proposed an algorithm for a Home Energy Management Scheduler (HEMS) to manage the consumption of residential electrical energy in order to reduce the cost of electricity. The proposal applied stochastic dynamic programming to manage the residential appliances. However, the proposal only evaluated the dynamic programming of seven residential appliances and did not consider the impact of modifying the programming of the appliances on the satisfaction and comfort of the consumers.

Samadi et al. [17] proposed two interactive algorithms based on the stochastic approximation technique to minimize peak-to-average ratio (PAR) in aggregate load demand. However, the results of the computational simulations show that the algorithms do not consider the simultaneous use of different categories of residential appliances and the level of satisfaction and comfort of the consumers faced with the optimized scheduling of such residential appliances.

Zhou et al. [18] proposed an approach to manage the consumption of residential electricity in real time. The proposal was planned to deal with complex operational environments and consequently reduce the cost of electricity associated with consumption. However, the proposal only evaluated electric water heaters, air conditioners, clothes dryers, electric vehicles, photovoltaic cells, critical loads, and battery systems without considering the other different categories of residential appliances.

Nair and Rajasekhar [19] proposed a DR algorithm based on the principles of multi-integer linear programming to manage residential energy consumption. The proposal aimed to modify the residential electricity consumption profiles considering the daily price of electricity and the preferences of consumers regarding the use of residential appliances. However, the proposal restricted itself to evaluating only five consumers with a single standard of consumption and seven residential appliances.

Zhao et al. [20] proposed an approach to manage residential loads in order to reduce the cost of electricity and the peak-to-average ratio (PAR) by scheduling the operations of apparatuses. The proposal was developed as a nonlinear programming problem. However, it only evaluated nine types of residential appliances. Moreover it only considered sixteen operations per planning horizon considered as a maximum for all the parameters (the time to start and end the operations of the devices, and the time interval of the operations) which must be programmed by consumers.

Chen et al. [21] presented an algorithm to schedule the operation of home appliances to minimize the cost of electricity based on real-time pricing. The proposal applied the stochastic scheduling technique based on the deterministic linear programming to deal with the uncertainties regarding the consumption of electric energy and the time of operation of the residential appliances. However, the proposal does not take into account the different categories of residential appliances and individualized loads.

Wang et al. [22] presented an algorithm based on mixed integer nonlinear programming to schedule the residential loads in relation to the use of the devices. The proposed system was able to schedule residential loads and reduce the electricity costs and is based on the characteristics of the thermal dynamics of thermostatically controlled loads by combining the operations of the algorithm and the particularities of the appliance commitment problem. However, the proposal restricted itself to evaluating only the dynamic programming of thermal devices, such as electric water heaters, without considering the other categories.

Logenthiran et al. [23] proposed an approach to simultaneously manage different categories of residential devices. The proposal was developed mathematically as a nonlinear programming problem. The proposal aimed to program the operations of the devices using the load shifting so that the final load consumption curve was as close as possible to the one defined by the utility and which would satisfy the desired management strategy. However, the proposal does not include the different categories of residential appliances.

Chen et al. [24] presented a real-time DR model to automatically schedule the operation of residential appliances of the final consumers. The model was developed mathematically as an integer linear programming problem. However, the results of the computational simulations show that the proposal is limited to evaluating the programming of only six residential apparatuses without considering the different categories of these apparatuses.

Pipattanasomporn et al. [2] presented an algorithm to manage the residential loads, to reduce the total consumption of electric energy considering the preferences of the consumers. In addition, the authors presented a simulation tool that was developed to simulate DR events to exemplify the applicability of the proposed algorithm. However, the proposal restricts itself to evaluating only the air conditioners, water heaters, clothes dryers and electric vehicles without considering the different categories of residential appliances.

Conejo et al. [25] proposed a real-time DR model developed as a linear programming problem, using the robust optimization technique to model changes in the price of electricity. The aim of the proposal is to adjust load levels in response to hourly electricity price changes, leading the residential consumer to use as little electricity as possible but not considering the inconvenience caused to him. The proposal also does not consider the different categories of residential appliances and the individualized representation of loads, which implies an optimal solution to the problem that is not feasible in a real scenario.

Along these lines of the above mentioned works this study presents a mathematically developed DR optimization model as a nonlinear programming problem that aims to determine the optimum programming of residential appliances. The purpose of the proposal is to reduce the cost associated with the consumption of electric energy taking into account the satisfaction and comfort of end consumers and the various restrictions associated with energy consumption such as minimum and maximum limits of the load for each time interval; ramp limits; minimum consumption related to the time horizon; and operational restrictions of the residential appliance categories. Genetic Algorithms (GA) [26] were used to specify the operation of each home appliance at each time interval.

The contributions related to the use of the model presented in this work include: (a) the definition of an optimized scheduling for the operation of the different categories of residential apparatuses taking into account time horizons with variable sizes; (b) the representation of various aspects such as geographic location, climate and temperature, consumer preferences and the hourly price of electricity and its implications on residential energy consumption; and (c) assessing the level of satisfaction and comfort of the final consumers to enable them to decide whether to join the DR program.

This work is arranged as follows. Section 2 presents the problem definition and the DR optimization model. Section 3 describes the optimized programming of residential appliances by the genetic algorithm. Section 4 presents a case study that shows the test scenario and the numerical results obtained in the computational simulation that applies the proposed model to minimize the cost of electricity associated with consumption. Section 5 explains the main contributions of this work and future research projects.

2. Problem Definition and Optimization Model

The operation of different categories of residential appliances needs to be managed so that the total cost of electricity can be minimized by considering the variations of electric energy prices as a function of the time interval. Therefore, there is a need for a residential load scheduling method that requires little attention from the consumers in their configuration and maintenance, allowing the comparison of the costs and benefits of different operating schedules of household appliances. Consequently, the planning of loads must be done automatically, for example, using optimization techniques.

The model proposed in this work aims to optimize the operation schedule of each residential appliance i, where $i \in N$ in a time interval t, where $t \in T$, taking into account the power (in kW) and the electric energy consumption (in kWh) of each residential appliance per time interval t. In addition, the proposal presented considers the scheduling of loads individually for each residential appliance and the price of electricity in the time interval t. Thus, the total cost of electricity in the time horizon T is given by:

$$Minimize \sum_{i=1}^{N} E_i \sum_{t=1}^{T} (Pr_t * DSA_{t,i})^2 \tag{1}$$

where N represents the number of residential appliances; $E_i(i = 1, \ldots, N)$ corresponds to the vector with an energy consumption of a home appliance i when it is in operation; T indicates the time horizon; Pr_t corresponds to the price of electricity in the interval of time t; and $DSA_{t,i}$ (Diary Setup of Appliances) corresponds to the load scheduling matrix with the following configuration:

$$DSA_{t,i} = \begin{cases} 1, & \text{if home apliances } i \text{ is on at time } t, \\ 0, & \text{otherwise.} \end{cases}$$

Equation (1) presents the objective function used in this work, which aims to program the operation of each residential appliance in the time horizon, and thus minimize the cost of electricity associated with electric energy consumption. Several constraints are applied to Equation (1):

Constraint 1 (Equation (2)) establishes that the load must be within the limits set for each time interval, denoted by d_t^{min} and d_t^{max}, respectively.

$$d_t^{min} \leq \sum_{i=1}^{N} DSA_{t,i} * P_i \leq d_t^{max}, \forall_{t=1,\ldots,T} \tag{2}$$

where $P_i(i = 1, \ldots, N)$ is the vector with the power (in kW) of each home appliance i.

Constraints 2 (Equation (3)) and 3 (Equation (4)) determine that the load variation of two consecutive time intervals must be between the minimum (r^D) and maximum (r^U) limits.

$$\sum_{i=1}^{N} (DSA_{t,i} - DSA_{t+1,i}) * P_i \leq r^D, \forall_{t=1,\ldots,T-1} \tag{3}$$

$$\sum_{i=1}^{N} (DSA_{t+1,i} - DSA_{t,i}) * P_i \leq r^U, \forall_{t=1,\ldots,T-1} \tag{4}$$

where r^D/r^U are the Up/Down demand ramping limits.

Constraint 4 (Equation (5)) states that the minimum consumption of electricity related to the time horizon, stipulated by the residential consumer, is fulfilled.

$$\sum_{i=1}^{N} \sum_{t=1}^{T} DSA_{t,i} * E_i \geq mdc \tag{5}$$

where mdc is the minimum energy consumption demanded by the consumer in the time horizon T.

Constraints 1–4 relate the common characteristics of energy consumption. In this work, the home appliances are categorized into three types, based on their operational characteristics [24]: interruptible and deferrable (A_I), uninterruptible and deferrable (A_{II}) and uninterruptible and non-deferrable (A_{III}). "Uninterruptible" and "Interruptible" are related to a task that can, or not, be stopped until finished. "Non-deferrable" and "Deferrable" determine if the task must start at the first time slot of the operational window, or not. Based on these definitions, it is possible to specify the constraints that deal with the different categories of residential appliances A_I, A_{II} and A_{III}.

Constraint 5 (Equation (6)) specifies that the start time of categories A_I home appliances may vary over the time horizon T as long as the required time Req_i is fulfilled.

$$\sum_{t=1}^{T} DSA_{t,i} \geq Req_i, \forall_i \in A_I \tag{6}$$

Constraint 6 (Equation (7)) establishes that the start time of A_{II} type residential appliance may be delayed in the time horizon T but, once its operation has started, it cannot be interrupted for the time required Req_i by the consumer.

$$\sum_{q=1}^{T} \prod_{t=q}^{Req_i+(q-1)} DSA_{t,i} \geq 1, \forall_i \in A_{II} \tag{7}$$

Finally, Constraint 7 (Equation (8)) assures that the operation between the start (St_i) and end (Ed_i) times, as determined by the consumers for the home appliances of type A_{III}, is uninterrupted for the required time Req_i over the horizon of time T.

$$\sum_{St_i}^{Ed_i} DSA_{t,i} \geq Req_i, \forall_i \in A_{III} \tag{8}$$

where (St_i) is equivalent to the start time of the operation of appliance i; (Ed_i) corresponds the final time of the operation of appliance i; Req_i is the required time for appliance i to finish its operation; A_I, A_{II} and A_{III} are the set of appliances of the categories: interruptible and deferrable, uninterruptible and deferrable, uninterruptible and non-deferrable, respectively; and q is the initial time slot of the interval that will be verified if the category A_{II} residential appliances were used without interruption.

Besides that, the proposed DR optimization model considers how the operating schedule of the residential appliances can interfere with the satisfaction and comfort of the final consumers via inconvenience values. Thus, Equation (9) aims to evaluate how the optimized scheduling of residential loads modifies the satisfaction/comfort of the final consumers. Therefore, Equation (9) compares the real energy consumption (*Baseline*) in the time interval t for the home appliance i of the family, which is analyzed through the Load Profile Generation (LPG) tool [27], and the consumption obtained by the optimization techniques (*OPT*) used in the computational simulations. The inconvenience value checks the difference between the actual consumption and the suggested consumption for each time interval and for each device under consideration, and shows how much the consumption suggested by the optimization technique distances itself from the actual consumption pattern of the family under analysis. Assuming that the solution considered optimal will affect the normal use of residential appliances minimally, besides reducing the final price, then the smaller the difference between the normal family consumption and the proposed optimized one, the better the solution will be. Thus, the matrix $Baseline_{t,i}$ can be defined as follows:

$$Baseline_{t,i} = \begin{cases} 1, & \text{if home apliances } i \text{ is on at time } t, \\ 0, & \text{otherwise.} \end{cases}$$

The $OPT_{t,i}$ is the load scheduling suggested by various DR models.

$$OPT_{t,i} = \begin{cases} 1, & \text{if home apliances } i \text{ is on at time } t, \\ 0, & \text{otherwise.} \end{cases}$$

The inconvenience value calculation is shown in Equation (9) and it is assumed that both $Baseline_{t,i}$ and $OPT_{t,i}$ are in the form of a binary matrix (made up of only 1s and 0s) to indicate which home appliances are in operation at each time interval.

$$\sum_{t=1}^{T} \sum_{i=1}^{N} (Baseline_{t,i} - OPT_{t,i})^2 \tag{9}$$

Based on this assumption, the calculation of the inconvenience associated with a home appliance operation scheduling allows the consumer to decide whether or not to join the DR program.

3. Optimal Scheduling of Home Appliances Through a Genetic Algorithm

The DR optimization model proposed in this work was based on the load shifting technique that modifies the pattern of residential electricity consumption over the time horizon [28]. Thus, the demand usually required in peak periods was shifted to another time of lower consumption; consequently, the consumer maintained the same total daily consumption without overloading the system during peak periods.

The genetic algorithm (GA) was used in the optimization process to manage the different categories of residential appliances and reduce the energy consumption costs of residential consumers. The GA chromosomes represent the solution of the problem and, in this study, are structured as a DSA matrix. The matrix DSA, shown in the Figure 1, is a binary matrix, whose elements $DSA_{t,i}$, $(t = 1, \ldots, T$ and $i = 1, \ldots, N)$, indicate whether a particular home appliance i is in operation at the time interval t. In Figure 1, the index home appliances two is on at the time intervals 1 and 2 and is off in the interval T.

$$
\begin{array}{c} \\ 1 \\ 2 \\ \vdots \\ T \end{array}
\begin{array}{c}
\begin{array}{cccc} 1 & 2 & \ldots & N \end{array} \\
\begin{bmatrix} 1 & \boxed{1} & \ldots & 0 \\ 0 & 1 & \ldots & 1 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \ldots & 1 \end{bmatrix}
\end{array}
$$

Figure 1. DSA matrix with T rows and N columns.

The size of the chromosome in the matrix is directly related to the time horizon T and to the number of residential devices N. Therefore, the size of the chromosome ($Size\_Chrom$) is given by:

$$Size\_Chrom = T * N \tag{10}$$

The GA optimization process consists of several steps shown in Figure 2 and detailed below:

(1) Initialize Population: The initialization is carried out randomly with a uniform distribution of the chromosome population that represents easy solutions.

(2) Evaluate each chromosome in the population: Evaluates the population of chromosomes from the fitness values obtained in Equation (11) to define an ancestor (father) among the selected chromosomes.

$$Fitness = \frac{1}{\sum_{i=1}^{N} E_i \sum_{t=1}^{T} (Pr_t * DSA_{t,i})^2 + 0.1} \tag{11}$$

(3) Elitism: Maintains the good solutions that are already part of the chromosome population, conserving a quantity ($Elitism\_Tax * Pop\_Size$) of the chromosomes already existing in the new population, produced in each generation.

(4) Selection: Uses the tournament selection method to randomly define a number ($Tour\_Size$) of chromosomes (parents) of the population, reevaluated according to the fitness values of Equation (11).

(5) Crossover: Determines the cutoff point, in which the parents selected in Step 4 are divided into a randomly selected point, which in this study is the column index ($i = 1, \ldots, N$) that divides the DSA matrix and divides the chromosome into two parts (*P1* and *P2*).

(6) Mutation: Occurs every time a child is generated and there is an inversion of all bits (1s and 0s) of the randomly selected column of the DSA matrix.

(7) Next Generatio: Produces a new population of chromosomes.

(8) Optimum Scheduling of Appliances: Finalizes the GA optimization process when the stopping criterion (maximum number of generations) is reached, providing the ideal configuration of the operation of the N residential devices along the time horizon T.

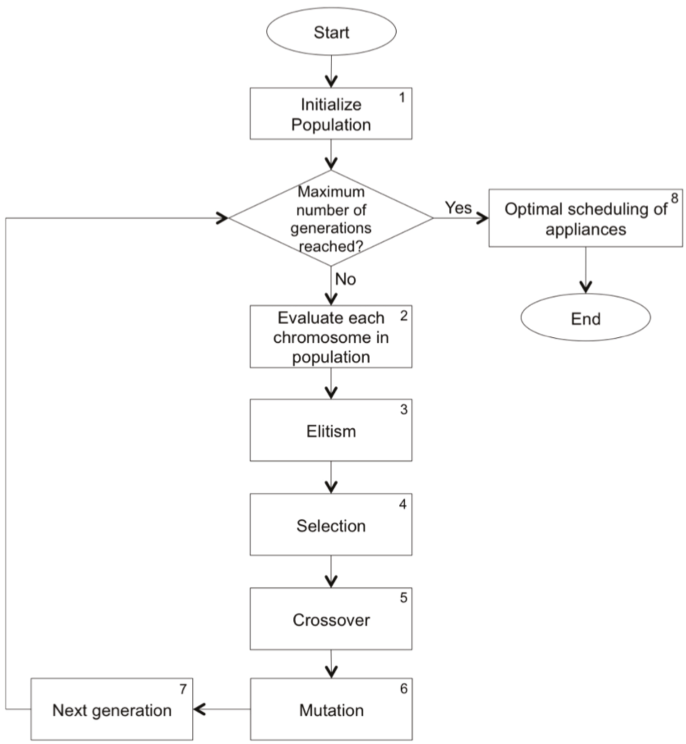


Figure 2. Flowchart genetic algorithm for optimal scheduling of home appliances.

4. Case Study

In the GA optimization process, several residential load consumption patterns were developed using the LPG tool [27]. The computational simulations considered the preferences of the consumers in terms of their home appliances, the price of electric energy per hour and the diversity of geographic information based on the location, the climate and their respective implications for each region of Brazil, as illustrated in Figure 3.

Figure 4 shows the average of the maximum and minimum temperature for the year 2016 [29]. Thus, it is possible to observe that given the dimensionality of Brazil there are several temperature values for each region throughout the year causing different profiles of family behavior in relation to the daily routine.

In addition, the dynamic electricity price provided by the Iberian Electricity Market (OMIE) of Portugal [30] was adopted, since Brazil still does not use dynamic charging and, consequently, there is no DR program based on the price in real time in Brazil. However, the GA optimization process allows the inclusion of price information from various types of analyzes (the prediction or the historical record of prices). Consequently, it is not restricted to the use of electricity prices of any specific country or locality, which is the price information is only considered as an input parameter. Figure 5 shows the price for unit power consumption at each sub-interval based on daily values of OMIE for one of the most energy-intensive days (3 July 2015) of Profile I in the city of Teresina-PI.

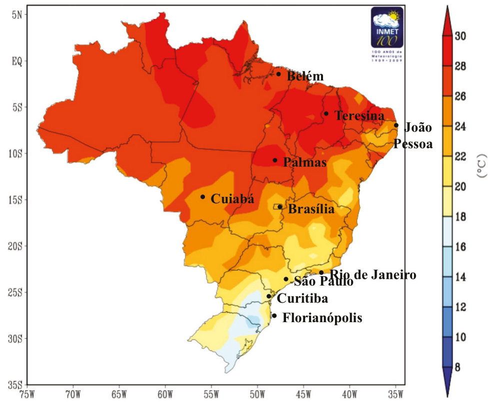
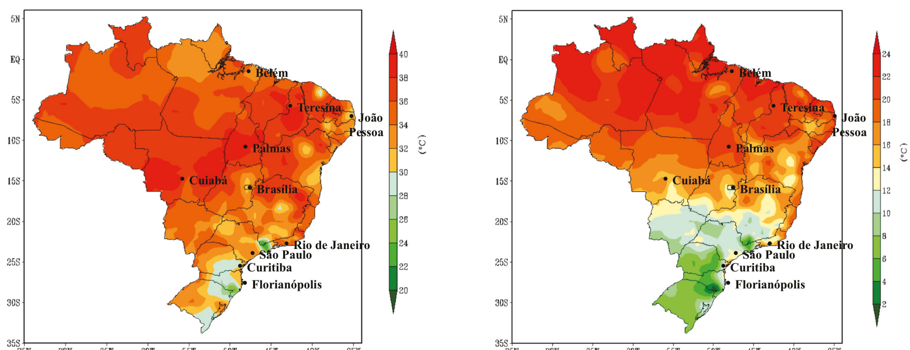


Figure 3. Average temperatures (°C) for 2016. Source: [29].



(a) **(b)**

Figure 4. Temperatures (°C) for 2016 by cities: (**a**) average annual maximum temperature; and (**b**) average annual minimum temperature. Source: [29].

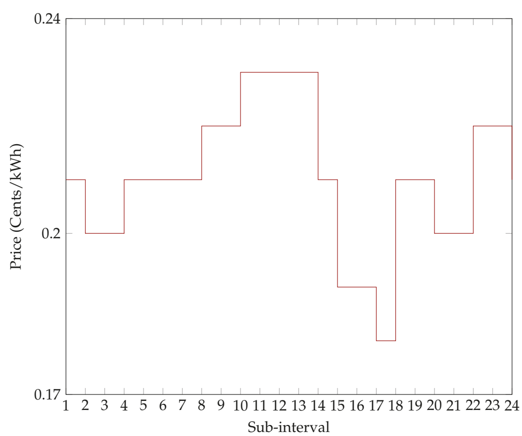


Figure 5. Price for unit power consumption.

4.1. Test Scenario

The computational simulations were applied to 10 families, each with two working adults and two adolescents. The families were resident in 10 Brazilian cities (Belém (PA), Palmas (TO), Brasília (DF), Cuiabá (MT), João Pessoa (PB), Teresina (PI), Rio de Janeiro (RJ), São Paulo (SP), Curitiba (PR) and Florianópolis (SC)) located in the five different regions of the country, respectively: North, Central West, Northeast, Southeast and South. These different regions present different climatic characteristics; for example, in the South and Southeast regions, there are certain times of the year when the temperatures are low and at these times the residents do not use air conditioners with such frequency, while the North and Northeast regions have a subtropical climate that is divided into dry and rainy periods, with high temperatures throughout the year. Consequently, these residents use air conditioners much more frequently. Thus, the families selected for the computational simulations have different patterns of electric energy consumption.

The time horizon T was for 240 days, with discretization per hour. Each interval of the horizon corresponds to an hour and contemplates the day with the largest and least consumption of electric energy per month for each family between 1 January 2015 and 31 December 2015, totalling a horizon with a size equal to 5760, according to the consumption standard provided by LPG. Each family was considered to have 29 appliances in their residence. Table 1 presents the residential appliances used in the computational simulations classified according to their respective categories (interruptible and deferrable (A_I), uninterruptible and deferrable (A_{II}) and uninterruptible and non-deferrable (A_{III})) An "interruptible" task may be stopped/interrupted before it finishes while an "uninterruptible" task may not be stopped/interrupted before it finishes. The term "non-deferrable" means that the task must start at the first time slot of the operational window, while "deferrable" means that this is not obligatory [24].

In the GA optimization process, a population of 500 chromosomes was used. Therefore, each chromosome (potential solution of the problem) stores a DSA matrix that, for this experiment, has a size of 5760 × 290, which corresponds to 1,670,400 elements of the matrix.

Table 1. Home appliance categories.

Categories	Home Appliances
A_I	100 W lamp, 20 W lamp, 60 W lamp, Satelite receptor, TV, Mobile charger, Microsoft Xbox 360, Digital signal receptor, Energy saving lamp, Laptop, CD/DVD Player, Computer, Router, Computer Monitor, Kitchen radio.
A_{II}	Home wine cellar, Steam iron, Hair dryer, Electric stove, Microwave, Electric oven, Juicer, Washing machine, Sandwich maker, Coffee maker.
A_{III}	Air Conditioner, Refrigerator, Freezer, Clothes dryer.

The one-point crossover of the genetic operators and binary mutation are used to create new chromosome populations based on the existing population. The crossover and mutation rates of 0.6 and 0.01, respectively, were found experimentally. Moreover, a rate of 0.1 was used in the elitism technique; therefore 10% of the current population is kept for the following generation. The reproduction chromosomes for the selection method were defined using a size 3 tournament, thus allowing new children to be generated for the population. The algorithm ends when 500 generations (maximum number allowed) is reached, and provides the optimal scheduling of N home appliances over the time horizon T. All these parameters used in the computational simulations involving the GA were obtained through a control mapping with the possible configuration values and, in this way, showed that this configuration can solve the DR problem exemplified in this work.

In addition, some parameters such as Maximum demand for time interval (d^{max}), Minimum demand for time interval (d^{min}), Ramping down limit (r^D) and Ramping up limit (r^U) with values of 3 kW, 0 kW, 1 kWh and 1 kWh, respectively. In addition, each city has a different mdc parameter as each family had a consumption based on the geographic locations with their respective climates and temperatures.

4.2. Simulation Results and Discussion

The computational simulations included two versions of the DR proposed model: a full one and a relaxed version called Proposed Model (WT). The proposed model-WT used by the authors does not contemplate the particularities of operation of the different categories of residential appliances, as the full version of the proposed optimization model, presented in Section 2, does. However, both were used to analyze the impact of the operating characteristics of the different categories of residential appliances on reducing the cost and consumption of electricity as well as the level of satisfaction and comfort of the end consumers with the optimized programming for residential apparatuses. In addition, the optimization models proposed in [23,25] were also used for comparison.

The impact of DR, as well as the application of the proposed DR optimization model was demonstrated though three aspects: the consumption of electric energy; the cost of electricity associated with consumption; and, the level of satisfaction and comfort of the final consumers. The results of the computational simulations show a reduction in the electric energy consumption of each family with the inclusion of the DR program. Table 2 and Figure 6 show a comparison of the electric energy consumption of each family in each city, according to the LPG tool, as well as the values obtained through the GA optimization process using the formulations analyzed in this work.

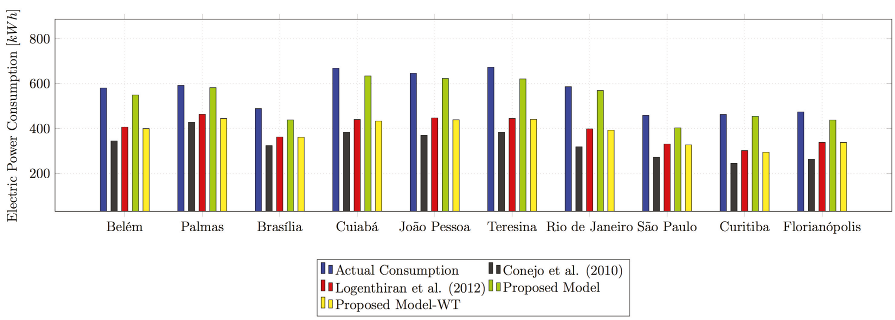


Figure 6. Electricity consumption by city.

Table 2. Electric energy consumption.

Cities	Without DR (kWh)	With DR (kWh)				Reduction (%)			
		[25]	[23]	Proposed Model	Proposed Model (WT)	[25]	[23]	Proposed Model	Proposed Model (WT)
Belém	573.85	334.74	403.40	545.51	401.25	41.67%	29.70%	4.94%	30.08%
Palmas	651.74	442.73	457.54	618.89	455.03	32.07%	29.80%	5.04%	30.18%
Brasília	498.59	305.19	359.62	486.21	357.72	38.79%	27.87%	2.48%	28.25%
Cuiabá	657.98	377.69	444.85	602.00	442.97	42.60%	32.39%	8.51%	32.68%
João Pessoa	639.47	371.86	442.43	598.68	440.19	41.85%	30.81%	6.38%	31.16%
Teresina	659.93	372.96	441.75	597.32	439.81	43.48%	33.06%	9.49%	33.36%
Rio de Janeiro	580.18	326.33	396.99	573.05	395.28	43.75%	31.57%	1.23%	31.87%
São Paulo	463.71	275.04	325.73	440.38	323.89	40.69%	29.76%	5.03%	30.15%
Curitiba	442.10	248.43	299.64	405.47	298.23	43.81%	32.22%	8.29%	32.54%
Florianópolis	467.94	276.30	336.35	455.19	334.89	40.95%	28.12%	2.72%	28.43%

The models proposed in Conejo et al. [25] and Logenthiran et al. [23] with the GA optimization process to manage the operation of the residential appliances obtained, in the city of Curitiba (PR), for example, a reduction in consumption from 442.10 kWh to 248.43 kWh and 299.64 kWh resulting in a decrease of approximately 43.81% and 32.22%, respectively. On the other hand, the model proposed in this work with the GA optimization technique and its relaxed version obtained in the city Curitiba (PR), a decrease in the consumption from 442.10 kWh to 405.47 kWh and 298.23 kWh totalling a reduction of approximately 8.29% and 32.54%, respectively.

However, the models proposed in Conejo et al. [25] and Logenthiran et al. [23], and the Proposed Model (WT) presented in this work do not consider the different categories of residential appliances, which implies an optimal solution to the problem, but which, when implemented, is not accepted as a practical and feasible solution. This reduction in consumption can result in increased dissatisfaction and discomfort of the final consumers because the different characteristics of each residential apparatus according to the real need of the consumer were not considered in the programming.

In addition, Table 3 shows a comparison of the electric energy consumption of residential appliances every hour in kWh, without DR (base consumption) and with DR guided by the proposed model. The proposed model shifts the load to times when the electricity price is lower (off-peak). For example, the microwave of the family living in Teresina (PI) operates without DR between 14 h and 18 h and with the performance of the proposed model (with DR) its operation is shifted to the time interval between 15 h and 19 h. The performance of the proposed model in comparison to the base consumption shows a satisfactory reduction in the total cost; the total cost of the microwave without the DR reaches R$ 1.14, while with the DR of the proposed model the cost is R$ 1.08, making a saving of R$ 0.06.

Another analysis (Table 4) was carried out to evaluate the impact of the formulations presented in this work to reduce the cost of electricity to final consumers. The models developed by the authors in Conejo et al. [25], Logenthiran et al. [23] and the Proposed Model (WT) obtained the largest reductions in the cost of electricity in the city of Rio de Janeiro (RJ) from R$ 107.13 to R$ 62.07, R$ 73.54 and R$ 73.20, totalling a decrease of 42.06%, 31.35% and 31.67%, respectively, in the final cost of electric energy. The DR optimization model proposed in this study obtained in the city of Rio de Janeiro (RJ) a reduction in the cost of electricity from R$ 107.13 to R$ 99.44, which is a drop of 7.18% in the final cost of electricity.

However, in addition to the reduction of electricity consumption, this significant reduction of cost is only possible in the formulations developed by Conejo et al. [25], Logenthiran et al. [23] and the Proposed Model (WT) because they do not consider the particularities of the different categories of residential appliances, and therefore allow a greater reduction of the cost of electricity to be achieved. Thus, Figure 7 presents a synthesis of the electricity costs associated to the consumption of electric energy of each family according to the LPG tool for the models created in Conejo et al. [25] and Logenthiran et al. [23] and the model proposed in this work.

Another analysis was the evaluation of the impact of the inconvenience, defined in Equation (9), which demonstrates how the change in the profile of using residential devices can interfere with the satisfaction and comfort of the final consumers. The results of the computational simulations show that, for example, in Brasília (DF), the model proposed in this study obtained a value of 62 for the level of inconvenience while the Proposed Model (WT) version and the formulation presented by the authors Logenthiran et al. [23] had values of 452 and 418, respectively. Table 5 gives a summary of all the values referring to the level of inconvenience of each family.

Table 5 shows that the proposed DR optimization model had lower inconvenience values than the Proposed Model (WT) version and the model presented by the authors Logenthiran et al. [23]. That is, the model in this study does not cause any significant level of dissatisfaction and discomfort to the final consumers in the face of changing the use of the devices over a time horizon.

The formulations applied by Logenthiran et al. [23] and Proposed Model (WT), Figure 8, caused high levels of inconvenience as they did not differentiate the residential appliance categories in their formulation, while the model proposed in this paper took into account the different particulars of the categories of residential appliances, and consequently managed to reach the very low level of inconvenience.

Table 3. Comparison of home appliance operation without and with optimization (in kWh).

Cities	Home Appliances	DR	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00	Total Cost (R$)
Brasília	Computer	Without	0.3	0	0	0	0.3	0.3	0.3	0	0	0	0	0	0	0	0	0	0.3	0.3	0	0.3	0	0	0	0.3	0.34
		With	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.32
	Microwave	Without	0	0	0	0	0	0	0	0	0	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	1.48
		Wiith	0	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.32
	Oven	Without	0	0	0	0	0	0	0	0	0	0	0	1.5	1.5	1.5	1.5	0	0	0	0	0	0	0	0	0	0.84
		With	0	0	1.5	1.5	1.5	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.78
	Stove	Without	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	0	0	0	0	0	0	0	0	0	1.68
		With	0	0	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.56
	Washing Machine	Without	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.66
		With	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.66
	Energy Price (R$/kWh)		0.22	0.21	0.20	0.20	0.20	0.20	0.22	0.26	0.27	0.27	0.27	0.27	0.28	0.28	0.27	0.27	0.26	0.26	0.26	0.24	0.26	0.27	0.24	0.21	–
Teresina	Computer	Without	0	0	0	0	0	0	0.3	0.3	0.3	0	0	0	0	0	0	0	0	0.3	0.3	0.3	0.3	0.3	0	0	0.33
		With	0	0	0	0	0	0.3	0.3	0.3	0	0	0	0	0	0	0	0.3	0.3	0.3	0.3	0.3	0	0	0	0	0.28
	Microwave	Without	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	0	0	0	0	0	0	1.14
		With	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	0	0	0	0	0	1.08
	Oven	Without	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	1.5	1.5	1.5	0	0	0	0	0	0	0	0.71
		With	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	1.5	1.5	1.5	0	0	0	0	0	0.62
	Stove	Without	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	0	0	0	0	0	0	0	1.41
		With	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	0	0	0	0	0	1.23
	Washing Machine	Without	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.66
		With	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.66
	Energy Price (R$/kWh)		0.18	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.15	0.16	0.15	0.14	0.14	0.13	0.11	0.09	0.10	0.11	0.13	0.16	0.19	0.18	0.16	–

Table 4. Total cost of electric energy.

Cities	Without DR (R$)	With DR (R$)				Reduction (%)			
		[25]	[23]	Proposed Model	Proposed Model (WT)	[25]	[23]	Proposed Model	Proposed Model (WT)
Belém	109.46	69.45	77.00	104.13	76.59	36.55%	29.65%	4.87%	30.03%
Palmas	122.89	83.86	86.84	117.47	86.36	31.76%	29.34%	4.41%	29.73%
Brasília	93.70	58.78	65.86	89.06	65.52	36.80%	29.18%	4.24%	29.55%
Cuiabá	115.81	69.19	79.30	107.29	78.95	40.26%	31.53%	7.36%	31.83%
João Pessoa	122.70	73.7	85.26	115.36	84.82	39.93%	30.51%	5.98%	30.87%
Teresina	120.87	72.57	81.79	110.57	81.43	39.96%	32.33%	8.52%	32.63%
Rio de Janeiro	107.13	62.07	73.54	99.44	73.20	42.06%	31.35%	7.18%	31.67%
São Paulo	87.87	52.76	61.06	82.56	60.71	39.96%	30.51%	6.04%	30.91%
Curitiba	79.37	46.68	53.26	72.04	53.01	41.19%	32.90%	9.24%	33.21%
Florianópolis	79.35	46.33	54.64	73.95	54.42	41.61%	31.14%	6.81%	31.42%

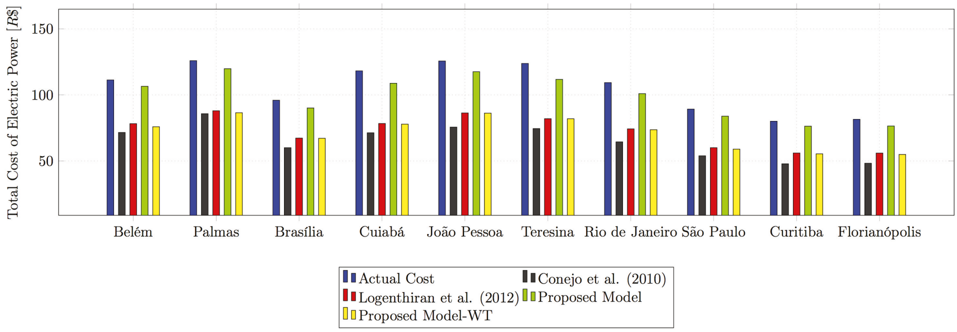


Figure 7. Cost of electricity by city.

Table 5. Inconvenience by cities.

Cities	Inconvenience		
	[23]	Proposed Model	Proposed Model (WT)
Belém	429	66	440
Palmas	435	73	438
Brasília	418	62	452
Cuiabá	422	70	440
João Pessoa	418	78	440
Teresina	419	66	445
Rio de Janeiro	414	70	456
São Paulo	410	64	447
Curitiba	447	71	441
Florianópolis	426	71	444

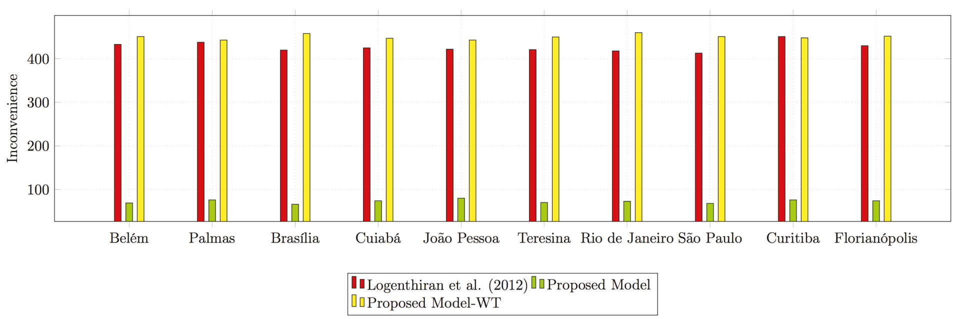


Figure 8. Level of inconvenience by city.

Inconvenience was not evaluated by the authors in Conejo et al. [25] because the structure of the formulation did not contemplate the load demand per device for each time interval, thus making such an analysis impossible.

The results of the computational simulations show that the GA optimization process using the model proposed in this work managed to effectively manage the different categories of apparatuses in the ten residences. Thus, the proposed model is able to reduce the cost associated with the consumption of electric energy and the level of inconvenience of the families when considering the preferences of the consumers in relation to the use of the residential apparatuses. In addition, the price variation of the electricity in real time and the different geographic locations, climates and temperatures and their respective implications in each region of Brazil were considered by the proposed model.

5. Conclusions

This article presented a DR optimization model that minimizes the cost of electricity associated with consumption for residential consumers. To achieve this cost reduction associated with consumption without harming the satisfaction and comfort of the residential consumer (confirmed by the inconvenience values), the technique of load shifting and the application of a genetic algorithm to manage the programming of the apparatuses based on the price of electric energy in real time and in the operational particularities of the different categories of apparatus was used.

Generally, consumer satisfaction and comfort are not contemplated when developing a DR model, since the main objective of most RD studies is only to minimize the costs. This fact is clearly seen when the model proposed in this work is compared with the other authors and the relaxed version of the proposed model, which achieved significant cost reductions, but did not consider the needs presented in the profile of each consumer and/or the particularities of the different categories of home appliances.

The goal of most DR optimization models is to reduce energy consumption and the final electric bill. However, most models, despite seeming very good in theory are usually unfeasible and not commercially viable as they do not consider the needs of the clients. The DR presented in this paper takes into account the different categories of domestic appliances and consumer satisfaction related to the innovative load scheduling of their domestic equipment, besides the proposed DR is more wide-ranging than the other models. Furthermore, this model is adaptable to all countries and under any energy setup.

The proposal for future research work includes the setting up of multi-objective evolutionary algorithms to evaluate the performance of the proposed model, which consider the inconvenience related to the satisfaction and comfort of residential consumers and maintain the minimization of the cost of electricity associated with consumption. In addition, statistical techniques will be applied to analyze and validate the research.

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

References

1. Ozturk, Y.; Jha, P.; Kumar, S.; Lee, G. A personalized home energy management system for residential demand response. In Proceedings of the IEEE Fourth International Conference Power Engineering, Energy and Electrical Drives (POWERENG'13), Istanbul, Turkey, 13–17 May 2013; pp. 1241–1246.
2. Pipattanasomporn, M.; Kuzlu, M.; Rahman, S. An algorithm for intelligent home energy management and demand response analysis. *IEEE Trans. Smart Grid* **2012**, *3*, 2166–2173.
3. Vardakas, J.S.; Zorba, N.; Verikoukis, C.V. A survey on demand response programs in smart grids: Pricing methods and optimization algorithms. *IEEE Commun. Surv. Tutor.* **2015**, *17*, 152–178.
4. Chanana, S.; Kumar, A. Demand response by dynamic demand control using frequency linked real-time prices. *Int. J. Energy Sect. Manag.* **2010**, *4*, 44–58.
5. Setlhaolo, D.; Xia, X.; Zhang, J. Optimal scheduling of household appliances for demand response. *Electr. Power Syst. Res.* **2014**, *116*, 24–28.

6. Pop, C.; Cioara, T.; Antal, M.; Anghel, I.; Salomie, I.; Bertoncini, M. Blockchain Based Decentralized Management of Demand Response Programs in Smart Energy Grids. *Sensors* **2018**, *18*, 1–21.
7. Brusco, G.; Burgio, A.; Menniti, D.; Pinnarelli, A.; Sorrentino, N.; Scarcello, L. An Energy Box in a Cloud-Based Architecture for Autonomous Demand Response of Prosumers and Prosumages. *Electronics* **2017**, *6*, doi:10.3390/electronics6040098.
8. Wang, Z.; Paranjape, R. Optimal residential demand response for multiple heterogeneous homes with real-time price prediction in a multiagent framework. *IEEE Trans. Smart Grid* **2017**, *8*, 1173–1184.
9. Ashabani, M.; Gooi, H.B. Multiobjective Automated and Autonomous Intelligent Load Control for Smart Buildings. *IEEE Trans. Power Syst.* **2017**, doi:10.1109/TPWRS.2017.2756660.
10. Guerrero-Martinez, M.A.; Milanes-Montero, M.I.; Barrero-Gonzalez, F.; Miñambres-Marcos, V.M.; Romero-Cadaval, E.; Gonzalez-Romera, E. A Smart Power Electronic Multiconverter for the Residential Sector. *Sensors* **2017**, *17*, doi:10.3390/s17061217.
11. Croce, D.; Giuliano, F.; Tinnirello, I.; Galatioto, A.; Bonomolo, M.; Beccali, M.; Zizzo, G. Overgrid: A fully distributed demand response architecture based on overlay networks. *IEEE Trans. Autom. Sci. Eng.* **2017**, *14*, 471–481.
12. Javaid, N.; Ahmed, F.; Ullah, I.; Abid, S.; Abdul, W.; Alamri, A.; Almogren, A.S. Towards Cost and Comfort Based Hybrid Optimization for Residential Load Scheduling in a Smart Grid. *Energies* **2017**, *10*, 1546.
13. Roh, H.T.; Lee, J.W. Residential Demand Response Scheduling With Multiclass Appliances in the Smart Grid. *IEEE Trans. Smart Grid* **2016**, *7*, 94–104.
14. Ma, K.; Yao, T.; Yang, J.; Guan, X. Residential power scheduling for demand response in smart grid. *Int. J. Electr. Power Energy Syst.* **2016**, *78*, 320–325.
15. Jovanovic, R.; Bousselham, A.; Bayram, I.S. Residential demand response scheduling with consideration of consumer preferences. *Appl. Sci.* **2016**, *6*, doi:10.3390/app6010016.
16. Vivekananthan, C.; Mishra, Y.; Li, F. Real-time price based home energy management scheduler. *IEEE Trans. Power Syst.* **2015**, *30*, 2149–2159.
17. Samadi, P.; Mohsenian-Rad, H.; Wong, V.W.; Schober, R. Real-time pricing for demand response based on stochastic approximation. *IEEE Trans. Smart Grid* **2014**, *5*, 789–798.
18. Zhou, S.; Wu, Z.; Li, J.; Zhang, X.p. Real-time energy control approach for smart home energy management system. *Electr. Power Compon. Syst.* **2014**, *42*, 315–326.
19. Nair, A.G.; Rajasekhar, B. Demand response algorithm incorporating electricity market prices for residential energy management. In Proceedings of the IEEE 3rd International Workshop on Software Engineering Challenges for the Smart Grid, Hyderabad, India, 1 June 2014; pp. 9–14.
20. Zhao, Z.; Lee, W.C.; Shin, Y.; Song, K.B. An optimal power scheduling method for demand response in home energy management system. *IEEE Trans. Smart Grid* **2013**, *4*, 1391–1400.
21. Chen, X.; Wei, T.; Hu, S. Uncertainty-aware household appliance scheduling considering dynamic electricity pricing in smart home. *IEEE Trans. Smart Grid* **2013**, *4*, 932–941.
22. Wang, C.; Zhou, Y.; Wang, J.; Peng, P. A novel traversal-and-pruning algorithm for household load scheduling. *Appl. Energy* **2013**, *102*, 1430–1438.
23. Logenthiran, T.; Srinivasan, D.; Shun, T.Z. Demand side management in smart grid using heuristic optimization. *IEEE Trans. Smart Grid* **2012**, *3*, 1244–1252.
24. Chen, Z.; Wu, L.; Fu, Y. Real-time price-based demand response management for residential appliances via stochastic optimization and robust optimization. *IEEE Trans. Smart Grid* **2012**, *3*, 1822–1831.
25. Conejo, A.J.; Morales, J.M.; Baringo, L. Real-time demand response model. *IEEE Trans. Smart Grid* **2010**, *1*, 236–242.
26. Holland, J.H. Adaptation in Natural and Artificial Systems. Ph.D. Thesis, University of Michigan, Cambridge, MA, USA, 1975.
27. Pflugradt, N.D. Modellierung von Wasser und Energieverbräuchen in Haushalten. Master's Thesis, Technische Universitat Chemnitz, Chemnitz, Germany, 2016.
28. Deng, R.; Yang, Z.; Chow, M.Y.; Chen, J. A survey on demand response in smart grids: Mathematical models and approaches. *IEEE Trans. Ind. Inform.* **2015**, *11*, 570–582.

29. INMET. Panorama Geral das Condições Meteorológicas e os Principais Eventos Extremos Significativos Ocorridos no Brasil. 2016. Available online: http://www.inmet.gov.br/portal/notas_tecnicas/Panorama-Geral-2016-Brasil.pdf. (accessed on 15 July 2017).
30. OMIE. Electricity Market Price. 2016. Available online: \unhbox\voidb@x\hbox{http://www.omie.es/files/flash/Resultados}Mercado.swf. (accessed on 7 October 2016).

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Digitalization and Environmental Aims in Municipalities

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Abstract: Many municipalities express a wish to use digital technologies to achieve environmental aims. However, there is still a need for a better understanding of how this should practically be done, both among municipalities and among ICT developers. We have used workshops and literature studies to formulate technological abilities of digitalization. We use two EU directives that are relevant for municipal environmental goals and combine the activities that these directives indicate with technological abilities of digitalization, in order to formulate practical implementations of digital technology to help these activities and reach the directives' goals. We suggest that this method can be used for any municipal goal, as follows: (1) Identify the objective (in our case set by the EU-directives); (2) Identify what activities these points will require or generate; (3a) From a municipal viewpoint: Based on the results of 1 and 2, formulate and structure ideas of how digitalization can support the objectives and how those ideas can be implemented; (3b) From a provider's viewpoint: Investigate what digital solutions supporting 1 and 2 exist, or how existing services can be tweaked to support the objectives and explore how new digital solutions supporting 1 and 2 can be developed.

Keywords: European Union; EU directives; municipalities; environmental aims; environmental goals; smart city; smart sustainable city; digitalization; ICT4S

1. Introduction

The last couple of years, the notion of "smart city" and the potential for digital innovations to help achieve societal goals have gained increased interest in the areas of city planning, environmental protection and digital development. Digital technology and information and communication technologies (ICTs) have been identified as having good potential for developing and managing cities more energy-efficiently [1–4] and sustainably [5,6] and for supporting a more sustainable urban lifestyle [1,7,8].

While ICTs are spreading to different parts of the world, their applications and use tend to differ globally between places—regions, cities, countries—depending not only on devices and access but also on culture and governance [9]. These factors impact their implementation for smart sustainable city development [5], just as city challenges and assets do. It is also apparent that different stakeholders have different understandings of the challenge and how it should be tackled [5,8]. Therefore, it is important to support industrial actors in understanding what problems cities face so that they can direct their solutions towards these problems. On the other hand, if ICT is going to have the positive impact that it has the potential for, cities need to understand how to make best use of the technology in a particular context [3]. There is a need for better co-operation between the ICT sector and public authorities [4,10].

In the European Union (EU), common problems on national levels are reflected in common aims and goals set by the EU, as well as to some extent common regulations. The explicit goals are specific to EU countries, but based on conditions that EU membership countries share with many other countries with similar conditions in terms of industrialization and building standards. While EU directives set frameworks of guidelines for the EU member nations, the frameworks are then interpreted and implemented in each member's national legislation and impact municipalities, producers and other stakeholders.

This article aims to formulate a way of identifying digital solutions to environmental problems important for municipalities, as identified in EU directives. This is done with the purpose of providing support for developers and municipalities to find, create and choose digitally based solutions to support environmental objectives.

European cities differ somewhat in the aspects mentioned above [9] but they also share common traits with each other, as well as with cities in other industrialized countries. For example, energy use from housing, traffic congestion, air quality and waste management tend to be important in more or less all cities. Drawing from this, we suggest that although this paper is largely based on EU directives, it can be relevant also for many cities in non-EU countries.

2. Methods

To choose what environmental perspectives to take and to find emerging technologies applicable to the field, we held iterative workshops and meetings with representatives from industry and from municipal and regional administrations in and around Stockholm, Sweden. Those meetings were held every one to two months over half a year. Due to scheduling issues, sometimes the same workshop concept was held several times with different representatives, resulting in thirteen such meetings and workshops during a 7 months period. The industry was represented by three employees from Ericsson Research and one from the network department at Telia Sweden. The participants from municipalities were three employees from the City of Stockholm (one from the IT and innovation department and two from the Spatial Development Office) and two from Täby municipality (both from the environmental department), a suburb situated north of Stockholm. A full day workshop was also held at the regional growth and development department of the county council.

During the workshops, the participants tried different ways to approach the environmental responsibility of municipalities. Eventually, it was decided to use EU environmental directives as proxies for environmental targets. The argument for this was that EU directives affect municipalities in many different countries, which makes management of them interesting for an international audience. We identified four environmental EU directives:

(1) Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe [11]
(2) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy [12]
(3) Directive 2008/98/EC, the "Waste Framework Directive," WFD [13]
(4) Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012, the "Energy Efficiency Directive," EED [14]

Bringing all four directives into this paper is not possible for reasons of space. An initial check of the documents revealed that the two first Directives mainly were concerned with monitoring. We found that too narrow and therefore choose to focus on the Waste Framework Directive (WFD) [13] and the Energy Efficiency Directive (EED) [14], as we saw a wider range of ways that digitalization could be interesting for these directives.

Furthermore, for the purpose of this paper, we chose to limit our analysis to only parts of the two directives. For the EED, "energy use in building renovations" and "exemplary role of public bodies' buildings" were chosen, as they together provide different types of issues: both bureaucratic issues of monitoring and carrying out energy efficiency measures. For the WFD, we concentrate on two parts of the waste hierarchy: "waste prevention" and "waste reuse." We chose these for primarily two reasons. Firstly, these parts have not been as well explored as recycling, energy recovery and disposal, and municipal representatives in the project pointed at those as most interesting. Secondly, these two steps have a number of different applications, both those that seem very direct and those that are harder to connect with ICTs.

From the chosen directives, we selected articles that were closely connected to the municipality and were directly connected to digitalization. After deep-reading the directives, a literature review of scientific literature and political reports was conducted to see how the implementation of the directives had been discussed in other sources. This included both literature explicitly discussing the directives and literature that concerned their themes without relating them directly to the directives themselves. From these readings, we found a number of actions to be carried out to reach the directives' goals.

As for digitalization (see Section 4), a team consisting of researchers from KTH, Telia and Ericsson identified technologies by gathering information from the Internet and different documents mainly produced by the two companies. We further discussed the way of defining digitalization with colleagues within computer science. This led to the formulation of the digitalization abilities in Section 4.

The actions indicated in directives and literature were then cross-read with the digitalization abilities to see how the abilities might be used to help realize the formulated actions.

Although using the municipality as a starting point for our work, this article does not focus on the actor perspective. According to the WFD, the municipality has the main responsibility for household waste, which motivates a municipal perspective on waste. However, several of the solutions we found need to be implemented in other parts of society, for example, in industry. There are also differences between countries regarding the importance of the municipal level. The question of actors and responsibilities is important but as a first step towards a more comprehensive understanding of digitalization for environmental issues, we have chosen to focus on digitalization as such, rather than on the actor.

We have not studied the actual effects of digitalization on the environment. Instead, we are looking at how the EU-directives can be supported. So, if the EU-directives are steering development in a more environmental friendly direction, then digitalization should support that.

3. Two EU Directives

A directive from the European Union is "a legislative act that sets out a goal that all EU countries must achieve" [15]. A directive sets up goals for the member states to reach but it is up to the individual countries to devise their own laws and formulate their own measures for reaching these goals. If the country already has rules according to the directive's prescription, it does not have to adopt additional rules. The directive states when, at latest, it should be implemented in the member states.

3.1. The Waste Framework Directive

The Waste Framework Directive (WFD) describes "waste" as "any substance or object which the holder discards or intends or is required to discard" [13]. The directive states that the primary objective should be that as little as possible enter the state of waste and includes two new recycling and recovery targets to be achieved by 2020: 50% preparing for re-use and recycling of certain waste materials from households and other origins similar to households and 70% preparing for re-use, recycling and other recovery of construction and demolition waste. As guidelines on how to achieve this, the WFD formulates an EU common waste hierarchy (see Figure 1). This is a priority ladder of how waste should be handled, unless life-cycle thinking (LCT) regarding a certain type of waste indicates that another course of action is more applicable.

Figure 1. The Waste Hierarchy [13].

The Directive requires that Member States adopt waste management plans and waste prevention programs. The directive also states that member states may take measures to extend responsibility to producers of a product in order to strengthen the prevention, reuse and recycling and other recovery of waste. The Member States should also encourage a product design adjusted in order to reduce their environmental impacts [13]. Municipalities of the EU membership countries are responsible for residents' household waste, except for what is included in producer responsibilities that the country implements.

As explained above, this paper focuses the first two steps of the waste hierarchy as shown in Figure 1. As municipalities tend to only have responsibility for consumer waste, we have chosen not to include waste minimization and reuse in the production process.

The first, waste prevention, means "measures taken before a substance, material or product has become waste, that reduce: (a) the quantity of waste, including reuse of products or the extension of the life span of products; (b) the adverse impacts of the generated waste on the environment and human health; or (c) the content of harmful substances in materials and products" [13]. Reuse, defined as "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived" [13], can be part of waste prevention. Preparing for reuse is explained as "checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be reused without any other pre-processing" [13].

Technically, because of the definition of waste explained above, "preparing for reuse" is a type of waste treatment, while reuse is a prevention measure. However, in practice these two measures are often interlinked. For example, in a EU Commission report on waste prevention [16], the following measures were identified as "preparing for reuse" if performed on waste but part of "reuse" and thereby waste-prevention if performed on non-waste:

- Straight reuse, possibly by someone else and/or in a different way
- Refurbishment and improvements
- Reparation
- Redeployment and cannibalization, where working parts are used elsewhere but broken parts are discarded
- Remanufacturing, which requires full treatment process to guarantee the performance of the finished object.

3.2. Energy Efficiency Directive

The Commission communication of 10 November 2010 on Energy 2020 places energy efficiency at the core of the Union energy strategy for 2020 and outlines the need for a new energy efficiency strategy to enable all Member States to decouple energy use from economic growth. The first paragraph of the Energy Efficiency Directive (EED), states its necessity: the "unprecedented challenges resulting from increased dependence on energy imports and scarce energy resources and the need to limit climate change and to overcome the economic crisis. Energy efficiency is a valuable means to address these challenges" [14]. According to the European Commission Energy Efficiency Plan [17], the greatest energy savings potential lies in buildings and the second greatest in transport. Since only the energy used in buildings is included in the EED, we have chosen to look at the building sector and targets concerning building renovations.

The EED sets up a number of goal categories that the EU member nations are required to meet. The goal categories are (1) Efficiency in energy use, (2) Efficiency in energy supply, (3) Horizontal provisions and (4) Final provisions. This paper is restricted to looking at the first of those. *Efficiency in energy use* promotes the establishment of a long-term strategy for mobilizing investments in the renovation of the national stock of buildings, both residential and commercial and both public and private. It includes ten Articles and we are here discussing two of those: Article 4, Building renovation and Article 5, Exemplary role of public bodies' buildings.

4. Digitalization

Brennen and Kreiss [18] argue that there is analytical value in distinguishing between "digitisation" and "digitalization." They call digitisation a material process, focused on converting analogue streams of information into digital bits. This is contrasted to digitalization, which is about social life's restructuring around digital communication and media infrastructures. We support those definitions and find them useful for highlighting the difference between the technological conditions necessary for digitally related societal change (digitisation) and the actual change (digitalization). The latter is increasingly referred to as digital transformation.

4.1. Technological Abilities

For our purposes, we complement Brennen and Kreiss' definitions with a suggestion of four technological abilities central for the digital world: Sensing and acting, Connecting, Storing and Processing. We also give four examples of how those abilities are combined into systems: Internet of Things, Cloud computing, Artificial intelligence and Computer visualization. The group of abilities are aimed as a tool for understanding digitalization and as help when investigating how digitalization can support the EU-directives. Below follows a short description of the abilities.

4.1.1. Sensing and Acting

A sensor is a device that can detect or measure a physical property and record, indicate, or otherwise respond to it. GPS-sensors are used to determine a position. An actuator is responsible for moving or controlling a mechanism or system, often acting on sensor data. Sensors are at the heart of Internet of Things, as described below. And the GPS-sensors, or other positioning sensors, are needed in positioning and navigation systems such as the satellite-based system GPS, "Global Positioning System." As stated by Pinder [19], GPS is now close to ubiquitous.

4.1.2. Connectivity

Connectivity and various telecommunication networks are at the core of digitalization. There are many types of networks with different capabilities and connectivity is a rather generic term. In essence, it can be described as an ability to connect devices in order to transfer data back and forth, for example, via the Internet. The Internet is the global system of interconnected computer networks using Internet protocols to link devices. Some other examples of technologies for connectivity are the radio access network, such as the cellular (mobile) networks 3G, 4G and 5G, fibre optic networks and cabled ones.

One of the most important differences of connectivity now in contrast to a few decades ago is increased ranges for where it is available. To put it simply, this ability has become wireless. Late 2016 there were 7.5 billion mobile subscriptions globally. That number is forecasted to increase to about 9 billion by 2020, whereof 90% are predicted to be mobile broadband subscriptions [20]. Although almost 90 % of all smart phone subscriptions globally are connected to 3G and 4G, GSM/EDGE is still the overall largest subscription category [20]. This is likely to change as 5G gain ground.

4.1.3. Storing

Without the ability to store data, the use of collecting and transmitting data is heavily reduced. Storing can be done locally in for example, cell phones or laptops, or in the cloud, which typically means at some data centre. Just as with the previous abilities, storing is an area that has developed enormously.

4.1.4. Processing

Processing power is needed to make something out of the data retrieved from a connected world. That processing power, or computing capabilities, can reside in the cloud, on local hardware, or in the human brain. Without digital processing power, we merely have data and are stuck with doing the calculations needed for making the data useful ourselves.

4.2. Combining the Abilities

The power of digitalization lies in combining the abilities described above and applying them to solve real world challenges without ignoring complexities. Moreover, by releasing and combining data and knowledge, systemic benefits can be achieved—if done right. There is a potential to generate benefits through new insights, systemic optimizations, efficiencies and understanding of inherent complexities et cetera. By not simplifying and ignoring complex cause and effect dependencies, sub-optimizations can be avoided and the full potential of digitalization reached. Below, we give four examples of how the abilities mentioned above have been combined into new systems with new capabilities.

4.2.1. Internet of Things

The Internet of Things (IoT) can be defined as the Internet between physical devices, buildings and other items embedded with electronics, software, sensors, actuators and network connectivity, enabling these objects to collect and exchange data and acting upon it. Connected sensors and actuators are enablers of IoT and smart environments, as they provide the ability to act and sense. Ericsson [20] defines a connected device as "a physical object that has an IP stack, enabling two-way communication over a network interface" (p. 33).

4.2.2. Cloud Computing

Cloud computing can be described as ways of providing shared computer processing and data storing resources to devices on demand. It enables ubiquitous access to a shared pool of configurable computing resources, such as storage, processing, applications, services and computer networks [21]. One of the most obvious benefits with cloud computing is the flexibility and scalability that comes with not having to own hardware or data centres and the ability to give otherwise simpler computer devices more advanced capabilities.

4.2.3. Artificial Intelligence

Artificial intelligence (AI) is an advanced kind of processing. AI can solve problems by five main principles; search, pattern recognition, learning, planning and induction [22]. The ability to perform advanced analytics and take autonomous decisions can be enabled by different forms of artificial intelligence and allow for deep insights and autonomous functions.

Machine learning is often described as a sub-discipline of AI, focused on the AI being able to learn from fed data, rather than being told what to do [23]. Deep learning is a less explored part of the machine learning field, where a computer system is fed with a lot of data and uses it to make sense of other data and a smaller subset of machine learning techniques is applied with the ambition of solving any sort of problem requiring "thought," either human or artificial [23]. Navigation in self-driving cars, based on sensor data as input together with on-board analytics, is one example of a deep learning application.

4.2.4. Computer Visualization

An important aspect in order to make data actionable for humans is visualization and other means of presenting data. Visualization is used to allow users to see, explore and understand information. It can be explained as using processing power to make, for example, sensing and acting, positioning, connecting and storing more intellectually available to humans through representing the data in some sensory way, usually visual.

Data visualization goes way back in time with, for example, maps representing how spatial places were located to one another. Today, information visualization and visual data mining can be useful for exploring large data sets [24,25], such as the large amount of data being generated and gathered via, for example, big data technologies and sensors. Humans with intact vision generally perceive visual attributes very well. Therefore many different data can be made easier to understand by "mapping" them to different visual attributes [26]. While visualizing data sets is nothing new, there is a range of new technologies allowing people to experience data in new ways, such as, augmented, mixed and virtual reality. Additional dimensions of representing data, like audio and haptics, can be added by utilizing more sensory modalities than only vision.

5. Digitalization, Waste Prevention and Reuse

In this section, we put together main points from the Waste Framework Directive (WFD) and scholarly literature with the abilities identified in Section 4 to see how the identified technological abilities that are the building blocks of digitalization can help working towards the main points of the WFD. We divide the section in three parts: Waste prevention, Reuse and preparation for reuse and finally a third section consisting mainly of a summary table. This is not entirely the same division as in the WFD (see Section 3.1) but gives a clearer outline of the paper.

5.1. Waste Prevention

Waste prevention is handled in two different ways in the WFD. The first is through Changed consumption patterns and the second is through Upkeep and reparation. In the following, they are presented in one Section each.

5.1.1. Changed Consumption Patterns

The WFD points out change in consumption patterns as necessary for waste reduction, as the increased consumption in Europe is one of the main causes for the increased waste flows [13]. Höjer et al. [27] define four ways that digitalization can reduce the environmental impact and resource use of consumption:

- substitute (doing something through a digital service instead of with a physical artefact)
- intensify (using things more intensely)
- improve efficiency (mainly relevant at production level and not included in this article)
- inform (to convince people to reduce environmental impact of their consumption).

Dematerialization is one of the more prominent ideas about how digitalization can contribute to a lower consumption of physical goods by substitution, partially replacing them with digital solutions [1,27]. An example of this is to consume streamed media instead of printed. An analysis of this shows that there is a potential environmental gain, but that it depends on how the printed respectively streamed media is used in practice [28]. Potential support from digitalization are through connectivity and ability to store data either in the cloud or locally, as they require a stable and fast connection for the user, as well as the ability to keep needed information stored and/or processed.

Sharing goods holds the potential of intensifying their usage, which could reduce the amount of physical goods consumed [27] and thereby the amount of waste generated. Sharing goods can signify both various forms of shared ownership, with several users of the same objects and passing on things between users, shifting ownership between them [29]. While sharing things is nothing new, digitalization simplifies matching of peers that do not know each other well beforehand. Economic theory has suggested that online platforms to connect buyers and sellers of second hand goods have the capacity to decrease waste generation through the second hand economy leading to lessened material flows [30]. It is also lifted as an example of waste minimization by the European parliament's guidance document [31]. The Nordic council of ministers have also published a report on environmental impacts of the sharing economy where they specifically look into transport, housing and smaller capital goods [32]. Key aspects from a digitalization point of view for sharing of goods are first of all connectivity and storage. To improve sharing services positioning can be useful as well as IoT where appliances can communicate directly to find a match between demand and supply.

Information, education, and awareness raising can be tools to uncover change [16,33], and are suggested by the European Parliament [31] as examples of waste prevention measures. Digital media—fundamentally based on connectivity, sometimes with cloud computing and elements of visualization—can be a good complement to traditional media for awareness campaigns about waste in general or targeting certain waste fractions [34,35].

As many municipalities already have online information on waste handling [8], this could include waste minimization. Another could be location based services and precise indoor positioning, enabling messages to be sent to users just in time on the right spot and contextually triggered messages. See also Table 1.

5.1.2. Upkeep and Reparation

There are some cases where ICTs might not be the main tool to help bring forth a change but can monitor implementation of other tools. A European commission report [16] proposes that regulatory and legal instruments are used to ensure waste minimization and that market-based/economic instruments can be used to influence behaviour towards waste-minimization, by influencing prices (e.g., with taxes) and quantities (e.g., with tradeable permit schemes). Here, ICT can play a role of informing how it works and be a valuable asset if permit schemes are implemented. It also suggests waste minimization with the help of eco-design, implemented through standards, education, information, financial support for research et cetera. Here, digital tools could be used for evaluating the eco-standard of a design. Digital databases can be used to provide examples and standards [16]. Connectivity can be used to collect big data from usage. The data can then be used in the development to make the products better adapted to true usage situations.

The WFD calls for extended producer responsibility, EPR, which puts part of the responsibility of the waste that a product produces on the producer. It could not only be useful to ensure that producers take responsibility after the product has entered the waste stream but also before, in a waste-prevention measure. This could include telepresence diagnostics and possibly eventually reparations, or at least maintenance. Sensors that report immediately if something is malfunctioning, or signal that it is time for maintenance, are already a reality. A dedicated development of the use of IoT for this kind of extended stewardship is plausible and could spread to more or less any goods.

Users can also be provided easily available and readily updated information and tutorials on how to best take care of their things, including electronic goods, and even repair them. While users are already now providing hardware reparation guides for each other, there are currently few producers that do the same. An exception to this is FairPhone, whose modular phones can be repaired at home and who also provide repair guides for the user online [36]. Online repair networks for household goods are also presented as an example of a suggested activity in a guidebook from the European Parliament [31]. A summary of activities and digitalization requirements are presented in Table 1.

5.2. Reuse and Preparation for Reuse

Digital technology could be used to tag products and packages to make them traceable. This way, producers can more easily be held accountable later or incentivize the collection of waste. With EPR, the producer will be held accountable for the environmental burden, pollution and depletion caused by the producing process but can also be asked to manage the impacts of a product during its life and at end-of-life [33]. Zaman & Lehmann [33] argue that it is not enough to legally and policy-wise introduce an EPR system but that its implementation needs constant optimization in order to be effective. While most EPR systems are focused on recycling, it could also be used to promote waste minimization and reuse. An example of this can be letting consumers trade in their old product for a producer-controlled second-hand reselling, such as with certain clothing brands and phone operators already today. For electronic products, connectivity and sensors can simplify tracking and managing. See also Table 1.

5.3. Summarizing Digitalisation and the Waste Framework Directive, WFD

In Table 1, we summarize the results regarding the WFD. The table consists of four columns. The first indicates the framework priority in question. The second column indicates an activity that can be done to support the framework priority. The third column is more detailed and describes a feature that can be supported by digitalization and the fourth and final column summarizes which technological abilities, see Section 4, can support the feature.

Table 1. Examples of the role of digitalization to support the Waste Framework Directive (WFD).

Framework Priority	Activity	Feature	Technological Abilities/Combination
Waste prevention/changed consumption patterns	Substitute	Streaming media	Connectivity Storage
		External data storage and processing	Cloud services
	Intensify	Online system for sharing of goods	Connectivity Storage Positioning IoT
	Inform	Awareness raising through campaigns	Connectivity
		Display of environmental effects	Computing Visualization
		Information available from municipality online	Connectivity
Waste prevention/upkeep and reparation	Monitoring	Databases	Sensors Cloud services Visualization
	Extended stewardship	Telepresence diagnostics; automatic maintenance; auto-updates	Cloud services IoT
	Inform	Online tutorials	Cloud services
Reuse and preparation for reuse	Traceability	Tag products	Sensors Positioning Cloud Connectivity
	Extended producer responsibility	Producer-controlled second-hand markets	Storage Positioning IoT

6. Digitalization for Energy Efficiency in Public Buildings

In this section, we have selected the parts of the Energy efficiency directive (EED) that are most relevant for this article. The section consists of two parts—Section 6.1 on Building renovation (Article 4 in EED) and Section 6.2 on Exemplary role of public bodies' buildings (Article 5 in EED). In Tables 2 and 3, by the end of Section 6.1 respectively Section 6.2, we summarize the results from respective Section.

6.1. Building Renovation (Article 4 in the EED)

Government buildings may succeed less than residential buildings with energy efficiency measures, since government buildings will not be likely to plead to its users' sense of monetary economics using information; as the majority of them will be employees and do not pay the energy bills themselves. On the other hand, housing inhabitants often fail to implement energy saving measures even when they would gain from it financially [37,38]. This suggests a potential role for interventions that is not based on price and financial savings but instead target behaviour directly with "nudging" [37,38]. We assume that this would also be applicable to government buildings.

According to Article 4 of the EED, all member states shall establish a strategy for investment in the renovation of the national stock of residential and commercial buildings, both public and private. That strategy shall encompass:

"(a) an overview of the national building stock based, as appropriate, on statistical sampling;
(b) identification of cost-effective approaches to renovations relevant to the building type and climatic zone;
(c) policies and measures to stimulate cost-effective deep renovations of buildings, including staged deep renovations;
(d) a forward-looking perspective to guide investment decisions of individuals, the construction industry and financial institutions;
(e) an evidence-based estimate of expected energy savings and wider benefits " [14].

In the following section, we discuss 4a and 4b in relation to digitalization. We do not directly discuss 4c–e, since they are not directly supported by digitalization.

6.1.1. Article 4a: Create an Overview of the National Building Stock

The EED proposes to create an overview of the national buildings stock, of both public and private buildings, based on statistical sampling. The public sector should also "undertake a comprehensive and accurate inventory of its own building stock, including energy performance" [31] (p. 10).

Another alternative is to collect real-time information on energy use from all buildings with the use of connectivity, cloud technology and sensors as part of data collection from smart meters.

Visualization would be relevant for the overview. For example, a map based visualization can be used to illustrate the energy usage [39].

Building data, such as building usage, components, operating rules and maintenance activities, is often stored in a Building information model (BIM) [40]. Artificial intelligence can use building data together with data on weather, users, global heat loss coefficient and day types to formulate realistic estimations of the actual energy use [41].

6.1.2. Article 4b: Identify Cost-Effective Approaches to Renovations Relevant to the Building Type and Climatic Zone

To identify best approaches of buildings it is needed to calculate energy savings and select optimal retrofit solutions. Virtual retrofit models apply artificial intelligence combined with BIM to create energy simulations and use multi-criteria decision support systems and virtualization to help understand possible outcomes [42].

To follow up the actual results, sensors as part of smart metering can collect data to be analysed automatically with the help of cloud technology and connectivity.

In Table 2, we summarize the results regarding building renovation in the EED. See Section 5.3 for an explanation of the table.

Table 2. Digitalization and building renovation in the Energy Efficiency Directive (EED).

Framework Priority	Activity	Feature	Digitalization Abilities/Combination
Article 4a: Create an overview of the national buildings stock	Data inventory	Read and register data on buildings' energy usage	Sensors Connectivity Cloud technologies AI
		Store data where it can be accessed	Cloud technology
		Show by visualizing data	Data Representation
	Formulate realistic estimations of energy use	Make pattern recognitions from building data	Artificial intelligence
		Collect real-time information	Connectivity Cloud Technology Sensors
Article 4b: Identify cost-effective approaches to renovations	Calculating energy savings and selecting optimal retrofit solutions	Virtual retrofit models	Artificial intelligence Cloud Technologies Visualization
	Follow up results	Smart metering Automatic analysis	Sensors Cloud technologies Cloud technologies Connectivity

6.2. Exemplary Role of Public Bodies' Buildings (Article 5 in the EED)

Municipalities and other public authorities can have political incentives to be early adopters of new technology. And according to the EED, buildings owned and occupied by central government need to take an exemplary role in improved energy performance by "lead[ing] by example and implement[ing] well-planned, high-quality deep renovations" [14] (p. 10). Only buildings that are owned by the central government—normally the state—are technically bound to this part of the directive. However, according to article 5.7, the member states shall also encourage other public bodies, including at regional and local level, to conduct actions for energy efficiency in saving [14]. Therefore, we draw the conclusion that the EED still speaks for energy efficiency and energy saving at a municipal level.

6.2.1. Article 5.1–5.4: Yearly Renovations

Each year, 3% of the total floor area of heated and/or cooled central government buildings should be renovated to meet the minimum energy performance requirement for buildings larger than 250 m^2 [14]. The buildings with the poorest energy performance shall be prioritized. Part of achieving this could be gathering data on energy performance of the governments' building stock, using sensors together with BIM stored in the cloud. The renovations could also be visualized beforehand, both individually and with map-based visualization, to support decision-making, similarly as suggested for article 4b in Section 6.1.2.

6.2.2. Article 5.5: Inventory of Government Buildings

Member states must establish an inventory of heated and/or cooled central government buildings and make it publicly available. According to the EU Coalition for Energy Savings [43], this is relevant for the whole public sector, which should undertake "a comprehensive and accurate inventory of its own building stock, including energy performance and other relevant energy data." This requires gathering data as well as making this data available. IoT technologies and cloud computing could be used to measure and store data on the energy use in the buildings. Data could also be made available and understandable by visualizations of energy use.

6.2.3. Article 5.6: Alternative Approach for Energy Savings

Article 5.6 suggests combining deep renovations with measures for behavioural change of occupants. According to Loviscach [44], this can be achieved through information, persuasion and advice (often referred to as nudging) or automation. According to Lehner et al. [38], there are four main types of nudging: "(1) simplification and framing of information, (2) changes to the physical environment, (3) changes to the default policy and (4) the use of social norms" (p. 168).

Digitalization can be used to make users aware of their energy use and as decision support tools [40]. This can be done in several ways—via traditional displays like monitors, as augmented reality, or analogously using real-world objects [45,46]. Digitalization enables collaboration, interaction through social media and knowledge sharing around energy efficiency and energy savings (Kramers, 2013), which support behavioural change. Moreover, digitalization enables real-time cues regarding energy use, especially through IoT. Visualizations of benefits of energy efficiency improvements in buildings can make it easier to understand the energy savings intuitively.

For automation, sensors and artificial intelligence are important (see, for example, [47]). Cloud technology can be used as part of analysing and processing the data dynamically in order to for example, send notifications when something needs to be acted upon. Connectivity is important for letting sensors, actuators and connected things in the home communicate with each other for increased efficiency.

6.2.4. Article 5.7: Energy Management and Efficiency

The EED says that public bodies should be encouraged to adopt an energy efficiency plan and put in place energy management systems including energy audits. It also suggests using energy service companies and energy performance contracting for financing renovations [14].

Here again virtual retrofit models can be used to understand benefits of renovations and choose the right alternative, similarly as for article 4b in Section 6.1.2. This can also be used to support an energy management system with energy audits.

In models on “energy savings as a service,” the renovation costs are paid using monetary savings from reduced energy use in the renovated buildings. This often means that an investor installs energy saving equipment in a building and the building owner pays it off by paying their historical utility bills to the investor, where the difference between the historical utility bills and the new lower bills pay for equipment and profit [48]. This could be more accurately achieved by using sensors tracking the energy usage, as well as connectivity and cloud technology enabling calculating the monetary savings using real-time price data and sending the information to the renovation company so they know what to charge.

In Table 3, we summarize the results regarding exemplary role of public buildings in the EED. See Section 5.3 for an explanation of the table.

Table 3. Exemplary role of public buildings in the EED.

Framework Priority	Activity	Feature	Digitalization Abilities/Combination
Article 5.1–5.4: 3% renovated per year	Prioritizing buildings with poorest energy performance	Gathering data on energy perform. of public building stock Visualization to support decision-making	Sensors Cloud technology (BIM stored in cloud) Map-based visualization Positioning
Article 5.5: Inventory of heated and/or cooled central government buildings	Establish inventory	Gather data	IoT Sensor networks
	Make inventory publically available	Make data available and understandable to the general public	Connectivity Visualization of energy use
Article 5.6.: Alternative approach: measures for behavioural change of occupants	Information, persuasion and advice (nudging)	Make users aware of their energy use and provide decision support Data collection (sensors) and analysis to map behaviours	Visualization Sensors Data analytics
		Collaboration, social media and knowledge serving	Connectivity
	Automation	Notification when something needs to be acted on	Data analytics Software/Systems for analysing and processing the data dynamically
		Efficiency improvements	IoT

Table 3. *Cont.*

Framework Priority	Activity	Feature	Digitalization Abilities/Combination
Article 5.7a and b: Encourage public bodies to adopt an energy efficiency plan and put in place an energy management system including energy audits	Evaluating energy efficiency benefits	Virtual retrofit models	Artificial intelligence Cloud technologies Visualization
Article 5.7c: Use energy service companies and energy performance contracting to finance renovations	Energy savings as a service	Sensors	Connectivity Cloud technology IoT

7. Concluding Discussion

In this paper, we have explored how digitalization can be used to support environmental targets at the municipal level. We identified the four abilities Sensing and acting, Connecting, Storing and Processing as the basic building blocks of digitalization. They are powerful technologies as such and in different combinations, they can create higher-level systems such as Internet of Things, Cloud computing, AI and Computer visualizations.

We treated a group of important policy documents—EU-directives—as a kind of municipal environmental targets. The directives led us to focus on some very specific topics without making the analysis dependent on a specific municipality, ensuring international relevance.

This paper proposes a method for better using digitalization to reach environmental targets and makes a first attempt to show a systematic way of starting such an effort. Civil servants need to look for new digital opportunities and providers must approach the municipal targets. Three steps are needed for this:

(1) Identify the objective (in our case the EU-directives). How are the objectives formulated in the directive? Here it can help to think in terms of Direct environmental improvement, Implementation of management principles or Monitoring, as described below.
(2) Identify what activities these points will require or generate. What activities supporting the targets can be identified in academic literature and other relevant documents from public organizations? What activities are identified from other stakeholders?
(3) (a) From a municipal viewpoint: Based on the results of 1 and 2, formulate and structure ideas of how digitalization can support the targets and how those ideas can be implemented. Then approach providers with the resulting ideas.
(b) From a provider's viewpoint: Investigate what digital solutions supporting 1 and 2 exist, or how existing services can be tweaked to support the targets and explore how new digital solutions supporting 1 and 2 can be developed. Then approach the municipality with the resulting ideas.

Using digitalization to support targets is to a high degree a matter of attitude and this simple method is designed to support a better understanding between municipalities and providers. 3a and 3b above would ideally take place in cooperation but there may be issues of public procurement complicating that. The idea with the method is to create a kind of communication space between municipalities and providers, where problems and solutions can meet.

The EED has a strong focus on goals and objectives for the member states to reach. The actions included in the EED are focused on how the member states can work with formulating policies for reaching these goals. The WFD also includes goals and objectives but they are all centred on the waste hierarchy and the WFD focuses on the waste hierarchy as the central changing factor for the future and to achieving the WFD goals. While the EED concentrates on an aspect of environmental performance—in this case energy savings—rather than actions, the waste hierarchy essentially consists of the actions to reach the objectives. The EED does contain actions towards reaching its goals but also includes numerous actions that mainly serve to monitor and control authorities, building companies, et cetera vis-à-vis the directive. From this, we have identified three types of objectives from the directives:

- Environmental performance (reduction of energy use)
- Implementation of certain principles of action (waste hierarchy)
- Monitoring important environmentally related features (building stock inventory).

There are many measures one can take that would support reduced waste and more efficient energy use but that are not included in the directives. They have not been studied here. Especially when it comes to the EED, there are many digitalization solutions that could improve energy efficiency but that do not easily connect to the directive. An example of this is smart metering and smart homes technologies that can be used to monitor and control electricity consumption in homes. The actual potential of this is debated with studies of contemporary use of smart metering indicating a reduction of energy use by up to 10 percent and highly dependent on the feedback mechanism. However, it has not been the aim of this paper to present a comprehensive set of digitalization techniques that can support environmental targets but to formulate a way of identifying digital solutions to environmental problems. We have highlighted the importance of specifying the target that is aimed at with the digital solution and emphasized that this can be useful both for a local authority and for developers. When other targets than those directly derived from the EU-directives are in focus, further digital solutions will be added.

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References

1. Mitchell, W.J. *E-Topia: "Urban Life, JIM—But Not as We Know It"*; MIT Press: Cambridge, MA, USA, 2000; ISBN 0262632055.
2. GeSI. *SMARTer 2020: The Role of ICT in Driving a Sustainable Future*; Technical Report, A Report by The Climate Group on Behalf of the Global e-Sustainability Initiative; GeSI: Brussels, Belgium, 2012.
3. Kramers, A.; Höjer, M.; Lövehagen, N.; Wangel, J. Smart sustainable cities—Exploring ICT solutions for reduced energy use in cities. *Environ. Model. Softw.* **2014**, *56*, 52–62. [CrossRef]
4. European Commission. *A Digital Single Market Strategy for Europe. COM(2015) 192 Final*; European Commission: Brussels, Belgium, 2015; Volume 20.
5. Höjer, M.; Wangel, J. Smart sustainable cities: Definition and challenges. *Adv. Intell. Syst. Comput.* **2014**, *310*, 333–349. [CrossRef]
6. ITU-T. Smart sustainable cities: An analysis of definitions. Available online: https://www.itu.int/en/ITU-T/focusgroups/ssc/Documents/website/web-fg-ssc-0100-r9-definitions_technical_report.docx (accessed on 17 April 2018).
7. Hilty, L.M.; Aebischer, B. *ICT for Sustainability: An Emerging Research Field What Is Sustainability?* Springer: Berlin, Germany, 2014; ISBN 3319092278.
8. Ringenson, T.; Höjer, M. Smart City Planning and Environmental Aspects? In Proceedings of the ICT for Sustainability 2016, Amsterdam, The Netherlands, 29 August–1 September 2016; pp. 159–166.

9. Wilson, M.I.; Corey, K.E. Approaching ubiquity: Global trends and issues in ICT access and use. *J. Urban Technol.* **2011**, *18*, 7–20. [CrossRef]
10. Granath, M. *The Smart City—How Smart Can 'IT' Be?: Discourses on Digitalisation in Policy and Planning of Urban Development*; Linköping University Electronic Press: Linköping, Sweden, 2016; ISBN 9789176856987.
11. EU. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. *Off. J. Eur. Commun.* **2008**, *152*, 1–43.
12. European Community. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *Off. J. Eur. Parliam.* **2000**, *L327*, 1–82. [CrossRef]
13. European Parliament and Council. *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives*; European Parliament and Council: Brussels, Belgium, 2008; pp. 3–30.
14. European Parliament. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency. *Off. J. Eur. Union Dir.* **2012**, 1–56. [CrossRef]
15. European Union. EUROPA—Regulations, Directives and Other Acts. Available online: https://europa.eu/european-union/eu-law/legal-acts_en (accessed on 18 April 2018).
16. European Commission; Hoornweg, D.; Bhada-Tata, P. *Analysis of the Evolution of Waste Reduction and the Scope of Waste Prevention*; European Commission: Brussels, Belgium, 2010; ISBN 3200687053.
17. European Commission. COM(2011)109 Energy Efficiency Plan 2011. Available online: https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/efficiency_plan_en.pdf (accessed on 18 April 2018).
18. Brennen, S.; Kreiss, D. Digitalization. The International Encyclopedia of Communication Theory and Philosophy, 1. Available online: https://doi.org/10.1002/9781118766804.wbiect111 (accessed on 18 April 2018).
19. Pinder, D. Dis-locative arts: Mobile media and the politics of global positioning. *Continuum* **2013**, *27*, 523–541. [CrossRef]
20. Ericsson. *5G Radio Access*. White Paper. Available online: https://www.ericsson.com/en/white-papers/5g-radio-access--capabilities-and-technologies/white-paper---5g-radio-access (accessed on 18 April 2018).
21. Mell, P.; Grance, T. The NIST Definition of Cloud Computing Recommendations of the National Institute of Standards and Technology. *Nist Spec. Publ.* **2011**, *145*, 7. [CrossRef]
22. Minsky, M. Steps toward Artificial Intelligence. *Proc. IRE* **1961**, *49*, 8–30. [CrossRef]
23. Marr, B. What Is The Difference Between Artificial Intelligence And Machine Learning? Available online: https://www.forbes.com/sites/bernardmarr/2016/12/06/what-is-the-difference-between-artificial-intelligence-and-machine-learning/#6d6bf74a2742 (accessed on 18 April 2018).
24. Keim, D.A. Visual exploration of large data sets. *Commun. ACM* **2001**, *44*, 38–44. [CrossRef]
25. Keim, D.A. Information visualization and visual data mining. *IEEE Trans. Vis. Comput. Graph.* **2002**, *8*, 1–8. [CrossRef]
26. Mazza, R. *Introduction to Information Visualization*; Springer: Berlin, Germany, 2009; ISBN 9781848002180.
27. Höjer, M.; Moberg, Å.; Henriksson, G. *Digitalisering och Hållbar Konsumtion*. Available online: https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6675-8.pdf?pid=15239 (accessed on 18 April 2018).
28. Achachlouei, M.A.; Moberg, A. Life Cycle Assessment of a Magazine, Part II A Comparison of Print and Tablet Editions. *J. Ind. Ecol.* **2015**, *19*, 590–606. [CrossRef]
29. Schor, J. Debating the Sharing Economy. *Gt. Transit. Initiat. Essay* **2014**, 1–19. [CrossRef]
30. Fremstad, A. Does Craigslist Reduce Waste? Evidence from California and Florida. *Ecol. Econ.* **2017**, *132*, 135–143. [CrossRef]
31. European Parliament. *Guidance on the Interpretation of Key Provisions of Directive 2008/98/EC on Waste*; European Parliament: Brussels, Belgium, 2010.
32. Skjelvik, J.M.; Erlandsen, A.M.; Haavardsholm, O. *Environmental Impacts and Potential of the Sharing Economy*; TemaNord 2; Nordic Council of Ministers: Copenhagen, Denmark, 2017; ISBN 9789289351560.
33. Zaman, A.U.; Lehmann, S. Challenges and Opportunities in Transforming a City into a "Zero Waste City". *Challenges* **2011**, *2*, 73–93. [CrossRef]
34. Davis, K.C.; Shafer, P.R.; Rodes, R.; Kim, A.; Hansen, H.; Patel, D.; Coln, C.; Beistle, D. Does digital video advertising increase population-level reach of multimedia campaigns? Evidence from the 2013 tips from former smokers campaign. *J. Med. Internet Res.* **2016**, *18*, 235. [CrossRef] [PubMed]

35. Farr-wharton, G.; Choi, J.H.-J.; Foth, M. Food Talks Back: Exploring the Role of Mobile Applications in Reducing Domestic Food Wastage. In Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures: The Future of Design, Association for Computing Machinery (ACM), Sydney, Australia, 5–7 December 2014; pp. 352–361. [CrossRef]
36. Proske, M.; Schischke, K.; Sommer, P.; Trinks, T.; Nissen, N.F.; Lang, K.D. Experts View on the Sustainability of the Fairphone 2. In Proceedings of the 2016 Electronics Goes Green 2016+, EGG 2016, Berlin, Germany, 6–9 September 2016.
37. Allcott, H.; Mullainathan, S. Behavior and Energy Policy. *Science* **2010**, *327*, 1204–1205. [CrossRef] [PubMed]
38. Lehner, M.; Mont, O.; Heiskanen, E. Nudging—A promising tool for sustainable consumption behaviour? *J. Clean. Prod.* **2016**, *134*, 166–177. [CrossRef]
39. Howard, B.; Parshall, L.; Thompson, J.; Hammer, S.; Dickinson, J.; Modi, V. Spatial distribution of urban building energy consumption by end use. *Energy Build.* **2012**, *45*, 141–151. [CrossRef]
40. Kramers, A. ICT applications to lower energy usage in the already built environment. *Smart Innov. Syst. Technol.* **2013**, *22*, 127–135. [CrossRef]
41. Wang, Z.; Srinivasan, R.S. A review of artificial intelligence based building energy use prediction: Contrasting the capabilities of single and ensemble prediction models. *Renew. Sustain. Energy Rev.* **2017**, *75*, 796–808. [CrossRef]
42. Woo, J.H.; Menassa, C. Virtual Retrofit Model for aging commercial buildings in a smart grid environment. *Energy Build.* **2014**, *80*, 424–435. [CrossRef]
43. The Coalition for Energy Savings. *Top 20 Checklist for Strong Implementation of the Energy Efficiency Directive*; Online Guide to the EU Energy Efficiency Directive. The Coalition for Energy Savings. Available online: http://eedguidebook.energycoalition.eu/checklist.html (accessed on 18 April 2018).
44. Loviscach, J. The design space of personal energy conservation assistants. *PsychNology J.* **2011**, *9*, 29–41.
45. Katzeff, C. Engaging design for energy conservation. *Metering International Magazine*; 2010, pp. 62–63. Available online: https://www.metering.com/regional-news/europe-uk/engaging-design-for-energy-conservation-in-households/ (accessed on 18 April 2018).
46. Katzeff, C.; Nyblom, Å.; Tunheden, S.; Torstensson, C. User-centred design and evaluation of EnergyCoach—An interactive energy service for households. *Behav. Inf. Technol.* **2012**, *31*, 305–324. [CrossRef]
47. Nguyen, T.A.; Aiello, M. Energy intelligent buildings based on user activity: A survey. *Energy Build.* **2013**, *56*, 244–257. [CrossRef]
48. Hilke, A.; Ryan, L. Mobilising Investment in Energy Efficiency: Economic Instruments for Low-energy Buildings. In *IEA Energy Papers*; No. 2012/10; OECD Publishing: Paris, France, 2012; Available online: http://dx.doi.org/10.1787/5k3wb8h0dg7h-en (accessed on 18 April 2018).

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Chemical Waste Management in the U.S. Semiconductor Industry

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Abstract: Sustainability has become the biggest concern of the semiconductor industry because of hundreds of high-purity organic and inorganic compounds involved in manufacturing semiconductors not being treated economically. The aim of this study was to understand how semiconductor companies manage their chemical wastes, by analyzing the U.S. Environmental Protection Agency's Toxics Release Inventory data for hydrogen fluoride, nitric acid, ammonia, *N*-methyl-2-pyrrolidone, hydrochloric acid, nitrate compounds, and sulfuric acid. Cluster analysis was adopted to classify the U.S. semiconductor companies into different performance groups according to their waste management approaches. On the basis of the results, twenty-seven companies were classified in the "best performance" category for the waste management of two or more chemicals. However, 15 companies were classified in the worst performance categories. The semiconductor companies can refer to our results to understand their performance and which companies they should benchmark regarding chemical waste management. City governments can also refer to our results to employ suitable policies to reduce the negative impacts of the chemical waste from regional semiconductor companies.

Keywords: waste management; sustainability; cluster analysis; semiconductor

1. Introduction

The semiconductor industry is one of the largest industries in the world with a production value of approximately US$400 billion [1]. The semiconductor production process usually comprises deposition, resist coating, light exposure, etching, resist removal, and rinsing, which generate considerable acid waste [2]. More than 200 high-purity organic and inorganic compounds and large quantities of ultrapure water are used during the production of semiconductor chips [3]. Furthermore, most of the discharged chemicals, incinerated at high temperatures, are human carcinogens, which could pose a serious health risk if not treated properly. Thus, wastewater from semiconductor fabrication facilities commonly contains a range of harmful contaminants, such as solvents, arsenic, antimony, acids, alkalis, salts, fine oxide particles, and other pure organic and inorganic compounds [4]. Numerous approaches have been developed to treat the pollution arising from different manufacturing processes. Several methods, such as distillation, adsorption, membrane separation, extraction, freeze concentration, photolysis, and melt crystallization, have been explored to recycle or recover organic solvents from a waste photoresist stripper [5,6]. Wastes such as chemical mechanical polishing wastewater can be treated to effectively reduce the suspension of silica particles and completely remove cetyltrimethylammonium bromide [7]. Chemical coagulation and reverse osmosis are used to remove 99% of the suspended oxide particles and reduce the chemical oxygen demand so that the wastewater can be reused post-treatment [8]. In semiconductor manufacturing, hydrofluoric acid is widely used in the etching processes and for cleaning wafers and quartz tubes. According to the Semiconductor Industry Association, waste solutions of hydrofluoric acid account for more than 40% of the hazardous substances produced in the semiconductor industry [9]. Excessive hydrofluoric acid can cause bone disease and tooth spots. Waste solutions of hydrofluoric acid are tightly regulated, and regulatory authorities are required to provide suitable treatment. A variety of methods have been developed and applied to treat hydrofluoric acid wastewater, including chemical coagulation with polyaluminum chlorides or aluminum sulfates, calcium salt precipitation, montmorillonite electrocoagulation, ion exchange, precipitate flotation, and reverse osmosis with montmorillonite or calcite [9].

Because environmental protection and sustainable development have become critical concerns, the semiconductor industry has gradually adopted sustainability considerations. Recently, the Carbon Disclosure Project launched a ban on hazardous substances that are unsustainable and cause global warming. Hence, the semiconductor industry faced various pressures and challenges [7]. Some companies have proactively solved these challenges and mitigated related risks, by reducing their reliance on chemicals and improving the treatment of water before discharge. To treat hazardous waste on-site and maintain strict environmental standards, some semiconductor manufacturers such as Samsung and Intel have invested in green technologies [10]. Other semiconductor companies (e.g., Hadco Corporation, Bindura Nickel Corp, and Cytec Solvay Group) have used different metal recovery techniques, such as electrowinning, to quantitatively remove copper from waste effluents and damage hydrogen peroxide [11–13]. Although many semiconductor companies have attempted to reduce the negative impacts of their chemical waste, few studies have been conducted to analyze their waste management performance. For example, Hsu et al. [7] used the fuzzy Delphi method and analytic network process to construct a sustainability-balanced scorecard for the semiconductor industry. Villard et al. [14] analyzed semiconductor manufacturing enterprises according to seven specific environmental indicators to assess the impact of wafer-manufacturing on environmental standards.

The aim of this study was to investigate the reactions of US semiconductor companies to environmental concerns and their methods of managing chemical waste. According to waste management hierarchy of the US Environmental Protection Agency (EPA), the best approach for managing chemical waste is source reduction and reuse, followed by recycling, recovery, treatment, and disposal [15]. Companies may incorporate different approaches to managing their chemical waste, due to limitations of the manufacturing process. We collected chemicals that were recycled, recovered, treated, and released (disposed) by the semiconductor companies. The chemical wastes investigated in this study included Hydrogen Fluoride (HF), Ammonia (NH_3), Nitric Acid (HNO_3), *N*-methyl-2-pyrrolidone (NMP), Hydrochloric Acid (HCl), Nitrate Compounds (NO_x) and Sulfuric Acid (H_2SO_4). Data were retrieved from the Toxics Release Inventory of the US EPA. Then, we used cluster analysis to classify the companies into groups according to their waste management approaches. The results indicate how each chemical was managed in the semiconductor industry and which companies used the best chemical waste management techniques. These techniques may be referred to by the poorly performing companies. Moreover, we analyzed the relationship between company locations and their chemical waste management performance. This study provides city governments with an overview of the existing semiconductor companies in their city. In addition, we examined the management of chemical waste by semiconductor companies from a regional perspective. Poorly performing cities can adopt the environmental policies of the best performing cities regarding the control of chemical wastes from semiconductor companies.

2. Waste Management of HF, NH_3, HNO_3, NMP, HCl, NOx, and H_2SO_4

The process of semiconductor manufacturing generates a significant amount of wastewater, because a huge quantity of ultrapure water is consumed in the course of the chemical mechanical polishing process [16]. High-purity HF is mainly used as a cleaning gas for removing unnecessary chemical substances that stick to the inside of the chemical vapor deposition furnace during semiconductor production [17]. According to a study from the Semiconductor Industry Association, HF accounts for over 40% of the total hazardous materials produced from this industry [18]. HF is a highly dangerous gas, which can damage the esophagus and stomach and cause lingering chronic lung disease, determined pain, bone loss, and nail bed injuries [19]. NH_3, a toxic gas, is used as a blending division for the calibration gases of emission as well as some specialty semiconductor manufacturing. NH_3 is very toxic to aquatic organisms because over-fertilization leaches into water bodies [20]. Moreover, exposure to high concentrations of ammonia causes irritation of the eyes, nose, and throat, and burning of the skin. In the semiconductor industry, HNO_3 is usually handled as a mixture with hydrofluoric acid, which is frequently used for etching and exposing the critical layer in front-end processing to adjust between the diffusion-limited and rate-limited etching. It is the oxidizing ingredient of many etching mixtures for metals such as silver, copper, aluminum, silicon, germanium, and gold [21]. HNO_3 is an extremely corrosive acid capable of rapidly causing chemical burns and even blindness. If the HNO_3 mist is inhaled, health risks such as the corrosion of the mucous membranes, delayed pulmonary edema, and death may occur [22]. In semiconductor processing, NMP is a very efficient polar solvent for resist removal and cleaning [23]. Currently, there exists no sustainable alternative to NMP with similar critical applications. NMP has a low hazard for ecological receptors and low persistence if released into aquatic or terrestrial environments. However, the risk evaluation report for NMP indicated that reproductive and developmental effects are more important health risks than effects on the hepatic, renal, immune, reproductive-developmental, and central nervous systems [24]. Meanwhile, HCl is the main chemical to produce silicon components in the manufacturing of semiconductors, because it not only engraves silica into a mix with an ammonium fluoride solution by using it in-house with nitric acid, but it also dilutes as a cleaning agent and removes residual oxides as well [25]. However, it causes the corrosion failure of transmission tubing, because the reaction of HCl with moisture eats through stainless tubes in plants manufacturing semiconductors [26]. Moreover, HCl may harm human skin, causing burns, ulcerations, or even scars; when inhaled, it may also cause coughing, hoarseness, inflammation, ulceration of the respiratory tract, chest pain, and even acute health effects such as vomiting, diarrhea or nausea [27]. NO_x derives from the partial or complete neutralization of nitric acid in semiconductor manufacturing [28]. Without proper treatment of this chemical waste, drinking water with high nitrate would interfere with the ability of red blood cells to transport oxygen. In an emergency case, it can lead to respiratory and heart problems, and even death [29]. H_2SO_4 uses huge amounts of resist stripping and wafer cleaning material in semiconductor manufacturing plants. Because the reuse of H_2SO_4 is highly valuable in the semiconductor manufacturing process, many techniques have been proposed to recover and purify the H_2SO_4 waste [30]. It is harmful to the eyes and skin and may cause third-degree burns and blindness upon contact. It can damage the lungs and teeth, or even act as a carcinogenic to humans [31].

Semiconductor manufacturers release (on-site and off-site), treat (on-site and off-site), recover, and recycle their chemical waste, in order to adhere to the criteria specified by the US EPA. The on-site release includes the emission of toxic chemicals into the air and discharge into water, onto land, and into underground injection wells, whereas off-site release includes the disposal of undestroyed chemicals in landfills or water. Another on-site treatment approach is used when the number of toxic chemicals destroyed during on-site waste treatment operations. Biological treatment, incineration, and chemical oxidation are the most common approaches for off-site treatment. Off-site treatment quantity depends on the amount of toxic chemicals that leave the facility boundary for treatment and not the amount that is destroyed at the off-site location. Recovery includes the combustion of toxic chemicals in waste to generate heat or electricity. Recycling is generally the optimal method for chemical waste management and includes the recovery of toxic chemicals from waste for reuse.

3. Methodology

In this study, we collected toxic emissions data for HF, NH_3, HNO_3, NMP, HCl, NO_x, and H_2SO_4 from the US EPA Toxics Release Inventory regarding semiconductor manufacturing (NAICS code 334,413) [32]. The chemical waste management techniques of 68 semiconductor manufacturing companies were analyzed. The collected data included the annual amount of chemical waste released on-site, released off-site, treated on-site, treated off-site, recovered, and recycled by semiconductor companies in the United States in 2013. We calculated the percentage of waste handled with different approaches. Thus, we determined the recycled proportion, the recovered proportion, the proportion treated on-site, the proportion treated off-site, the proportion released on-site, and the proportion released off-site for HF, NH_3, HNO_3, NMP, HCl, NO_x, and H_2SO_4.

To understand how semiconductor companies in the United States have managed their chemical waste, cluster analysis was adopted to classify the companies into three or four performance groups according to their waste management approaches. Cluster analysis was performed to separate several elements into homogeneous groups. In other words, data clustering is the process of placing data items into different groups—clusters—in such a way that items in a particular group are similar to each other and different from those in other groups. The most basic form of clustering uses namely the *K*-means algorithm [33]. In this study, *K*-means clustering was adopted because of its simplicity and general applicability with a widely used algorithm in practice [34]. We first selected *K* initial centroids, where *K* is the user-specified number of clusters desired. In the second step, points were assigned to the updated centroids, and the centroids were updated. Each point was assigned to the closest centroid, and each collection of these points formed a cluster. To assign a point to the closest centroid, we required a proximate measure that quantified the notion of "closest" to the specific data under consideration. The Euclidean distance is often used for data points in a Euclidean space, whereas cosine similarity is more appropriate for documents. The data were analyzed as a percentage and hence did not have a unit and was not standardized. For the objective function, we used the sum of the squared error, which is known as the scattering.

$$SSE = \sum_{i=1}^{K} \sum_{x \in C_i} dist(x, \mu(C_i)) \quad (1)$$

where $\mu(C_i)$ is the centroid of cluster C_i and $dist(x,\mu(C_i))$ is the distance between x and centroid of cluster C_i. Given these assumptions, the centroid that minimizes the *SSE* of the cluster is the mean. Using the notation in Equation (1), the centroid (mean) of the *i*th cluster is defined as follows:

$$c_i = \frac{1}{m_i} \sum_{x \in C_i} x \quad (2)$$

where m_i is the number of objects in the *i*th cluster and m is the number of objects in the data set. In normal practice, the default distance is chosen to be Euclidean distance as

$$d_{euclidean}(x, \mu(C)) = \left[\sum_{i=1}^{d} (x_i - \mu(C)_i) \right]^{\frac{1}{2}} \quad (3)$$

for d-dimensional of the data point.

Steps 3 and 4 of the *K*-means algorithm involve minimizing the *SSE*. In Step 3, clusters are formed by assigning points to their nearest centroid. In Step 4, the centroids are recomposed to further minimize the *SSE*. The approaches of *CH* index, *DB* index, and *SH* index are generally adapted to determine the optimal value of *K* [35]. In this study, *CH* index was applied by the following formula:

$$CH = \frac{SSB/(M-1)}{SSW/(N-M)} \quad (4)$$

where *SSB* is the sum square between cluster variance, *SSW* is the sum square within cluster variance, *N* is 68 in this study, and *M* is a number of clusters [36]. The clustering result of the chemical waste management is displayed according to the mean percentage of each approach. We numbered the clusters with the percentage of the preferred waste management approach. According to the waste management hierarchy established by the Pollution Prevention Act of 1990, the preferred management methods are recycling, followed by burning for energy recovery, treating, and, as a last resort, releasing the waste. Hence, companies classified as Type 1 had high percentages of preferred waste management approaches, and companies classified as Type 4 usually had high percentages of undesirable waste management approaches.

4. Results

4.1. Clustering Analysis

We start with the discussion of clustering results regarding HF, where four types of waste management approaches were clustered. Table 1 lists the average percentage of the HF waste managed by the approaches of on-site released, off-site released, on-site treatment, off-site treatment, recovered, and recycled by each semiconductor manufacturer. The Type 1 category includes companies with the best performance. In their manufacturing processes, more than 65.4% of the chemical waste was recycled, approximately 20% was treated, and approximately 13% was released. Only one company was classified in this category. The Type 2 category includes companies in which an average of 0.3%, 96.8%, and 2.9% of the HF waste was recycled, treated, and released, respectively, during the manufacturing process. Thirty-three of the 37 companies were classified as Type 2, and on-site treatment was the most adopted approach. Only one company was classified as Type 3, and all of its waste was treated off-site. Type 4 companies released all their HF waste on-site without any treatment.

Table 1. Clustering results of the HF waste.

Approach	Type 1	Type 2	Type 3	Type 4
On-site Release	1.6%	2.6%	0%	100%
Off-site Release	11.4%	0.3%	0%	0%
On-site Treated	19.3%	95.9%	0%	0%
Off-site Treated	2.3%	0.9%	100%	0%
Recovery	0%	0%	0%	0%
Recycle	65.4%	0.3%	0%	0%
Number of Companies	1	33	1	2

The NH_3 waste management results are provided in Table 2. The Type 1 category includes companies that had the best management method for NH_3 waste. In these companies, 0.6% of the ammonia waste was recycled, nearly 0.1% was recovered, 62.7% was treated, and 36.6% was released on-site (27.4%) and off-site (9.2%). Five companies treating ammonia waste were classified in this category. In the Type 2 companies, 93% of the ammonia waste was treated, 6.7% was released, and 0.3% was recycled. Of the 21 companies analyzed, 11 were classified in the Type 2 category (52.4% of the observations). These companies used the most efficient method for treating the ammonia waste before disposing of it in the environment. Companies employing suboptimal NH_3 waste management techniques were classified as Type 3, where approximately 45.7% of the ammonia waste was treated on-site, 28% was treated off-site, approximately 26% was released, and only 0.3% was recycled. Five companies were classified in this category.

The clustering results of HNO_3 waste are given in Table 3. Type 1 companies treated 98.9%, recycled approximately 0.1%, and recovered 0.1% of the nitric acid waste. Most companies were classified in the Type 1 category and treated nitric acid waste suitably before discharging it into the environment. Type 2 companies treated 99.3% and released 0.7% of their total HNO_3 waste. One company was classified in this category. Companies using suboptimal HNO_3 waste management techniques were classified as Type 3. In these companies, approximately 90% of total HNO_3 waste was treated, and more than 10% of the waste was released; only one company was classified in this category. The Type 4 category includes companies in which 100% of the HNO_3 waste was released without treatment.

Table 2. Clustering results of the NH_3 waste.

Approach	Type 1	Type 2	Type 3
On-site Release	27.4%	4.5%	12.6%
Off-site Release	9.2%	2.2%	13.4%
On-site Treated	7.7%	85.0%	45.7%
Off-site Treated	55.0%	8.0%	28.0%
Recovery	0.1%	0%	0%
Recycle	0.6%	0.3%	0.3%
Number of Companies	5	11	5

Table 3. Clustering results of the HNO_3 waste.

Approach	Type 1	Type 2	Type 3	Type 4
On-site Release	0.8%	0.7%	10%	0%
Off-site Release	0.1%	0%	0%	100%
On-site Treated	98.1%	56.5%	66.6%	0%
Off-site Treated	0.8%	42.8%	23.4%	00%
Recovery	0.1%	0%	0%	0%
Recycle	0.1%	0%	0%	0%
Number of Companies	32	1	1	1

Table 4 shows the clustering results of waste approaches on NMP. The release category occupied a small proportion of all the clusters, and the release of each cluster was close. Therefore, the degree of discrimination was low and thus ignored. The Type 1 category includes companies that recycled 73.6%, recovered 5.2%, treated less than 13% and released 0.9% of their NMP waste. The Type 2 category includes companies with suboptimal NMP waste management: these companies recovered 80%, recycled less than 5%, treated approximately 10%, and released 5% of their total NMP waste. The Type 3 category includes companies that treated 84%, recovered approximately 8%, and released approximately 8% of the NMP waste. The analysis of 30 companies provided a relatively uniform classification result. Table 4 indicates that all companies treated the chemical wastes released by them during semiconductor manufacturing. Ten companies were classified as Type 1, fifteen companies were classified as Type 2, and four companies were classified as Type 3.

Table 4. Clustering results of the NMP waste.

Approach	Type 1	Type 2	Type 3
On-site Release	9.0%	5.2%	6.9%
Off-site Release	0%	0.2%	1.0%
On-site Treated	10.5%	6.0%	2.5%
Off-site Treated	1.7%	3.3%	81.9%
Recovery	5.2%	81.0%	7.6%
Recycle	73.6%	4.3%	0.0%
Number of Companies	11	15	4

Additionally, we also analyzed the waste management approaches of HCl waste and summarize its clustering results Table 5. One company was classified as Type 1, which treated on-site 74.3%, recycled approximately 4.5%, and released 21.2% of the HCl waste. Type 2 companies recycled 0.5%, treated 96.7% and released 2.7% of their total HCl waste. Most companies were classified in the Type 2 category and treated HCl waste suitably before discharging it into the environment. In type 3 companies, more than 48% of total HCl waste was treated on-site, and approximately 52% of the waste was released; only one company was classified in this category.

Table 5. Clustering results of the HCl waste.

Approach	Type 1	Type 2	Type 3
On-site Release	21.2%	2.7%	51.9%
Off-site Release	0%	0%	0%
On-site Treated	74.3%	95.9%	48.1%
Off-site Treated	0%	0.8%	0%
Recovery	0%	0%	0%
Recycle	4.5%	0.5%	0%
Number of Companies	1	17	1

The NO_x waste management results are provided in Table 6. The Type 1 category includes companies that had the best management method for NO_x waste. In these companies, 74.2% of NO_x waste was recycled, and 25.8% was released. These companies used the most efficient method for recycling the NO_x waste before disposing of it in the environment; 24 companies (80% of the observations) treating NO_x waste was classified in this category. In Type 2 companies, 92.6% of NO_x waste was treated, 20% was on-site released and 7.2% was off-site released. Of the 30 companies analyzed, 2 were classified in the Type 2 category. Companies employing suboptimal NO_x waste management techniques were classified as Type 3, where approximately 25.4% of the NO_x waste was treated on-site and 84.5% was released on-site (74.5%) and off-site (10%); only one NO_x waste management company was classified in this category. The Type 4 category includes companies in which 100% of the NO_x waste was released without treatment.

Table 6. Clustering results of the NO_x waste.

Approach	Type 1	Type 2	Type 3	Type 4
On-site Release	0%	20%	74.5%	0.1%
Off-site Release	25.8%	7.2%	10%	99.9%
On-site Treated	0%	0%	25.4%	0%
Off-site Treated	0%	92.6%	0%	0%
Recovery	0%	0%	0%	0%
Recycle	74.2%	0%	0%	0%
Number of Companies	24	2	1	3

The clustering results of H_2SO_4 waste are given in Table 7. Sixteen companies (88.9% of observations) were classified as Type 1, which treated 98.7% and released 1.3% of the H_2SO_4 waste. Most companies were classified as Type 1, and treated H_2SO_4 waste suitably before discharging it into the environment. Type 2 companies treated 49.9% and released 5.1% of their total H_2SO_4 waste. One company was classified in this category. The Type 3 category includes companies in which approximately 31% of total H_2SO_4 waste was treated, and more than 69% of the waste was released.

Table 7. Clustering results of the H_2SO_4 waste.

Approach	Type 1	Type 2	Type 3
On-site Release	1.3%	50.1%	69.4%
Off-site Release	0%	0%	0%
On-site Treated	98.7%	49.9%	30.6%
Off-site Treated	0%	0%	0%
Recovery	0%	0%	0%
Recycle	0%	0%	0%
Number of Companies	16	1	1

4.2. Clustering Results by City and Company

To understand the clustering results from the perspectives of cities and companies, we summarized each company's waste management performance for HF, NH_3, HNO_3, NMP, HCl, NO_x, and H_2SO_4 in relation to geographical location in Table 8. According to our analysis, San Jose (CA, USA), Phoenix (AZ, USA), Sunnyvale (CA, USA), and Austin (TX, USA) had the highest number of semiconductor companies. Regarding the waste management of HF, only one company, located in El Segundo (CA, USA), was classified in the best performance category (Type 1). Two companies, located in Santa Clara and Milpitas, were classified in the worst performance category (Type 4). For NH_3 waste management, five companies, located in Chandler (AR, USA), San Jose, Woburn, and Austin, were classified in best performance category (Type 1). Moreover, five companies, located in San Jose, Santa Clara, Austin, Sherman (TX, USA), and Vancouver (WA, USA), were classified in the worst performance category (Type 3). For the waste management of HNO_3, 91.4% of the analyzed companies were classified in the best performance category. San Jose had the highest number of semiconductor companies as well as the highest number of companies in top performance categories. The worst performing company (Type 4) is located in Richardson (TX, USA). According to the results of the *N*-methyl-2-pyrrolidone waste treatment, four companies were classified in the worst performance category (Type 3). These companies are located in Phoenix, San Diego (CA, USA), Boise (ID, USA), and Austin. For HCl waste management, one company, located in Austin, were classified in best performance category (Type 1). Meanwhile, one company, located in Chandler—was classified in the worst performance category (Type 3). For the waste management of Nitrate (NO_3) compounds, 80% of the analyzed companies were classified in the best performance category. San Jose had the highest number of semiconductor companies and also the highest number of companies in the top performance categories. The three worst performing companies (Type 4) are located in Foster (CA, USA), Portland (MA, USA) and Youngwood (PA, USA). Based on the results of the H_2SO_4 waste treatment, only one company were classified in the worst performance category (Type 3). This company is located in Santa Clara. Most companies (nearly 90% of analyzed companies) were classified in the best performance category. San Jose had the highest number of companies in the best performing categories.

From the perspective of the company, Table 8 shows that there is one company, namely Samsung Austin Semiconductor, which was classified as the best performer for the management of five chemical wastes (NH_3, HNO_3, HCl, NO_3, and H_2SO_4). Moreover, Fairchild Semiconductor was listed as a suboptimal best performer because it manages well with four types of chemical waste: NH_3, HNO_3, NO_3, and H_2SO_4. Eleven companies were classified as the best performers for the management of three chemical wastes, including Sumco Phoenix Corp., On Semiconductor (Phoenix, AR, USA), Avalog Device Inc. (Wilmington, MA, USA), and Wafertech LLC. (Camas, WA, USA); In this group, Texas has two companies—Texas Instrument Inc. (Sherman, TX, USA), Freescale Semiconductor (Austin, TX, USA)—and California has five: Globalfoundries U.S. Inc. (Santa Clara, CA, USA), Microchip Technology Inc. (San Jose, CA, USA), International Rectifier Corp. (El Segundo, CA, USA), TSI Semiconductors LLC. (Roseville, CA, USA), and Spansion Inc. (Sunnyvale, CA, USA). Apart from this, thirteen companies were grouped in the best performance category for the management of at least two chemical wastes. For example, Sanyo N.A. (Forrest, AR, USA), First Solar (Tempe, AR, USA), Emcore Corp. (Alhambra, CA, USA), Voltage Multipliers Inc. (Visalia, CA, USA), Hewlett-Packard Co. (San Diego, CA, USA), Seh America Inc. (Vancouver, WA, USA), Micron Technology Inc. (Boise, ID, USA), Vishay Intertechnology (Malvern, PA, USA), Sunedison Inc. (El Segundo, CA, USA), and Electronic Devices Inc. (Yonkers, NY, USA) comprised the benchmark group for the management of HNO_3 and NO_x waste. IBM Corp. (Foster, CA, USA) was classified in the best performance category for HNO_3 and H_2SO_4 waste management. Voltage Multipliers Inc. (Visalia, CA, USA) and Philips N.A. (Andover, MA, USA) are two of the best performers for Nitrate (NO_3) compounds and HNO_3 waste management. Diodes Inc. (San Jose, CA, USA) is the best performer for the management of NO_x and H_2SO_4 waste. With only one analyzed chemical waste, there are six companies that always showed their best performance in waste management: Innovative Micro Technology (Goleta, CA, USA), Global Communication Semiconductor LLC. (Torrance, CA, USA), and M/A-Com Inc. (Lowell, MA, USA) outperformed for NMP wastes, whereas Truesense Imaging Inc. (Rochester, NY, USA), Honeywell International Inc. (Morristown, NJ, USA), X-Fab Foundries Ag. (Lubbock, TX, USA) outperformed for H_2SO_4 chemical wastes. On the other hand, five companies were classified in the lagging group for their chemical manufacturing, namely E. I. du Pont de Nemours & Co. (Wilmington, DE, USA), Flipchip International LLC. (Phoenix, AR, USA), Micrel Semiconductor (San Jose, CA, USA), Qualcomm Corp. (San Diego, CA, USA), and Cleanpart U.S (Richardson, TX, USA). Moreover, some companies exhibited both the best and the worst performance for chemical treatment. Atmel Corp (Chandler, AR, USA) used the best methods to treat NH_3 waste but the worst methods to treat HCl waste. Micron Technology Inc. (Boise, ID, USA) was classified in the best performance category for HNO_3 and HCl waste management and the worst performance category for NMP waste management. The waste management performance of Intersil Corp. (Milpitas, CA, USA) was the best for NMP and the worst for HF. Furthermore, Globalfoundries U.S. Inc. (Santa Clara, CA, USA) showed the best performance for HNO_3, NO_x, and H_2SO_4, but a lag performance for NH_3. Freescale Semiconductor (Austin, TX, USA) is the best performer for HNO_3, NO_x and H_2SO_4 waste management and simultaneously the worst performer for NMP waste management. With the best performance for HNO_3 waste management and the worst performance in NO_x waste management, Siltronic Corp. (Portland, MA, USA) was classified in this benchmark. Spansion Inc. (Sunnyvale, CA, USA) was the best for HNO_3, NO_x and H_2SO_4 and the worst for NH_3. Seh America Inc. (Vancouver, WA, USA) was classified in the best performance category for HNO_3 and NO_x waste management, and the worst performance category for NH_3 waste management. In addition, Intel Corp. (Santa Clara, CA, USA) exhibited a strong performance for HNO_3 waste management and a poor performance of waste management for two chemicals such as HF and H_2SO_4.

Table 8. Clustering results of chemical waste approaches by company.

State	City	Company	Chemicals						
			HF	NH_3	HNO_3	NMP	HCl	NO_x	H_2SO_4
AR	Forrest	Sanyo N.A.	2		1			1	
	Tempe	First Solar			1			1	
	Chandler	Atmel Corp.	2	1			3		2
	Phoenix	Sumco Phoenix Corp.	2		1	1	2	1	
		Flipchip International LLC.				3			
		On Semiconductor	2	2	1			1	1
CA	Alhambra	Emcore Corp.			1			1	
	San Jose	Cypress Semiconductor	2	3					
		Diodes Inc.			3	2	2	1	1
		Fairchild Semiconductor Corp.	2	1	1		2	1	1
		Maxim Integrated Products Inc.	2		1	2			
		Micrel Semiconductor	3						
		Microchip Technology Inc.	2	1	1			1	
	Visalia	Voltage Multipliers Inc.			1			1	
	Santa Clara	Globalfoundries U.S. Inc.	2	3	1		2	1	1
		Intel Corp.	4	2	1	2	2		3
	Sunnyvale	Spansion Inc.	2						
		Infinera Corp.				2			
		Alpha & Omega Semiconductor	2				2		
	San Diego	Qualcomm Corp.				3			
		Hewlett-Packard Co.	2		1			1	
	El Segundo	International Rectifier Corp.	1		1		2	2	1
		Sunedison Inc.	2		1		2	1	
	Milpitas	Intersil Corp.	4			1			
		Linear Technology Corp.	2						1
	Roseville	TSI Semiconductors LLC.	2		1			1	1
	Goleta	Innovative Micro Technology				1			
	Torrance	Global Communication Semiconductor LLC.				1			
	San Francisco	Bridgelux		2					
	Foster	IBM Corp.	2	2	1	2	2	4	1

Table 8. *Cont.*

State	City	Company	Chemicals						
			HF	NH_3	HNO_3	NMP	HCl	NO_x	H_2SO_4
CO	Colorado Springs	DPIX LLC.				2			
DE	Wilmington	E. I. du Pont de Nemours & Co.						3	
GE	Norcross	Suniva Inc.	2						
ID	Boise	Micron Technology Inc.	2		1	3		1	
IL	Chicago	The Boeing Co.		2		1			
IO	Iowa	Newport Fab LLC (DBA Towerjazz)	2	2	1				
MA	Andover	Philips N.A.		2	1			1	
	Woburn	Skyworks Solutions Inc.		1		1	2		
	Wilmington	Analog Devices Inc.	2		1	1	2		1
	Portland	Siltronic Corp.			1		2	4	
	Lowell	M/A-Com Inc.				1			
	Waltham	Perkinelmer Inc.				2			
	New Bedford	North East Silicon Technologies Inc.	2		1				
MI	Durham	General Motors LLC.	2						
MN	Yonkers	Polar Semiconductor LLC.	2			2	2		
NC	Greensboro	RF Micro Devices Inc.				1			
	Durham	Cree Inc.	2	2	2	2			
NY	Rochester	Truesense Imaging Inc.							1
	Yonkers	Electronic Devices Inc.	2		1			1	
	New York	Toshiba America Inc.		2					
		L3 Communications Holdings Corp.				2			
NJ	Morristown	Honeywell International Inc.							1
OR	Portland	Siltronic Corp	2						
	Hillsboro	TriQuint Semiconductor				2			
		SolarWorld Ag	2	2	1			2	
PA	Malvern	Vishay Intertechnology	2		1	2		1	
	Youngwood	Powerex Inc.	2		1			4	
	Mendota Heights	Avago Technologies	2			1			
TX	Austin	Samsung Austin Semiconductor		1	1	2	1	1	1
		Freescale Semiconductor	2		1	3	2	1	1
		Spansion Inc.		3	1			1	1
	Richardson	Cleanpart U.S			4				
	Allen	Okmetic Inc.					2		
	Lubbock	X-Fab Foundries Ag.							1
	Sherman	Texas Instruments Inc.		3	1	2	2	1	1
WA	Vancouver	Seh America Inc.	2	3	1		2	1	
	Camas	Wafertech LLC.	2	2	1	1		1	
	Bellevue	Emagin Corp.				2			

4.3. Discussion

To further understand the differences between the best performance cluster and the worst performance cluster, we compared the waste management approaches adopted by the best performing company and the worst performance company for each chemical in Table 9. Regarding the waste of HF, International Rectifier was the best performer in Type 1, having recycled 65.4% of the waste, while Intel was the worst performer, having recycled only 0.6% of the waste. With regard to NH_3, the best performer, Samsung Austin Semiconductor, only released 10.4% of the waste onsite. However, the worst performer, Cypress Semiconductor, released 31% of NH_3 wastes. Regarding HNO_3, Cleanpart U.S was listed as the worst performer, because it released 100% of the waste offsite. On the other hand, Samsung Austin Semiconductor, was classified in Type 1, which recycled 0.3%, recovered 2.9%, treated 93.5% and released 3.3% of total disposal waste. With regard to NMP, Avago Technologies recycled 97% of chemical wastes, while Flipchip treated nearly 82% of NMP waste offsite. For HCl, Samsung Austin Semiconductor was the best Type 1 performer, with more than 74% of waste using treatment approach. However, Atmel Corp, the worst performer, treated 48.1% onsite and released 51.9% of waste onsite. First Solar, a Type 1 company regarding NO_x, treated 100% of NO_x offsite. Siltronic Corp was a Type 4 company, having released 100% of the NO_x. In terms of H_2SO_4, Truesense Imaging Inc.

was the best performer, with 100% of the waste treated onsite. Intel was the worst performer which treated 30.6% of the wastes onsite and released 69.4% of the waste onsite.

Table 9. Comparisons between the best performance company and the worst performance company by chemical waste.

Chemical Waste	Approach / Company	Onsite Release	Offsite Release	Onsite Treated	Offsite Treated	Recovery	Recycle
HF	International Rectifier Corp.	1.60%	11.40%	19.30%	2.30%	0.00%	65.40%
	Intel Corp.	0.60%	0.00%	99.40%	0.00%	0.00%	0.00%
NH_3	Samsung Austin Semiconductor	10.40%	32.40%	5.30%	48.30%	0.40%	3.30%
	Cypress Semiconductor	31.00%	0.00%	30.30%	38.70%	0.00%	0.00%
HNO_3	Samsung Austin Semiconductor	0.60%	2.70%	93.50%	0.00%	2.90%	0.30%
	Cleanpart U.S	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%
NMP	Avago Technologies	2.00%	0.00%	0.00%	0.00%	1.00%	97.00%
	Flipchip International LLC.	18.20%	0.00%	0.00%	81.80%	0.00%	0.00%
HCl	Samsung Austin Semiconductor	21.20%	0.00%	74.30%	0.00%	0.00%	4.50%
	Atmel Corp.	51.90%	0.00%	48.10%	0.00%	0.00%	0.00%
NO_x	First Solar.	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
	Siltronic Corp.	99.70%	0.30%	0.00%	0.00%	0.00%	0.00%
H_2SO_4	Truesense Imaging Inc.	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
	Intel Corp.	69.40%	0.00%	30.60%	0.00%	0.00%	0.00%

According to the clustering result for HF waste management, most companies were classified in the second-best performance group, in which 96% of the chemical waste was treated on-site. Two companies, located in Santa Clara and Milpitas (CA, USA) were classified in the worst performance category: they released 100% of their chemical waste directly into the environment without any treatment. Although the Santa Clara government created the Office of Sustainability in April 2010 and committed itself to maintaining ecological integrity, our results indicate that improvements are still required. According to the results for the waste management of NH_3, most companies were classified as Type 2 and recycled approximately 75% of their ammonia waste. Two companies classified in the worst performance category for ammonia waste management are located in Texas. Regarding HNO_3 waste, most companies were classified in the best performance category, because they treated nearly 98% of their waste on-site and released only 0.8% without treatment. Only one company, located in Richardson (TX, USA), exhibited a poor performance and did not treat the nitric acid waste after manufacturing. Texas has a strict environmental policy through laws and regulations passed at all governmental levels. It spent US$356.6 million on its environmental and natural resources departments in the fiscal year 2015 [37]. However, our results indicate that the Texas government may need to provide stricter controls on nitric acid waste for semiconductor manufacturing. The results of the waste treatment of NMP indicated that most companies used a combined approach of onsite and offsite treatment. The onsite and offsite release approaches were also popular among the semiconductor companies, because NMP usually does not present a significant risk to the environment [38]. As for the clustering result for HCl waste management, most companies were classified in the second-best performance group, in which 96.7% of the chemical waste was treated on-site (95.9%) and off-site (0.8%). One company, located in Austin (TX, USA) was the best performer, with more than 74% of total chemical waste treated before discharging into the environment. One company, located in Chandler (AR, USA), was classified in the worst performance category: they released 51.9% of their chemical waste directly into the environment without any treatment. In the past, Arizona seemed to not put too much of effort on sustainability [39]. In 2015, Arizona spent $208.2 million in its Environmental Quality and Game and Fish departments [40]. Our results indicate that waste control policies of HCl should be monitored in this area. In addition, the results of the waste treatment of NO_x indicated that 24 companies (80% of analyzed companies) were classified into the best performing group, using recycling approaches for 74.2% of total wastes and off-site releasing for 25.8% of total nitrate compounds wastes. There are three companies listed in the worst-performance category located in Foster (CA, USA), Portland (MA, USA) and Youngwood (PA, USA). Although MA and PA have their own policy to protect the environment and allocated US$1.4 billion and US$7.1 billion respectively in fiscal 2015 [41], there is still room for improvement when it comes to the waste management policy on NO_x. Based on results for the waste management of H_2SO_4, 88.9% of analyzed companies were classified as Type 1 and treated approximately 99% of their H_2SO_4 waste. One company classified in the worst performance category for H_2SO_4 waste management; it is located in Santa Clara, CA, USA.

5. Conclusions

In the semiconductor industry, environmental sustainability during the research, development, and manufacturing of products is crucial. Companies have attempted different approaches to treat their chemical wastes and are searching for efficient waste management approaches to reduce energy costs. In this research, a benchmarking method is proposed to evaluate the chemical waste management performance of semiconductor manufacturers. To the best of our knowledge, this study is the first to address waste management from the perspective of waste management approaches in relation to company locations. Cluster analysis was adopted in this study to classify the U.S. semiconductor companies into different performance groups according to their waste management approaches. The results indicate how each chemical was managed and which companies used the best chemical waste management techniques, which may be referred to by the poorly performing manufacturers. In addition, our results indicate that two companies were classified in the best performance category for the waste management of four or more chemicals. Eleven companies were listed as the best performers for the management of three chemical wastes. Thirteen companies were grouped in best performance category for the management of at least two chemical wastes. With only one analyzed chemical waste, there were six companies that always showed their best performance in waste management, while five companies were classified in the lagging group for their chemical manufacturing. Moreover, eleven companies exhibited both the best and worst performance for chemical treatment, depending on the particular chemical. One company was classified in the worst performance categories for at least two chemical wastes. Semiconductor companies can refer to our results to determine their performance and which companies they should benchmark regarding chemical waste management. City governments can also refer to our results to employ suitable policies to reduce the negative impacts of the chemical waste from regional semiconductor companies.

This research still has some limitations to overcome. For example, the methodology presented here is suitable and useful only for those countries that have a Pollutant Release and Transfer Register (PRTR) disclosure system in place, such as the Toxics Release Inventory in the USA. The waste management results from different countries with the PRTR system can be compared to understand the current global situation. Future research can analyze the management of other chemical wastes. Moreover, other performance evaluation methods, such as data envelopment analysis, can be used to determine the efficiency of waste management approaches.

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References

1. World Semiconductor Trade Statistics. More Than 25 Years Authentic Market Monitoring by Wsts. Available online: https://www.wsts.org/ (accessed on 16 March 2017).

2. Shin, C.-H.; Ju-Yup, K.; Jun-Young, K.; Hyun-Sang, K.; Hyang-Sook, L.; Debasish, M.; Jae-Woo, A.; Jong-Gwan, A.; Bae, W. A solvent extraction approach to recover acetic acid from mixed waste acids produced during semiconductor wafer process. *J. Hazard. Mater.* **2009**, *162*, 1278–1284. [CrossRef] [PubMed]
3. De Luna, M.D.G.; Warmadewanthi; Liu, J.C. Combined treatment of polishing wastewater and fluoride-containing wastewater from a semiconductor manufacturer. *Colloids Surf. A Physicochem. Eng. Asp.* **2009**, *347*, 64–68. [CrossRef]
4. Heaslip, G. Services operations management and humanitarian logistics. *J. Hum. Logist. Supply Chain Manag.* **2013**, *3*, 37–51. [CrossRef]
5. Jun, I. Low Temperature Voc Recovery Method for Performing Removal of Moisture and Recovery of Cold Using Adsorbent. Japanese Patent 161743, 17 July 2008.
6. Junichi, M.; Zenichi, T.; Hideji, K.; Masahiro, T. Solvent Recovering Apparatus. Japanese Patent 208038, 17 September 2009.
7. Hsu, C.-W.; Hu, A.H.; Chiou, C.-Y.; Chen, T.-C. Using the FDM and ANP to construct a sustainability balanced scorecard for the semiconductor industry. *Expert Syst. Appl.* **2011**, *38*, 12891–12899. [CrossRef]
8. Lee, T.-C.; Liu, F.-J. Recovery of hazardous semiconductor-industry sludge as a useful resource. *J. Hazard. Mater.* **2009**, *165*, 359–365. [CrossRef] [PubMed]
9. Won, C.-H.; Choi, J.; Chung, J. Evaluation of optimal reuse system for hydrofluoric acid wastewater. *J. Hazard. Mater.* **2012**, *239–240*, 110–117. [CrossRef] [PubMed]
10. EG. How the Semiconductor Industry Is Becoming Greener. Available online: https://www.wateronline.com/doc/how-the-semiconductor-industry-is-becoming-a-greener-industry-0001 (accessed on 2 March 2017).
11. Vogel, K. Metals Reclaim Using an Electrowinning Process. Available online: www.unh.edu/p2/nhppp/reports/p2i00kvf.doc (accessed on 2 March 2017).
12. Brown, P.G.; Mason, H.T. Electrowinning of nickel at the bindura smelting and refining company. *J. S. Afr. Inst. Min. Metall.* **1977**, *7*, 143–145.
13. CSG. Solvent Extractants. Available online: https://www.cytec.com/businesses/in-process-separation/mining-chemicals/products/solvent-extractants (accessed on 15 March 2017).
14. Villard, A.; Lelah, A.; Brissaud, D. Drawing a chip environmental profile: Environmental indicators for the semiconductor industry. *J. Clean. Prod.* **2015**, *86*, 98–109. [CrossRef]
15. EPA. Sustainable Materials Management: Non-Hazardous Materials and Waste Management Hierarchy. Available online: https://www.epa.gov/smm/sustainable-materials-management-non-hazardous-materials-and-waste-management-hierarchy (accessed on 15 March 2017).
16. Zant, P.V. *Microchip Fabrication: A Practical Guide to Semiconductor Processing*; McGraw-Hill: New York, NY, USA, 1997; p. 623, ISBN 978-0071821018.
17. Denko, S. Showa Denko Strengthens High-Purity Hydrogen Fluoride Supply System—Coping with Increasing Range of hf's Use in Semiconductor Production. 2015. Available online: http://www.sdk.co.jp/english/news/14436/14456.html (accessed on 21 April 2017).
18. Chuang, T.-C.; Huang, C.J.; Liu, J. Treatment of semiconductor wastewater by dissolved air flotation. *J. Environ. Eng.* **2002**, *128*, 974–980. [CrossRef]
19. OPHPR. Facts about Hydrogen Fluoride (Hydrofluoric Acid). Available online: https://emergency.cdc.gov/agent/hydrofluoricacid/basics/facts.asp (accessed on 22 April 2017).
20. Agency, S.E.P. Ammoniac. Available online: http://apps.sepa.org.uk/spripa/Pages/SubstanceInformation.aspx?pid=1 (accessed on 1 February 2017).
21. Microchemicals. Nitric Acid. Available online: https://www.microchemicals.com/products/etchants/nitric_acid_hno3.html (accessed on 5 February 2017).
22. Zdrazil, T. The Dangers of a Nitric Acid Chemical Spill. Available online: https://www.absorbentsonline.com/spill-containment-blog/the-dangers-of-a-nitric-acid-chemical-spill/ (accessed on 23 December 2017).
23. SIA. SIA Comments on the Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: *N*-methylpyrrolidone (NMP). Available online: https://www.semiconductors.org/clientuploads/directory/DocumentSIA/Environment/SIA%20Comments%20to%20EPA%20on%20N-Methylpyrrolidone%20(NMP)%20March%2015,%202017.pdf (accessed on 20 March 2017).
24. EPA. Scope of the Risk Evaluation for *N*-Methylpyrrolidone. Available online: https://www.epa.gov/sites/production/files/2017-06/documents/nmp_scope_6-22-17_0.pdf (accessed on 5 June 2017).

25. PREVOR. What Kind of Splashes in Semiconductors Industry? Available online: http://www.prevor.com/en/chemical-risks-in-semiconductors-industry (accessed on 3 February 2017).
26. Haynes. Hastelloy® C-22® Alloy for HCl in Semiconductor Manufacturing. Available online: http://haynesintl.com/tech-briefs/corrosion-resistant-alloys/corrosion-resistant-alloy-applications/hastelloy-c-22-alloy-for-hcl-in-semiconductor-manufacturing-(H-2053) (accessed on 20 March 2017).
27. Purchiaroni, J. What Are the Dangers of Hydrochloric Acid to Humans? Available online: https://healthyliving.azcentral.com/what-are-the-dangers-of-hydrochloric-acid-to-humans-12506828.html (accessed on 30 September 2017).
28. EPA. Toxics Release Inventory. Available online: https://www.epa.gov/sites/production/files/documents/2000nitrates.pdf (accessed on 30 December 2017).
29. Health. Nitrates and Their Effect on Water Quality—A Quick Study. Available online: http://www.wheatleyriver.ca/media/nitrates-and-their-effect-on-water-quality-a-quick-study/ (accessed on 24 July 2017).
30. Ogata, H.; Tanaka, N. Reduction of waste in semiconductor manufacturing plant (sulfuric acid recycling technology). *Spec. Issue Glob. Environ. Oki Tech. Rev.* **1998**, *63*, 41–44.
31. NPI. Sulfuric Acid. Available online: http://www.npi.gov.au/resource/sulfuric-acid (accessed on 26 May 2017).
32. EPA. Tri Data and Tools. Available online: https://www.epa.gov/toxics-release-inventory-tri-program/tri-data-and-tools (accessed on 26 May 2017).
33. McCaffrey, J. Test Run—Data Clustering Using Category Utility. Available online: https://msdn.microsoft.com/en-us/magazine/dn198247.aspx (accessed on 25 May 2017).
34. Tan, P.N.; Steinbach, M. *Data Mining Cluster Analysis: Basic Concepts and Algorithms*; Pearson: London, UK, 2005.
35. Chui, K.; Tsang, K.; Chung, S.; Yeung, L. Appliance signature identification solution using k-means clustering. In Proceedings of the IECON 2013—39th Annual Conference of the IEEE Industrial Electronics Society, Vienna, Austria, 10–13 November 2013; pp. 8420–8425.
36. Gungor, V.C.; Sahin, D.; Kocak, T.; Ergut, S.; Buccella, C.; Cecati, C.; Hancke, G.P. A survey on smart grid potential applications and communication requirements. *IEEE Trans. Ind. Inform.* **2013**, *9*, 28–42. [CrossRef]
37. Ballotpedia. Environmental Policy in Texas. Available online: https://ballotpedia.org/Environmental_policy_in_Texas (accessed on 15 June 2017).
38. Åkesson, B. *N*-methyl-2-pyrrolidone. Available online: http://www.who.int/ipcs/publications/cicad/en/cicad35.pdf (accessed on 26 May 2017).
39. Melnick, R. Sustainability for Arizona the Issue of Our Age. Available online: https://morrisoninstitute.asu.edu/sites/default/files/content/products/APC2007_Sustainability-IssueOfOurAge.pdf (accessed on 11 November 2017).
40. Ballotpedia. Environmental Policy in Arizona. Available online: https://ballotpedia.org/Environmental_policy_in_Arizona (accessed on 26 May 2017).
41. Pedia, B. Environmental Spending in the 50 States. Available online: https://ballotpedia.org/Environmental_spending_in_the_50_states (accessed on 26 May 2017).

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Sustainability in Smart Farms: Its Impact on Performance

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Abstract: In Spain, more than 30% of producers have run out of business because of a lack of sustainability. They search for managerial guidelines that allow them to reach the farm's economic viability. When trying to improve the performance of farms and farming systems, a complementary consideration of sustainability dimensions is required. The aim of this paper consists of offering a complementary and integrative approach from the sustainability concept in four different dimensions: economic; technological; organizational; and training in Manchego Cheese Protected Designation of Origin (PDO). Sustainability through the putting into practice of some managerial concepts has been able to reach better results and smarter farms. To perform this study, metrics to analyze each of the mentioned dimensions of sustainability have been applied to a sample of 157 farms with the main objective to identify the sustainability dimensions and its impacts on farm's final results promoting smarter farms. The Structural Equation Model (SEM) has been applied to measure the impact of each dimension of sustainability on final farm's results. Results reported that the farm's economic and organizational sustainability have been influenced by the returns on investment.

Keywords: protected designation of origin (PDO); farms; smart villages; economic sustainability; technological sustainability; organizational sustainability and training sustainability

1. Introduction

Sustainability is a concept first coined in ecology. It is composed by both, sustain and ability, and it is a property of systems to remain diverse and productive on time [1]. The term 'sustainability' should be viewed as humanity's target goal of human-ecosystem equilibrium (homeostasis), while 'sustainable development' refers to the holistic approach and temporal processes that lead us to the end point of sustainability [2]. Moreover, bio economy is a managerial tool for sustainability. The European Commission indicates that bio economy is aimed to reach sustainable socio-economic development, through an efficient use of natural resources [3]. Spain chose a policy model of "sustainable intensification", with a direct application in search of "smart farms". Smart farms are accurate farms oriented to increase efficiency and reduce the environmental impacts of animal production practices. Farms must learn to implement technology properly to minimize cost and maximize efficiency [4].

This holistic approach of sustainability has to do with properly combining different skills and/or firm's abilities to reach economic, technological, organizational, and training sustainability. Some researchers have linked sustainability with smarter production, smarter services, smarter environments and opportunities, and economic advantages [5–9].

Economic sustainability refers to the ability of an economy to support a defined level of economic production indefinitely. It is oriented to the analysis of the environment to understand customer needs better than competitors [10]. Technological sustainability refers to a more valuable use of technologies to reach best objectives and greatly reduce ecological impact among other technological benefits. It is referred to as the ability to integrate various interaction routines through interrelation with technologies [11]. Organizational sustainability refers to ensuring the sustainability of the organization concerning efforts to incorporate sustainability considerations into strategic and operational decision-making processes [12]. Training sustainability refers to a process that increases knowledge and sharpens skills, enhancing employee performance. Sustainability training helps improve staff and management's knowledge of sustainability issues, as well as to develop their skills for managing a company sustainably [13,14].

This research offers a complementary and integrative approach to previous analysis by offering an exploration from the sustainability concept in four different dimensions: economic, technological, organizational, and training. Sustainability can explain the reasons why some farms through putting into practice some managerial concepts have been able to reach better results and therefore can be considered as smart farms. It is important to analyze and identify what are the main differences amongst farms in terms of sustainability. More sustainable farms can become an inspiration for the others in the drive to become smarter rural ecosystems [1,10].

The empirical analysis is applied to the PDO (Protected Designation of Origin) cheese brand in Castilla-La Mancha, Spain. This product generates over 55% of the economic value of this kind or products in Spain. However, more than 30% of producers have run out of business because of lack of sustainability. The PDO award purports the maximum international recognition of quality within the UE. Manchego Cheese PDO links a quality product to a territory and a traditional and sustainable production system. It is also a guarantee of food safety and food processing. The strategic value of this PDO lies in the perception of quality by the consumer. This is a determining factor in the purchase decision [3,12,15].

Literature in this regard, as [15–17], reduces the dimensions of variables by applying multivariate analysis (factor and principal components analysis). Schader et al. [2], Rangel et al. [4] and Spangenberg [10] building management and sustainable indicators by using a participative and consensus methodology; Ramdhani et al. [18], advanced in systematic analysis of trade-offs and synergies between sustainability dimensions; Van Hooft & Wollen [19] and Angón et al. [20] developed a methodology to choose semi-quantitative signals based on expert ranking decisions. Dealing with the validation of indicators, Chou & Chen [21] proposed the use of canonical correlation and evaluated the impact of indicators on final results. Opposite to the literature described in previous sentences, in this research the use of Structural Equation Model (SEM) is proposed to validate models defining causal relationships amongst variables. SEM analysis presents a great potential for exploratory analysis and goes in deep into the analysis of dependency, multiple and cross relations amongst latent variables, considering simultaneously, the measurement error of the estimation process.

The research question we try to answer is: does the implementation of sustainable practices, from the economic, technological, organizational, and training perspectives allow smart farms to reach best results? Therefore, the main objective of this research consists of analyzing the causal relationships among different dimensions of sustainability and final results at farms. From the empirical perspective, data have been collected from farms belonging to the sheep system in Castilla-La Mancha region, Spain. Unlike previous publications, in this article, as a first exploratory approach, SEM methodology has been applied, to deepen the knowledge of the four dimensions of a smart farm's sustainability. In the following paragraph, the theoretical framework is presented.

2. The Theoretical Framework

To analyze the effect of sustainability on farm's results, a brief description and a way of measuring each of the sustainability dimensions are considered in this analysis. Economic, technological, organizational, and training sustainability are described. As previously mentioned, these sustainability dimensions have been considered in the literature but, to our knowledge, an integrative approach of the four has not been built so far.

2.1. Economic Sustainability

Economic sustainability refers to the firm's ability to diagnose the environment and understand the customer needs better than their competitors [14,15]. The capability of firms to get adapted to markets is a key issue to reach economic sustainability and because of that, firms must be aware of the environment and customer's needs [16,17]. Ikerd [3] describe how the firm's capability to get adapted to different markets is key. The authors of Lozano [13] and Ramdhani et al. [18], describe that the market product's target shows the capability of the organization to get adapted, since the spread of markets and products is the capability result to respond to external opportunities. Therefore, the marketing from farms of products such as lambs, rams, live females and males, cheese, wool, manure, and different cheese varieties implies that previously a segment of customers demanding these products has been identified. The same happens with the direct commercialization to consumer or wholesaler, since an opportunity has been identified by widen customers and therefore increasing the activity field.

Smallholders live on the threshold of poverty, within fragile ecological systems showing a high degree of marginalization. Small-scale livestock provides resilience capability, increases the level of diversification and strengthens synergies among activities [19]. Mixed crop-livestock system, with a part of grazing native pasture and crop residues on communal lands, within a multifunctional livestock are frequent [1]. Milk production and quality depends on sheep's feeding, as it is the case of the use of pastures, by making use of the natural resource coming from land. In the same way, ref. [4] relate intrinsic quality and nutritional milk content with the kind of animal management. The animal feeding relies on grass for the roughage, crop residues, by-products, and other local roughage that represent the major source of feed utilized in this livestock system. The Food and Agriculture Organization of the United Nations (FAO) [1] and Angón et al. [20] indicate that the use of endogenous resources contributes to sustainable livestock, mitigates environmental problems; reduces the dependence of external inputs and decreases production cost, increasing the system's resilience [1].

Economic planning helps satisfying customer's needs by means of the development of products. Planning reproduction implies a market analysis, determining how many animals would be required so that customers can value the final product. This way, reproduction planning would facilitate the exploration of future customer's needs. The planning of any organizational process is based in the initial detection of customer's needs with the main objective to reach firm's strategic objectives. Lozano [13] and Chou & Chen [21] show examples of it. Henningsen et al. [22] highlight how managerial skills are key elements to improve firm's economic results. By considering previous arguments, the present Hypothesis 1 is provided: The farm's economic sustainability will positively influence the return of assets (ROA) and return on investment (RF) as profit indicators.

2.2. The Measure of Economic Sustainability

The access to information is key for organizations as managers who can identify changes in the markets and impacts in the detection capability [23,24]. Such information enables them to achieve a competitive advantage [25–27]. Being a member in "Manchego cheese" PDO and the incorporation of unified type feed systems can be considered as indicators of the detection capability. They both allow accessing to timely and accurate information for the achievement of the strategic objectives of livestock farms.

Doppelt [14] pointed out that the modern information systems allow organizations create new business according to customer needs. Thus, farms that keep registers have enough information on most demanded products and their evolution and, therefore, they can analyze this information to detect new niches. The domain market-product is the result of having developed a capability to respond to external opportunities [12,13]. Consequently, the variety in the sales of products implies the detection of new needs. Feeding has changed, increasing the weight of products that come from agriculture due to cultural changes [2], so farms that have land available to agriculture use and produce food, which responds to a detected need. This is similar to the use of grazing as it increases the quality of the product [4].

The purpose of planning is to meet the needs of customers through product development. This way, planning reproduction allows farms get adapted to future customers' needs [14]. According to previous considerations, next table shows the different variables considered in this research to measure farm's economic sustainability.

2.3. Technological Sustainability

The use of information systems provides technological sustainability to organizations [28,29]. Firm's information systems allow making decisions on production. The information can have an impact in the way organization routines take place or in the design of new ones. Nieves [24] reinforces the key role that the access to information by managers plays as main path to reach better results when changes must be identified in the market and respond to them. According to his research, external relations impact on firm's technological sustainability. Examples of technological sustainability can be found in the use of farm's information systems. For example, by properly warehousing data, information systems allow making decisions on the level of reproduction capability of animals. This information can also promote changes on the existing organizational routines and in the design of new ones.

Although farms that belong to the sheep industry do not count on with modern information systems, as for example Big Data [30], we can consider that just having registers offer enough information on what the most demanded products are and how the demand on products is evolving. This permits a better analysis of the information and detects different customer's segments with uncovered needs so far. Collins et al. [25] and Pearlson et al. [31] reinforce the importance for firms to access to proper information by allowing information to be located in the best position to reach a competitive advantage. From this perspective, being part of the "Manchego cheese" Protected Designation of Origin, as the including of unified breed systems of by products can be taken into account as indicators of technological sustainability since they allow the access to accurate and proper information to the achievement of farm's strategic objectives. By considering previous arguments, the present Hypothesis 2 is provided: The farm's technological sustainability will positively influence the return on assets (ROA) and return on investment (RF) as profit indicators.

2.4. The Measure for Technological Sustainability

For [11] the integration of knowledge is the result of the process of sharing and combining information arising from the interaction of group members that share their individual knowledge. Rangel et al. [4] and Bravo & Herrera [32] consider that knowledge management and organizational routines establish the firm's technological sustainability as they allow the integration of the information. They stress the importance of properly using technology to conduct knowledge transfer. The authors of Satish & Yue [9] and Aquilani et al. [15] reinforced how knowledge includes data, information and experience. According to his analysis, knowledge means the combination of facts, analysis, trainings and lessons learnt that comprise knowledge for an individual. Petter et al. [33] describe how IT systems have migrated from being a tool to manage data and fulfill management reporting needs, to provide mechanisms for strategic management decisions, and promote collaboration amongst internal and external agents. Beath et al. [34] support how information technology has played an important role to enable knowledge management within organizations. The Food and Agriculture Organization of the United Nations (FAO) [1] explained the role of information and communication technologies as facilitators for communication issues and remarked their impact on the processing and transmission of information.

The Food and Agriculture Organization of the United Nations (FAO) [1] refer to the situation where hidden patterns and data knowledge are considered one of the most vital assets within organizations. In their view, making use of these assets must be a major concern for managers which can also lead them to improve business decisions. Besides, Beath et al. [34] highlight that a good system of internal information management increases firms' sustainability by increasing its absorptive capability and integrating external knowledge into their activities. The farm's events record system (births, death, sales, etc.) is a database that stores relevant information on farm's operative process. This database allows the use and exchange of information among employees [31,32] and it can be used for decision-making, by increasing the information efficiency and resulting in a greater understanding than that provided separately by each of activities of the farm's value chain.

The planning process refers to the definition of the firm's goals and the more appropriate means to achieve them; that is, it involves making decisions in the present about the firm's future and, according to [16] it is a firm's organizational capability. Managers need to know the existing resources in the firm. It influences the development of sustainability [35,36] and information systems allow firms establish relationships with external environment [37]. They facilitate the coordination of employees and the development of behavioral patterns. Wang et al. [38] and Toro-Mújica et al. [39] described different ways to improve the business position, as example planning. According to previous considerations, next table shows the different variables considered in this research to measure farm's technological sustainability.

2.5. Organizational Sustainability

Understanding how sustainability strategies and initiatives come to be perceived as legitimate by managers and executives is a fundamental step toward facilitating their adoption and effective implementation, since attitudes such as perceived legitimacy can influence an individual's intention to act, and intentions are important antecedents to behavior. Effective organizational innovations—the successful introduction of new strategies, structures, or processes—are highly dependent upon the attitudes, support, and cooperation of employees [37]. In order to reach organizational sustainability, it is relevant to develop new markets and products, by properly coordinating innovative processes and behaviors [30,38].

Manchego cheese has been considered a product for national consumption until 2015. This year over a 60% of cheese was commercialized in the European Union or other countries; this means that firms have developed organizational sustainability through the opening of new markets. The development of different varieties of cheese, as for example light, implies the development of organizational sustainability too. Farms are each time more applying the sustainable concept to obtain and maintain a competitive edge due to their particular efficiency and effectiveness throughout several parts of the value chain. According to [31], a business is profitable if the value it creates exceeds the cost of performing the value activities. To gain a competitive advantage over its rivals, a company must either perform these activities at a lower cost or perform them in a way that leads to differentiation and a premium price (more value). A sustainable value chain can provide a differentiation in terms of value creation through sustainability [30].

Last years, an intensification and specialization of production has taken place at PDO farms [39]. Changes have been oriented to increase production, by means of higher qualified labor, the increase of technologies and the progressive decrease of grazing [20,40]. These structural changes imply a risk in the viability of farms, since they influence their multifunctional character and reduce the degree of resilience and complementarity amongst activities.

The implementation of process management programs in reproduction and genetic improvement have been identified as a major trend in this industry [4]. Different dimensions [20] compose the management of processes and its study requires from a dynamic and holistic process where the existent interactions amongst the different elements in the system are considered [30,41]. In this conceptual framework, the different activities constitute a process where the activities are managed in a systematic way [42]. According to what it has been explained in the Operative Program (2014), 96% of Small and Medium Size Firms (SMEs) in Castilla-La Mancha region present specific problems as a consequence of the low level in terms of capitalization, reduce turnover and difficulties in the access to finance, lower levels of inter-firm cooperation and lacks in the managerial, commercial, and innovation capabilities. This last agrees with the results obtained by [27] about the low performance on sheep production systems in Castilla-La Mancha. In the last years, some analyses have been done in this industry to better understand the situation and the future trends. Difficulty in accessing financial resources [41], lack of proper processes oriented to results [40], lack of technological packages and lack of managerial abilities [27] seem to be most outstanding problems. By considering previous arguments, the Hypothesis 3a is provided: The farm's organizational sustainability will positively influence the return of assets (ROA) and return on investment (RF) as profit indicators.

2.6. The Measure of Organizational Sustainability

Organization sustainability implies the putting into practice of new processes to decrease the production or distribution, improvement of quality, or the production or distribution of new or significantly improved products [41].

The use of breeding techniques allows increasing the number of lambs per calving [39]. As [41] noted, productivity will increase as the reproductive index increases, since more liters of milk and kilograms of meat per lamb will be available. The use of reproductive techniques also may promote organizational sustainability. Explain how artificial insemination allows preserving the genetic variability of the species subject to a continuous process of improvement of its productive characteristics, which means a substantial introduction in the productive process. Process management programs in reproduction and genetic improvement increase organizational sustainability [40,41]. According to previous considerations, next table shows the different variables considered in this research to measure farm's organizational sustainability.

2.7. Training Sustainability

Collins et al. [25] noted that as a complement to the production experience, firms also invest in training sustainability when they provide training to their employees. To understand the sources of a firm's training sustainability, the attention must be paid to the structure of communication between the external environment and the organization, as well as among the subunits of the organization, and on the character and distribution of expertise within the organization. As [42] describes, it consists of acquiring and assimilating the external information by integrating it in the firm's knowledge base with the main objective of improving processes and strategies applied to organizations. Firms that possess a high level of training sustainability, present high levels of learning capabilities, by properly integrating external information and converting it into knowledge that can be warehoused [30,42].

This way, as firms have access to different sources of information, as it can be the access to experts in the various activities realized in a farm (as the advisers and experts in PDO) workers will be able to improve their knowledge though including in the firm the external information accessed. The establishment of processes and the selection of people and leaders are fundamental, since the employees' educational level is a key factor in the absorption capability [26,42]. By considering previous arguments, the Hypothesis 4 is described: The farm's training sustainability will positively influence the return on assets (ROA) and return on investment (RF) as profit indicators.

2.8. The Measure of Training Sustainability

Different authors have stressed the importance of training, recruitment, and selection processes as absorption training sustainability indicators. Petter et al. [33] studied what factors are associated with the competitive success of Spanish small and medium enterprises (SME). They concluded that those SME that apply human resource practices of recruitment and selection and training achieve best results in 71.5% and 84.2% of farms, respectively. Wang et al. [38] referred to the concepts "knowledge absorption" and "training sustainability". In their work, they performed an empirical study about the direct impact of IT support for knowledge management on knowledge-based dynamic capability that influences the final firm's performance on a sample of 113 managers from manufacturing industries. To measure the training sustainability, five indicators were used: absorb new knowledge from external/market sources; absorb new knowledge from suppliers, competitors and customers; absorb new knowledge from educational/research establishments; absorb new knowledge from patents; and absorb new knowledge from personnel mobility. They concluded that higher levels of training sustainability were associated with higher levels of firm's performance.

Murovec & Prodan [43] provided an empirical analysis with a sample based on the responses to Spanish and Czech Republic's third Community Innovation Survey (CIS3). They distinguished between demand-pull training sustainability and science-pull training sustainability, and noted the training of personnel as determinant in both of them. Angón et al. [20] applied an innovative learning strategy that promotes the development of training sustainability to reach a better position of students in market. Baumgartner et al. [12] and [13] have stressed the importance of hiring new people, as a way of acquiring new ideas and experiences. Likewise, the firms take advantage of investing in training, hiring people becomes very important in a good recruitment and selection process. Training is a key factor. Beath et al. [34] pointed out in their study about the adoption of practices of integrated management since former survey participants presented the highest rates of adoption of practices requiring more knowledge or being more labor intensive. According to previous considerations, next table shows the different variables considered in this research to measure farm's organizational sustainability.

2.9. Financial Indicators

Collins et al. [25] consider that value creation and profitability are interlinked concepts that cannot be divided. They distinguish between return on assets (ROA) and return on investments (ROI).

2.10. Return on Assets (ROA)

It measures the benefit before interests and taxes as the proportion between benefit before interests and taxes (BBIT) divided by the total net assets (TNA) at the organization. It can also be calculated as the product between the margin over sales and assets rotation. Where Margin over sales = BBIT/Sales; Assets turnover = Sales/TNA and Margin over sales represents to what extent benefits are related to farm activity, while assets turnover represents the efficiency in the use of assets.

2.11. Return on Investments (RF)

RF or ROI are measured as the division between the benefit after investments and taxes (BAIT) and firm's equity. According to [25], return on investments depends on return on assets and how external funds are managed in assets presenting profitability over or under financial costs. Considering the approach provided by [44], in this research both metrics ROA and RF or ROI have been used to show final results. Some other authors have also used these same ratios to analyse final firm's performance. Table 5 shows these studies. Figure 1 shows the conceptual model considered for this research.

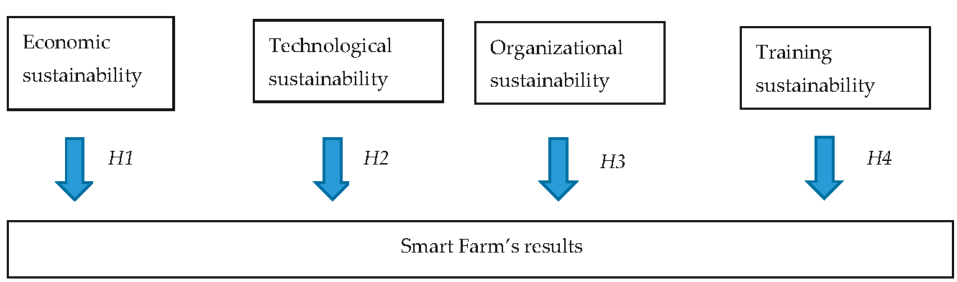

Figure 1. Conceptual model.

Existing literature on sustainability indicators and performance was reviewed to support the indicators used in the research model. Four basic types of sustainability have been considered: economic; technological; organizational; and training. All four support a global sustainability concept.

3. Materials & Methods

The study area was the Spanish region of Castilla La Mancha (38°–41° N; 1°–5° W), whose surface area of roughly 800,000 ha with Mediterranean continental climate, dry winters and hot and dry summers. The study population was 907 farms of Manchego sheep from "La Mancha" region, into the Protected Designation of Origin (PDO) "Queso Manchego". In addition, information in situ from the 157 smallholders in their farms was collected [27,39,40] through the application of a 226 question survey. A selection of sustainable indicators was conducted according to their relevancy on mixed cereal Manchego sheep system [41]. The indicators selection was based on an extensive literature review. Subsequently, the selection process consists of experts' judgments by means of successive iterations of a questionnaire, to show convergence of opinions and to identify dissent or non-convergence [40].

Initially, the percentages of the farmers that accomplished the indicator have been calculated regarding each dimension of sustainability. This analysis allowed us to determine the weaknesses of the studied farms. All the attributes used for the implementation of the indexes are shown on Tables 1–5). The values of each variable were calculated by the Delphi method [27,30,42] using the opinion of 157 farmers. They were assessed by means of a one to five Likert scale, where one was the least important and five the most important. From a database with indicators collected through a survey [41] related to production and economic structure, organization, flock management, productivity, socio-economic aspects and farm management, 57 indicators of sustainability and performance were analyzed (Tables 1–5) [39–41]. Tables from 1 to 4 show the indicators associated with the different dimensions of sustainability, and Table 5 shows the indicators to measure results.

Table 1. Indicators for measurement of economic sustainability.

Indicator	Authors
MERCH—direct selling from consumer to wholesaler	[12]
CHVAR—kind of cheese sold	[14]
SLAMBS—selling of lambs	[12]
SRAMS—selling of milk per ewe	[1]
FSL—female sale	[27]
MSL—male sale	[12]
CHSO—cheese sold	[23]
WOSO—wool sold	[2]
MASO—manure sold	[12]
UNFE—use of unified as integral food system	[13]
SUBP—use of by-products as animal food	[13]
PRON—use of pastures	[13]
LANDA—use of agriculture for food production	[4,24]
REPRO—reproduction planning	[14]
KREC—availability of registers	[13]

Table 2. Indicators for measurement of technological sustainability.

Indicator	Authors
REGB—system of registers (births, deaths, sales, etc.)	[12]
UINF—use of information to make decisions	[35]
MILK—milk control as a managing strategy	[16]
PLAN—planning of operational processes (reproduction, health, breed, etc.)	[9,15]
INTP—Integral planning of different areas	[37]
GENP—genetic improvement	[1]
DIET—degree of agreement between animal diet and level of production	[36]
MINE—use of minerals	[34]
SUPL—use of supplements	[33]
HEALP—use of health plans	[15]
HYGP—use of Hygienic plan	[30]
PREV—use of prevention plans	[35]
CONSE—conservation of extra materials	[4]
STRHE—Strategies for managing animals	[35]
TECH—technologies in the milking parlour	[27]
ECOG—use of echographia	[1]
ANDRO—andrological evaluations	[4]
ANSE—animal selection	

Table 3. Indicators for measurement of organizational sustainability.

Indicator	Authors
IDENT—individual identification of animals	[27,41]
CTPAR—control of internal and external parasites	[41]
HECON—health control in the udder and in milk quality	[39]
NIDIS—disinfection of the nipple after milking	
DRTR—application of drying treatment	[41]
STREF—putting into practice any strategy to improve the efficiency in the use of water and conservation of land	[40]
DISTR—the organization of different areas according to a logic sequences in terms of flowing of animals, machines and workers	[41]
DIMEN—availability of milking place according to the flock dimension and easy access to animals and workers	[39]
ATANK—availability of milking place a proper refrigeration (in terms of volume and capacity)	[40]
CLMI—availability of automatic cleaning equipment and use of protocols in the milking place	
ROEQ—availability of place and equipment for the artificial breed of lambs	
RPTE—the use of reproductive techniques (flushing, matting, hormonal treatments, etc.)	
INDR—reproduction index (birth/sheep/year)	
ARTI—the use of artificial insemination as a tool to improve genetics	

Table 4. Indicators for measurement of training sustainability.

Indicator	Authors
TRAIN—training actions	[43]
STARE—staff's recruitment	[25]
SOING—sources of information	[13]
USEAD—use of advisors	[43]
TYAD—kind of advisors	[13]
CONA—conditions for advisors	[20]
GRASC—be part of a cooperative	[34]
KINDA—kind of cooperative	[16]

Table 5. Indicators for measurement of firm's results.

Indicator	Authors
ROA—return on assets RF (ROI)—return on investments	[3,17] [3,8,10] [6]

The relevance of this study is to find out if relationships among different dimensions of firm's sustainability presented in the theoretical framework significantly influence financial results in sheep farming in Spain. We hypothesize that performance in the sheep-breeding sector in Spain is dependent on tangible and intangible factors. Quantitative analysis was carried out analyzing data collected from sheep farms in Central Spain. The same dataset analyzed in [41] is used to apply the theoretical framework presented and the classification of technological packages established by [20] were also considered. Two approaches to achieving business efficiency, sustainability and the results-based approach have been considered. Intangible cluster variables using groups of indicators that are directly measurable have been estimated. Allocation of these manifest variables follows from literature on sustainability namely economic, technological, organizational and training, as presented in the theoretical framework [10].

To evaluate the influence of sustainability on farm's performance, an empirical analysis with a dataset of 157 farms has been performed. Four hypotheses have been formulated displayed in Figure 1 and described previously. Structural Equation Model (SEM) has been applied to measure the impact of each dimension of sustainability on final farm's performance. Each set of indicators of sustainability have been facing to return of assets (ROA) return on investment (RF) as profit indicators. The hypotheses were disaggregated into H_{ia} and H_{ib}, respectively.

4. Results

To test the posited hypotheses a non-lineal structural equations model with latent variables (types of sustainability) is specified and estimated. Figure 2 shows relationships results with its corresponding *p*-values. Arrows indicate posited relationships, and ovals latent variables representing sustainability and profits. Path (beta) coefficients were normalized, taking values between 0 and 1, measuring the strength and direction of the relationships. The model was estimated by means of Warp PLS 6.0 software [45].

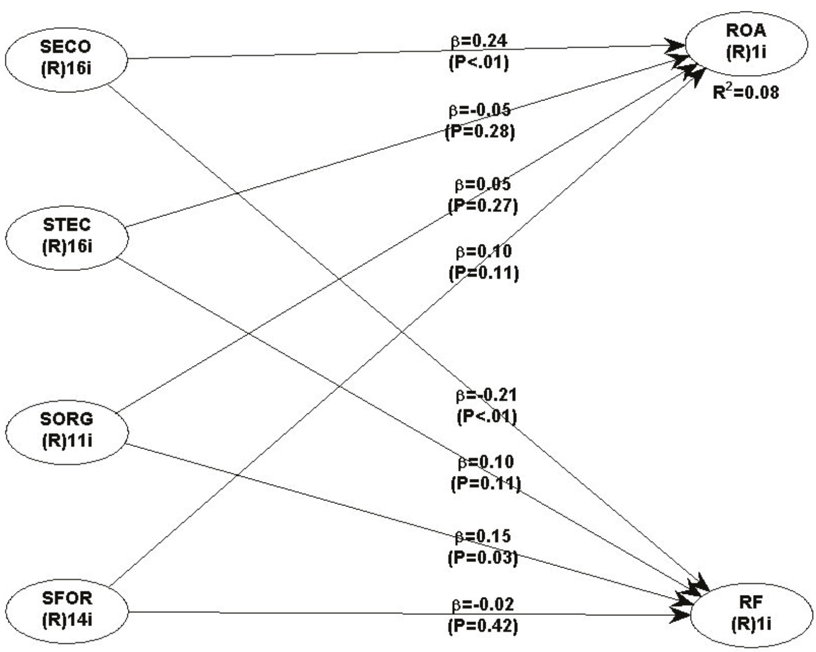

Figure 2. Research Model Scheme and main results.

Table 6 summarizes model fit and quality indices and its interpretation. The following indices were used to test hypotheses and model fit [45]: average path coefficient (APC); average R-squared (ARS); average adjusted R-squared (AARS); average block variance inflation factor (AVIF); average full collinearity VIF (AFVIF); Tennenhaus goodness-of-fit index (GoF); Sympson's paradox ratio (SPR); R-squared contribution ratio (RSCR); statistical suppression ratio (SSR); and non-linear bivariate causality-direction ratio (NLBCDR). All quality indices met recommended thresholds.

Table 6. Model fit and quality indices overview.

Index	Value	Value Interpretation
Average path coefficient (APC)	(APC) = 0.112, p = 0.038	Significant if $p < 0.05$
Average R-squared (ARS)	(ARS) = 0.040, p = 0.154	Significant if $p < 0.05$
Average adjusted R-squared (AARS)	(AARS) = 0.014, p = 0.214	Significant if $p < 0.05$
Average block VIF (AVIF)	VIF (AVIF) = 1.874	Acceptable if ≤ 5, ideally ≤ 3.3
Average full collinearity VIF (AFVIF)	(AFVIF) = 3.320,	Acceptable if ≤ 5, ideally ≤ 3.3
Tenenhaus GoF (GoF)	(GoF) = 0.146	Small ≥ 0.1, medium ≥ 0.25; large ≥ 0.36
Sympson's paradox ratio (SPR)	(SPR) = 0.750	acceptable if ≥ 0.7, ideally = 1
R-squared contribution ratio (RSCR)	(RSCR) = 0.711	Acceptable if ≥ 0.9, ideally = 1
Statistical suppression ratio (SSR)	(SSR) = 1.000	Acceptable if ≥ 0.7
Non-linear bivariate causality direction ratio (NLBCDR)	(NLBCDR) = 0.750	Acceptable if ≥ 0.7

A summary of the main model parameters values, and their corresponding *p*-values is presented in Table 7. This table shows the influence of the four types of sustainability on ROA and ROI (RF).

Table 7. Total effects and *p*-value.

		Types of Sustainability			
		SECO	**STEC**	**SORG**	**SFOR**
Financial Indicators	ROA	**0.236** ***(0.001)***	−0.047 *(0.276)*	0.048 *(0.272)*	0.096 *(0.110)*
	RF	**−0.210** ***(0.003)***	0.095 *(0.112)*	**0.150** ***(0.027)***	−0.015 *(0.424)*

Estimation results show that Hypothesis 1a: the farm's economic sustainability (SECO) will positively influence the return of assets (ROA) as profit indicator is accepted (p = 0.001). Figure 3 shows the behavior of these two magnitudes. At lower to middle levels, there is a strong positive relation the relationship between the both, followed by a decrease and stabilization.

Surprisingly, results relative to Hypothesis 1b: the farm's economic sustainability (SECO) will positively influence the return on investment (RF) as profit indicators are also significant (p = 0.003), but the parameter sign is opposite to the expected (−0.210). Figure 3 shed light on this apparently odd result. To attain a positive relation between economic sustainability (SECO) and return on investment, SECO needs to reach a minimum level after which takes place the expected positive relationship. Hypothesis 3b: The farm's organizational sustainability (SORG) will positively influence the return on investment (RF) as profit indicator is also confirmed (p = 0.027). Like the behavior of ROA against SECO there is a step initial relationship between SECO and RF (measured by ROI. Once a level is reached the intensity of the relationship oscillates, although a high level (Figure 3). Others posited hypotheses could not be confirmed at the required 95% confidence level (see Figure 2 or *p*-values Table 7).

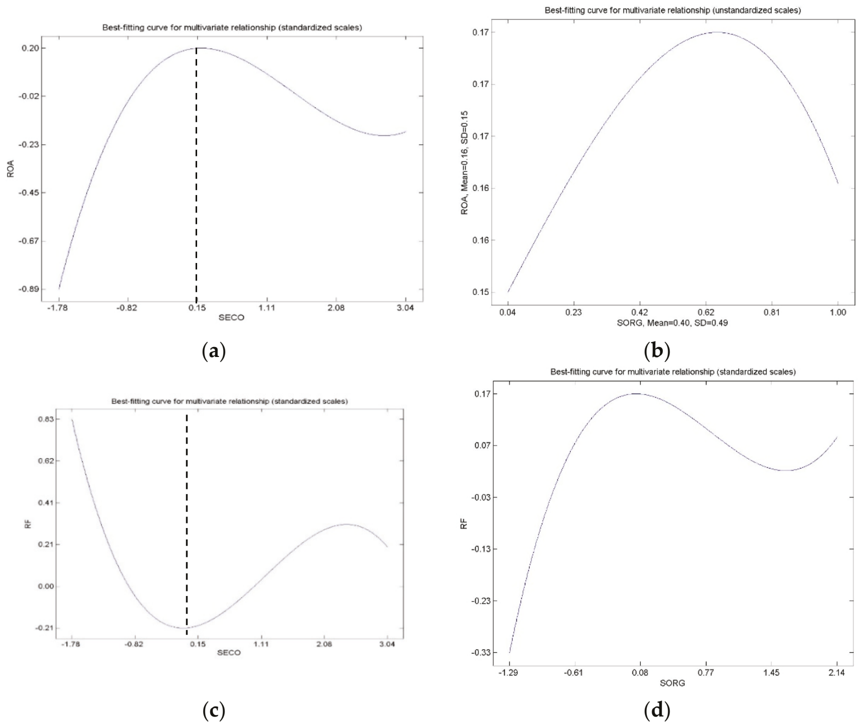

Figure 3. Economic and Organizational sustainability (SECO and SORG) and final performance (return of assets (ROA) and return on investment (RF)) relationship curves. (**a**,**c**) Economic sustainability (SECO); (**b**,**d**) Organizational sustainability (SORG).

5. Discussion and Implications

With respect to the main objective of this paper, we conclude that organizational, training, economic, and technological sustainability indexes used agreed and showed strong impact in performance indexes. The methodology applied to determinate the indexes were adequate. Rangel et al. [4] evaluated the incidence of indicators in the final results through logistic regression and seeks an *ex ante* evaluation of innovation. Nevertheless, the Structural Equation Model (SEM) has been a useful method to determine the quantitative relationship amongst sustainability indexes and the final results of the farms.

This is an exploratory analysis and results agree with [27,41] in cattle, [4,40] in double purpose cattle in Latin America that indicated the great difficulty of modeling an integrated mixed system with multiple synergies and trade-offs amongst activities [2,22]. Hypothesis 1 has been validated, where the farm's economic sustainability influences the return of assets (ROA) and return on investment (RF). Same way, Hypothesis 3 has been partially accepted: The farm's organizational sustainability was influenced by the return on investment (RF). In this sense, Hypothesis 3 is confirmed: The farm's organizational sustainability (SECO) is influenced by the return on investment (RF).

In both cases, the low value of the determination coefficient in the model indicates the need to include other indexes to evaluate final results and this agrees with previous analyses done in mixed systems. The authors of [19] indicate the importance of deepening the knowledge of different objectives, potentials, limitations, and "right of being" of the farms [1,40]. These systems could be modelled by taking into account the four dimensions of sustainability proposal (economic, technological, organizational, and training). Moreover, the farmer's objectives must be considered in order to achieve a good fit of the proposed model. The authors of The Food and Agriculture Organization of the United Nations (FAO) [1], Rangel et al. [4], Morantes et al. [27] and García-Martínez et al. [40] describe that smallholders in Mediterranean basin, American tropic (Mexico and Ecuador), and South Africa present similar strategic challenges: they seek food security, family welfare, and reduction of poverty. Most of the farms are of small-scale size and subsistence (85%), and only the 15% of the smallholders had clear business objectives and they were looking for an increased productivity [4,19]. In this context, ROA and RF may not be enough to explain results; this is an important reason that shows us why some result was in opposite to expected and the low determination coefficients obtained. In this way, [41] proposes using viability as an indicator. Farm's viability is based on its economic results, and it must be calculated according to the ability of the farm to generate, over the long term, sufficient profits for guaranteeing the maintenance of the family unit. Therefore, it could be included in future analyses.

Hypothesis 1 has been validated: The farm's economic sustainability (SECO) positively affects the return of assets (ROA). It was accepted with negative sign: The farm's economic sustainability (SECO) affects the return on investment (RF). The opposite sign in both hypotheses mainly explains the effect of scale [20], the progressive intensification and the rising price of factors [39,41]. Figure 3a shows a first ascending section of the curve that concentrates the greatest part of farms, increases the economic dimension as consequence of an intensification in the system (more dimension and more productivity), and increases the ROA. Opposite, Figure 3b shows a decrease in the curve. This indicates how as production is intensified and more factors are acquired (land and animals mainly) the return on investments mainly decreases. In Manchega ewe's case, land is a very limited resource that has already been distributed, and with difficult access [27,39,40]. It competes with other more profitable industries that show higher levels of return; i.e., it constitutes a strong barrier of entry and a high opportunity cost, which explains the increasing abandon of the activity. Once the point of inflexion has been overcome in both curves, the indicators behave as expected [41]. ROA in a decreasing way and RF in an increasing way according to [20] in technified pastoral systems. SORG behavior (Figure 3c,d) agrees with expectations; increasing both indicators (ROA and RF) as the curve moves to the right in the axis of abscissas. The response of the model is nonlinear (Figures 2 and 3) according to the curve of diminishing returns of innovation [20,39]; Nevertheless, [41] and [40] indicate that larger size of the farm entail structural changes; such as more worker force, adjustments in management and more external inputs. Besides, larger scale not necessarily implies more economic efficiency [19–22]. In this case, the law of decreasing returns explains why the first hypothesis is accepted and the second is rejected.

The model proposed in Table 6, shows the four dimensions of sustainability and provides a priority according to their effect on ROA and RF. Economical dimension is the one that presents higher impacts on the indicators considered. The second one is the organizational dimension. The third one, the technological and last the training one presenting low values to the whole group of data as it has been indicated by [27,41] in these systems. The fourth is sustainability dimensions are dynamic and sequential in time according to the degree of the systems' evolution [39].

Large intensive livestock farms in developed countries currently have serious problems of environmental, economic and animal welfare viability and high dependence of external inputs. It does not seem the most appropriate model for developing countries, which need their own model for territorial competitiveness with integrated mixed farms [18,19]. The circular economy proposes a change of production model with longer life cycles face a greater intensification of production [1,3,15]. This evolution agrees with [4,40,41] who indicate that those smallholders applying a low-cost strategy, using endogenous resources (native pastures, local breeds, etc.) and appropriate levels of innovation reach best results. In this way, the results showed: firstly, the important an economic dimension (H1) was considered and secondly, the organizational one was taken into account as a strategy to improve results (H3).

Apart from this, the research showed that the number of indicators used is high (57). Maybe the dimension could be reduced by applying multivariate techniques that enable the selection of indexes providing more discriminant capability. In this sense, the application of canonical discriminant analysis with graphical hypothesis-error and structure of a multivariate is suggested [27].

Future analysis should go in deep into the knowledge of interactions amongst sustainability indicators and final farm results. The implementation of improvement practices requires of a holistic and dynamic approach of sustainability, where the existent of synergies and trade trade-offs amongst the four sustainability dimensions should be considered [2,30]. The knowledge of the four types of sustainability is the first step to improve the feasibility and competitiveness of farms [39].

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References

1. Food and Agriculture Organization of the United Nations (FAO). *Sustainability Assessment of Food and Agriculture Systems (SAFA)*; FAO: Rome, Italy, 2014.
2. Schader, C.; Baumgart, L.; Landert, J.; Muller, A.; Ssebunya, B.; Blockeel, J.; Weisshaidinger, R.; Petrasek, R.; Mészáros, D.; Padel, S.; et al. Using the Sustainability Monitoring and Assessment Routine (SMART) for the Systematic Analysis of Trade-Offs and Synergies between Sustainability Dimensions and Themes at Farm Level. *Sustainability* **2016**, *8*, 274. [CrossRef]
3. Ikerd, J.E. *The Essentials of Economic Sustainability*; Kumarian Press: Bloomfield, CT, USA, 2012.
4. Rangel, J.; Espinosa, J.; de Pablos-Heredero, C.; Barba, C.; Vélez, A.; Rivas, J.; García, A. Adoption of innovations and organizational practices in management, animal feeding and reproduction in dual-purpose bovine of small farms in Mexico. *Rev. Científ. FCV-LUZ* **2017**, *27*, 44–55.
5. Boons, F.; Montalvo, C.; Quist, J.; Wagner, M. Sustainable innovation, business models and economic performance: An overview. *J. Clean. Prod.* **2013**, *45*, 1–8. [CrossRef]
6. Höjer, M.; Wangel, J. Smart sustainable cities: Definition and challenges. In *ICT Innovations for Sustainability*; Springer: Cham, Switzerland, 2015; pp. 333–349.
7. Tussyadiah, I.P.; Pesonen, J. Drivers and barriers of peer-to-peer accommodation stay—An exploratory study with American and Finnish travellers. *Curr. Issues Tour.* **2018**, *21*, 703–720. [CrossRef]
8. Laszlo, C.; Zhexembayeva, N. *Embedded Sustainability: The Next Big Competitive Advantage*; Stanford University Press: Palo Alto, CA, USA, 2017.
9. Satish, J.; Yue, L. What is corporate sustainability and how do firms practice it? A management accounting research perspective. *J. Manag. Account. Res.* **2016**, *28*, 1–11.
10. Spangenberg, J.H. Economic sustainability of the economy: Concepts and indicators. *Int. J. Sustain. Dev.* **2005**, *8*, 47–64. [CrossRef]
11. Weaver, P.; Jansen, L.; Grootveld, G.V.; Spiegel, E.V. *Sustainable Technology Development*; Greenleaf Publishing Book: Austin, TX, USA, 2017.
12. Baumgartner, R.J.; Rauter, R. Strategic perspectives of corporate sustainability management to develop a sustainable organization. *J. Clean. Prod.* **2017**, *140*, 81–92. [CrossRef]
13. Lozano, R. Creativity and organizational learning as means to foster sustainability. *Sustain. Dev.* **2014**, *22*, 205–216. [CrossRef]
14. Doppelt, B. *Leading Change toward Sustainability: A Change-management Guide for Business, Government and Civil Society*; Routledge: Abington-on-Thames, UK, 2017.

15. Aquilani, B.; Silvestri, C.; Ioppolo, G.; Ruggieri, A. The challenging transition to bio-economies: Towards a new framework integrating corporate sustainability and value co-creation. *J. Clean. Prod.* **2018**, *172*, 4001–4009. [CrossRef]
16. Trondsen, T. Value chains, business conventions, and market adaptation: A comparative analysis of Norwegian and Icelandic fish exports. *Can. Geogr./Le Géographe Canadien* **2012**, *56*, 459–473. [CrossRef]
17. Tomczak, T.; Reinecke, S.; Kuss, A. Introduction. In *Strategic Marketing*; Springer: Wiesbaden, Germany, 2018; pp. 1–18.
18. Ramdhani, M.A.; Aulawi, H.; Ikhwana, A.; Mauluddin, Y. Model of Green Technology Adaptation in Small and Medium-Sized Tannery Industry. *J. Eng. Appl. Sci.* **2017**, *12*, 954–962.
19. Van't Hooft, K.; Wollen, T. *Sustainable Livestock Management for Poverty Alleviation and Food Security*; Cab International: London, UK, 2012; pp. 120–130.
20. Angón, E.; Perea, J.; Toro-Mújica, P.; Rivas, J.; De-Pablos, C.; García, A. Pathways towards to improve the feasibility of dairy pastoral system in La Pampa (Argentine). *Ital. J. Anim. Sci.* **2015**, *14*, 643–649. [CrossRef]
21. Chou, S.; Chen, J.C. Six Sigma-Based Optimization of Shrinkage Accuracy in Injection Molding Processes. World Academy of Science, Engineering and Technology. *Int. J. Ind. Manuf. Eng.* **2018**, *5*, 3.
22. Henningsen, A.; Czekaj, T.G.; Forkman, B.; Lund, M.; Nielsen, A.S. The relationship between animal welfare and economic performance at farm level: A quantitative study of Danish pig producers. *J. Agric. Econ.* **2018**, *69*, 142–162. [CrossRef]
23. Bhatt, G.D.; Grover, V. Types of information technology capabilities and their role in competitive advantage: An empirical study. *J. Manag. Inf. Syst.* **2005**, *22*, 253–277. [CrossRef]
24. Nieves, J. Relaciones sociales, capacidades dinámicas e innovación: Un análisis empírico en la industria hotelera. *Revista Europea de Dirección y Economía de la Empresa* **2014**, *23*, 166–174. [CrossRef]
25. Collins, C.; Clark, K. Strategic Human Resource Practices, Top Management Team Social Networks, and Firm Performance: The Role of Human Resource Practices in Creating Organizational Competitive Advantage. *Acad. Manag. J.* **2003**, *46*, 740–751.
26. Mao, H.; Liu, S.; Zhang, J.; Deng, Z. Information technology resource, knowledge management capability, and competitive advantage: The moderating role of resource commitment. *Int. J. Inf. Manag.* **2016**, *36*, 1062–1074. [CrossRef]
27. Morantes, M.; Dios-Palomares, R.; Peña, M.E.; Rivas, J.; Perea, J.; García, A. Management and productivity of dairy sheep production systems in Castilla-La Mancha, Spain. *Small Rumin. Res.* **2017**, *149*, 62–72. [CrossRef]
28. Dao, V.; Langella, I.; Carbo, J. From green to sustainability: Information Technology and an integrated sustainability framework. *J. Strateg. Inf. Syst.* **2011**, *20*, 63–79. [CrossRef]
29. Altieri, M.A. *Agroecology: The Science of Sustainable Agriculture*; CRC Press: Boca Raton, FL, USA, 2018.
30. De-Pablos-Heredero, C.; Fernández-Renedo, C.; Medina-Merodio, J.A. Technical efficiency and organ transplant performance: A mixed-method approach. *Int. J. Environ. Res. Public Health* **2015**, *12*, 4869–4888. [CrossRef] [PubMed]
31. Pearlson, K.E.; Saunders, C.S.; Galletta, D.F. *Managing and Using Information Systems, Binder Ready Version: A Strategic Approach*; John Wiley & Sons: Hoboken, NJ, USA, 2016.
32. Bravo Ibarra, E.R.; Herrera, L. Capacidad de innovación y configuración de recursos organizativos. *Intang. Cap.* **2009**, *5*, 301–320.
33. Petter, S.; Delone, W.; McLean, E.R. The Past, Present, and Future of "IS Success". *J. Assoc. Inf. Syst.* **2012**, *13*, 341–362. [CrossRef]
34. Beath, C.; Becerra-Fernandez, I.; Ross, J.; Short, J. Finding Value in the Information Explosion. *MIT Sloan Manag. Rev.* **2012**, *53*, 18–20.
35. Shahbazi, R.; Haghshenas, M.; Nassiriyar, M.; Sadeghzadeh, A. Methodology Presentation for the Integration of Knowledge Management and Business Intelligence. *Int. J. Serv. Sci. Manag. Eng.* **2016**, *3*, 26–31.
36. Daneels, E. Trying to become a different type of Company: Dynamic capability at Smith Corona. *Strateg. Manag. Rev.* **2010**, *32*, 1–31. [CrossRef]
37. Wallace, J.C.; Butts, M.M.; Johnson, P.D.; Stevens, F.G.; Smith, M.B. A multilevel model of employee innovation: Understanding the effects of regulatory focus, thriving, and employee involvement climate. *J. Manag.* **2016**, *42*, 982–1004. [CrossRef]
38. Wang, E.; Klein, G.; Jiang, J.J. IT support in manufacturing firms for a knowledge management, dynamic capability link to performance. *Int. J. Prod. Res.* **2007**, *45*, 2419–2434. [CrossRef]

39. Toro-Mújica, P.; García, A.; Aguilar, C.; Vera, R.; Perea, J.; Angón, E. Economic sustainability of organic dairy sheep systems in Central Spain. *Ital. J. Anim. Sci.* **2015**, *14*, 3625. [CrossRef]
40. García-Martínez, A.; Rivas, J.; Rangel, J.; Espinosa, J.A.; Barba, C.; De-Pablos-Heredero, C. A methodological approach to evaluating the technological innovation in small-scale farming. *Future Internet* **2016**, *8*, 25. [CrossRef]
41. Rivas, J.; Perea, J.; Angón, E.; Barba, C.; Morantes, M.; Dios-Palomares, R.; García, A. Diversity in the dry land mixed system and viability of dairy sheep farming. *Ital. J. Anim. Sci.* **2015**, *14*, 179–186. [CrossRef]
42. De-Pablos-Heredero, C.; Fernández-Valero, G.; Blanco-Callejo, M. Supplier Qualification Sub-Process from a Sustained Perspective: Generation of Dynamic Capabilities. *Sustainability* **2017**, *9*, 730. [CrossRef]
43. Murovec, N.; Prodan, I. Absorptive capacity, its determinants, and influence on innovation output: Cross-cultural validation of the structural model. *Technovation* **2009**, *29*, 859–872. [CrossRef]
44. Laaksonen, O.; Peltoniemi, M. The essence of dynamic capabilities and their measurement. *Int. J. Manag. Rev.* **2018**, *20*, 184–205. [CrossRef]
45. Kock, N. *Warp PLS 6.0*; ScriptWarp Systems: Laredo, TX, USA, 2017.

sustainability

Article

Development and Challenges of Social Enterprises in Taiwan—From the Perspective of Community Development

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Abstract: Social enterprises (SEs) have formed a naturally conscientious atmosphere in Taiwan, which has not only diluted the boundary between society and enterprises, but also transformed the inherent thinking of nonprofit organizations (NPOs). SEs operate under cross-organizational and cross-departmental models. For years, the rapid economic development of Taiwan has focused on the pursuit of profit without focusing on the development of NPOs. Only after the economy began to slow down did society gradually see a new trend based on the concept of SEs and the cultivation of community self-sufficiency to solve social problems. Its successful implementation is of great significance to the sustainable development of Taiwan. Community industry is based on the community and it is people-oriented. From the perspective of sustainable development, community industry is invested in economic activities and creates multiple benefits to a sustainable community and to social, environmental, cultural, financial, and other developments. From the early "production and welfare construction" to the "new hometown overall construction policy", Taiwan has placed emphasis on inherent local industry activation, such as the establishment of local industrial exchange centers, local industry sustainable mechanism construction, local characteristic small community enterprises, as well as economic plans, including "Sustainable Employment Hope Project" and "Diverse Employment Development Program", promoted by the Labor Commission since 2001. All of these are focused on building and developing a community industry, and relevant authorities look forward to the vitality of the community industry to create more job opportunities and community interests. Based on literature review of social enterprise, this paper leads small- and medium-sized community industries to meet the development of business models from the economic perspective of commercialization and the social perspective of social innovation in order to solve the quality crisis that is faced by nonprofit organizations and to maintain the sustainable development of the enterprise. By the design of a nonprofit and mutual-assistance mechanism, poverty relief results can be obtained. SEs, which are similar to regular enterprises, can encounter challenging business environments and they must also possess the ability to assume business risks. Specifically, SEs must consider the dual goals of having a social mission while achieving economic goals. This study provides a detailed understanding of the existence and operational characteristics of SEs in Taiwan.

Keywords: social enterprise; community industries; social economy; Taiwan

1. Introduction

Social Enterprise is a newly developed field of study and it has also attracted much attention from academic and practical circles (Mair, 2006) [1], which regard to it as a global social issue (Nicholls, 2006) [2]. Although the study of social enterprises is increasing, it is still in its infant stage, and the subject of study is more focused on business models, case studies, instrumental analysis of operational benefits, or best practices (Bomstein, 2004) [3]. The main theoretical ground is often based on business research, and the methodology also prefers to highlight certain specific cases of a business strategy or depict the heroic image of social entrepreneurs. Although these studies have helped to highlight the research field of social enterprises, there are few theoretical discourses. For a new field of study, social enterprises not only lack an explanation from sociology, but also lack studies from the angle of social work and social policy. The rise of social enterprises can be said to be the result of both practical and theoretical efforts, giving us the opportunity to challenge, question, and mull over the common paradigm that we want to build (Mair & Matti, 2006) [4]. Austin (2006) defined social enterprise as follows: "Social enterprise are innovative conjunctures that may appear simultaneously in non-profit, commercial, and public sector, between departments, and activities that increase social value" [5]. Gidron & Hasenfeld (2012) and Battilana, J. (2010) believed that social enterprises are mixed organizations that are designed to achieve social and environmental goals through certain forms of business or trading activities [6,7].

According to the Taiwan Social Enterprise Innovation and Entrepreneurship Society, social enterprises (SEs) are organizations that are characterized by both a desire for profitability and to make a positive impact on society, which transforms or develops corporate social responsibility (CSR) into a sustainable business [8,9]. Chen (2014) stated that, in Taiwan, initiatives that are related to SE and social innovation are derived from two separate schools of thought, management, and sociology: one describes enterprises' emphasis on social responsibility and application of management rules to create SEs, whereas the other in the fields of sociology and social welfare hopes that businesses can find self-supporting revenue sources in addition to government subsidies and donations [10]. Hu et al. (2012) stated that SEs are a new type of self-sufficient enterprise that integrate social values and financial sustainability to help solve neglected societal needs [11].

The trend toward SEs has become global, and Taiwan has begun to gradually establish an SE ecosystem through promotion by relevant organizations and individuals. This model of social change does not entirely rely on government resources; thus, SEs in Taiwan do not lose their autonomy due to receiving government subsidies. Instead, organizations form civil groups and obtain capital and resources from the market. These civil groups are not the same as regular nonprofit organizations (NPOs); instead, they are SEs acting in the public interest [12].

Lin (2008) believed that SEs are business ventures that are formed on the basis of "reducing or alleviating social problems or market failures". These enterprises use entrepreneurial spirit, innovation, and market mechanisms to operate and generate social value. Consequently, sustainable business practices and serving society become complementary goals [13]. To gauge the status of Taiwan's SEs, Kuan categorized them into five types: work integration or affirmative business, local community development organization, social enterprises providing social services and products, venture capital business created for the benefits of NPOs, and social cooperatives [14]. Most SEs in Taiwan promote the integration of disadvantaged groups into the community by providing work opportunities and vocational training. By a literature review of other researchers' experiences, the authors learned the structure and background of this topic from numerous second-hand materials, including academic journals, media reports, community discussions, and relevant statistics of governmental agencies, in order to further studies in this field.

According to the Social Enterprise Development Investigation Report [15] that was published by the Global Social Entrepreneurship Network (GSEN) in 2015, only 1% of social enterprises can successfully find their business model and grow in scale. In other words, 99% of social enterprises fail.

From this, we could state that starting up a social enterprise is not a sweet dream, but a long journey full of difficulties.

2. Status of SE Development in Taiwan

In September 2014, the Executive Yuan announced the "Social Enterprise Action Plan" to provide a clearer definition of what constitutes an SE in Taiwan. This plan defined SEs as nonprofit or for-profit organizations that solve social problems in areas including long-running challenges related to food, clothing, shelter, transportation, education, and entertainment, as well as newer concerns, such as geriatric care, community building, and environmental protection. Additionally, in response to the rapid expansion of the SE sector, many SEs provide support services to other SEs, such as consulting, venture capital, marketing, and professional information and communications technology services [16–22].

According to a survey that was conducted by Kuan and Wang in 2016, the objectives of SEs that were established in Taiwan are as follows: to create employment opportunities for disadvantaged groups (70.9%), to enhance the self-sufficiency of organizations (62.7%), to increase the income of disadvantaged groups (60.9%), to provide vocational training (56.4%), to enhance the social integration of disadvantaged groups (55.5%), and to increase the funding available for organizations (42%) [23]. Community development has also become a new direction for the development of SEs in Taiwan. These results are summarized in Table 1. Table 1 describes the process of Taiwan social enterprises. Under policy guidance, projects have slowly evolved, and community development has become the focus of social enterprises.

From Kuan and Wang's work, the primary objective for the establishment of SEs in Taiwan is still the advancement of social causes. However, economic advancement has also begun to emerge as a leading purpose since revenue from engagement in production and marketing operations can enhance the self-sufficiency of organizations (Chan, Kuan and Wang, 2011) [24]. The Workforce Development Agency of the Ministry of Labor has continued promoting civil groups and creating various local community industries. This has not only directly created local employment opportunities but also indirectly contributed to local community development and struggling community industries. According to data from the Ministry of Labor, the programs that were implemented by civil organizations and groups can be divided into several categories: social services, cultural industries, tourism and recreation, environmental maintenance, and community industries.

Under the guidance of government policies, SEs in Taiwan have passed through the initial stages of foundation, development, and growth, demonstrating their sustainability and Taiwan's desire for innovation.

Table 1. Purpose of Social Enterprises in Taiwan.

Priority	2006	2010	2013
1	Employment and poverty alleviation	Employment and poverty alleviation	Employment and poverty alleviation
2	Empowerment and general public welfare	Bolster self-sufficiency of organizations	Bolster self-sufficiency of organizations
3	Bolster the self-sufficiency of organizations	Empowerment and general public welfare	Empowerment and general public welfare
4		Community industries development	Community industries development

Source: Kuan and Wang (2016) [23].

2.1. Foundation Stage

After the 921 Jiji Earthquake in Taiwan in 1999, the Council of Agriculture launched an employment and reconstruction plan in disaster-stricken areas by employing those seeking work from affected households in the reconstruction of their homes, thereby providing them with motivation and a source of income [25]. Subsequently, under government guidance, the concept of community building gradually took form, in addition to the related aspects of labor division, fostering talent, and developing strategic alliances, thereby transforming community organizations [26]. Through careful planning by government and civil groups, the Multi-Employment Promotion Program to "promote local industry development as a means to create local employment opportunities" has resulted in mutually beneficial and reinforcing reconstruction efforts. In 2007, Taiwan officially introduced the concept of SEs. This has gradually become a mutually supportive SE ecosystem in terms of innovation incubation, venture capital, education promotion, community exchange, and community industry. Even before 2007, Taiwan had practitioners within industries or NPOs who used forward-looking and innovative thinking in order to create public-welfare value; some even had business models that employed sustainable development practices [27]. Kuan (2007) determined the following to be behind the rise of SEs in Taiwan: responding to social needs, NPOs seeking financial autonomy, privatization of social welfare, policy inducement and government subsidization, and focusing on the need for CSR [28].

Based on the 2013 analysis of 597 NPOs in the Multi-Employment Promotion Program by the Workforce Development Agency, NPOs are generally divided into community economy models (502 organizations), cooperative economy models (15 organizations), and work integration models (80 organizations) [18]. This distribution is outlined in Table 2.

Table 2. Distribution of Three Major nonprofit organization (NPO) Models.

Model	Number of NPOs	Proportion	Organization Type
Community economy model	502	84.1%	Includes unions, associations, farming and fishing associations, and community development associations
Cooperative economy model	15	2.5%	Organizations that are primarily cooperatives
Work integration model	80	13.4%	Includes social welfare groups (organizations) and disability groups

Source: Workforce Development Agency, Ministry of Labor.

The numbers in Table 2 show that the community economy model remains the core of SE foundation in Taiwan. Table 2 shows the distribution of social enterprises in Taiwan. The community economic model accounts for as high as 84.1%, which is in line with the fact that community development type is the cornerstone of existing Taiwan social enterprises. This also echoes with Table 1.

2.2. Development Stage

After 2009, the SEs of Taiwan entered a period of development. Organizations focused on welfare provision considered methods to further develop business activities that could create self-supporting revenue to increase organizations' financial autonomy, whereas SE industries demonstrated a greater concern for social problems and actively examined how market demands could help to fulfill social responsibility, encourage innovation, and create shared value. Using the broadest definition of an SE, many civil organizations can be considered as planning to develop into SEs, including associations, foundations, sheltered workshops, and production cooperatives. SEs are considered the "blue ocean" strategy to resolving social problems in Taiwan. Social entrepreneurs or NPO directors in Taiwan have never ruled out the use of existing market models in order to develop businesses with sustainable financial income to achieve social value, and in fact, many have attempted to make reaching financial autonomy their primary strategy for fulfilling organizational missions.

Emerging industries require policy support, and this is also true for social enterprises, meaning a combination of business value and public welfare. In recent years, social enterprises in Taiwan have accumulated a lot of experience in local economy and social enterprise innovation. This wave of energy also draws the attention of public departments, which have launched related policy support. On 4 September 2014, the Executive Yuan announced the "Social Enterprise Action Plan", which confirmed the importance of SEs in Taiwan [16]. Through this announcement, the government intended to construct a vision of "building an ecological environment conducive to SE innovation, entrepreneurship, growth, and development" by adjusting regulations, establishing platforms, raising funds, and advocating the development of relevant strategies, as listed in Table 3. Governmental departments have implemented the Social Enterprise Action Plan for three years, and prepared a budget of NTD160 million since 2014. Table 3 shows the implementation willingness of social enterprises. According to the co-ordination unit, the implementation of social enterprises is a cross-department, across-organization work. Whether it is policy, regulation, exchange platform, capital budgeting, or talent cultivation, all aspects must be fully considered in order to maximize the output.

Table 3. Summary of Social Enterprise Action Plan.

Plan Strategy	Primary Work Items	Sponsor	Coordinating Unit
Amend regulations	Examine existing laws and regulations by means of regulatory flexibility mechanisms to strengthen the legal environment of SEs.	Competent Authorities for Business Objectives, Ministry of Health and Welfare, Ministry of Economic Affairs, Ministry of Finance, Public Construction Commission	Ministry of Economic Affairs
Establish platforms	Advertise to public and private sectors and establish SE benchmarks.	Ministry of Economic Affairs, Ministry of Labor	Ministry of Labor
	Connect SE communities and nonconventional networks.		
	Set up a guidance system for SEs and establish a one-stop window and guidance dispatch mechanism.	Ministry of Economic Affairs, Ministry of Labor, Ministry of Health and Welfare	
	Use SE mechanisms for a preliminary assessment of public requirements.	Ministry of Health and Welfare, Council of Agriculture, Environmental Protection Administration	
	Conduct international forums and exchange activities for SEs and establish connected networks.	Ministry of Labor	
Raise funds	Introduce resources such as venture philanthropy and angel investors to assist SEs in obtaining funds.	Ministry of Economic Affairs, Ministry of Labor, National Development Council	Ministry of Economic Affairs
	Proposals for corporate organizations that practice CSR to invest relevant resources into SEs.	Ministry of Economic Affairs	
	Proposals for the addition of an SE credit guarantee project for small and medium business to guarantee credit.		
	Creation of a cabinet system to expand channels for the recommendation of SEs and encourage public participation.	Financial Supervisory Commission	
Advocate development	Encourage existing educational centers to add a SE educational guidance mechanism.	Ministry of Economic Affairs	Ministry of Economic Affairs
	Use existing entrepreneurial development resources at colleges to assist with nurturing SE talents.	Ministry of Economic Affairs, Ministry of Labor, Ministry of Education	
	Combine the resources of private enterprises and business incubation centers to establish an SE guidance team.	Ministry of Economic Affairs, Ministry of Labor	
	Take inventory of resources such as unused campus or public spaces for use in SE promotion and incubation.	Ministry of Education, Ministry of Transportation and Communications	

Source: Executive Yuan (2014) [16].

During the initial stages of the government's action plan, associations and workstations devoted their efforts to the construction of numerous local group industries. Although these were located in rural areas, after several years of implementing the Multiple Employment Promotion Project, impressive results were achieved in terms of organizational operation, industry development, and employment.

2.3. Growth Stage—Community Industry Development

Although rural communities may lack talent, technology, equipment, and funds, such communities often possess abundant alternative resources found only in the local area, such as indigenous cultures, cultural landscapes, stories, folk wisdom, native species, historic sites, cultural crafts, and local cuisine.

2.3.1. Community Industry's Birth as a Social Innovation

A social innovation does not come from the imagination, but from knowledge and the concise study of problems. By using design thinking, good ideas that meet the requirements of the real world can be produced. Design thinking is a people-oriented problem-solving methodology that consists of five steps: empathize, define, ideate, prototype, and test, in order that the feasibility of the concept can be tested. After comprehensive thinking, a business idea can be closer to the spirit and implication of social innovation.

Products and services are no good if nobody uses them, even if the entrepreneur believes them to be good. If people are willing to use products but they are not willing to pay for them, they have no market value. According to the Lean Startup theory [29], entrepreneurs shall further stretch the concept of a prototype by using the minimum viable product. In times of change, market validation is an unstoppable process.

Changing social issues is a long journey, and community industries must find their sustainable development model to obtain enough resources and continue to change the targeted problem. If a social enterprise can bring more positive impacts to society, then its original start-up intention can be viewed as achieved.

2.3.2. Social Mission and Enterprise Governance of Community Industry

The original intention of a social enterprise was to solve social problems. However, we should not forget that the enterprise itself is also a small society, and it must manage people and money. Thus, social enterprises must consider their profits, as well as many other aspects. Social Enterprise Insights suggests that entrepreneurs construct a triangle of social responsibilities, organizational responsibilities, and enterprise promises in order to achieve their original intention. The first angle, social responsibilities, is more than the enterprise itself, meaning that it must be recognized by a third-party to publish a public welfare report for the public to learn about the operations of the organization; or, the enterprise can apply for the certification of B Lab in the United States, and such certified enterprises can be given the social responsible title of B Corp. The second angle is organizational responsibilities. Company law stipulates that board of directors and shareholder meetings must be held before the end of June each year. The executive team should prepare the previous year's business report, financial statements, and profit and loss provision table, and submit them for the board of directors' approval and for the recognition of the shareholders'. If these procedures are not conducted, then the enterprise violates the law. However, above the legal bottom line, social enterprises can also increase disclosure of information, strengthen governance transparency, and demonstrate the social benefits of implementing business operations. The third angle is the enterprises promises. Company law stipulates that if the company has a surplus, it must allocate a certain percentage of it to its employees. However, if social enterprises wish to demonstrate their commitment to the long-term prospect, they may set up a special surplus reserve fund, regulate its use in through the company's regulations, and continue to develop its social mission.

Social enterprises should not forget their original intention. In addition to focusing on product quality and pursuing profit growth, they should return to their beginning point and conduct dynamic adjustment to meet beneficiaries' real needs, maintain stable service energy, and continue to exert their influence.

2.3.3. Cooperative Innovation of Community Industry and Enterprise

The topic of how to expand community industry has always drawn many eyes. At present, more and more general enterprises have noticed the emerging power of community industries and have started to cooperate with community industries in various ways, such as financing, procurement, and counseling, in order to expand their social influence. This atmosphere can also serve as an opportunity for community industries to expand in scale, as community industries also hope to find the right enterprise partner and to enter the corporate supply chain. According to the Social Enterprises and Global Corporations Collaborating for Growth with Impact, as published by the Social Enterprise Startup Investment Acumen Fund in 2015, the cooperation of social enterprises and general enterprises can be categorized into different types, and the differences lie in priorities that are put on various aspects, such as motivation, goal, funding, and performance. The cooperation of social enterprises and general enterprises can be categorized into the following three types: channel partnership, skill partnership, and venture partnership. From this report, it is clear that community industry has the insights and innovation capabilities of social issues, while general enterprises have a large scale and more resources. Therefore, through cooperation between the two parties, enterprises can develop their core professionalism, enhance their brand image, and embrace the effects of "1 + 1 > 2", in order to solve the social problems that are highlighted by community industries and produce mutually beneficial win-win effects.

2.3.4. Community Industry and Governmental Support

All emerging industries need policy support, and this is also true for social enterprises, meaning a combination of business value and public welfare. In recent years, social enterprises in Taiwan have accumulated a lot of experience in local economy and social enterprise innovation. This wave of energy has also drawn the attention of public departments, and such departments have launched related policy support by outlining the complete appearance of Taiwan's social enterprise policy development through mutual inspections and studies from the two perspectives of government and civil enterprises. In 2014, the Executive Yuan launched a three-year Social Enterprise Action Plan with a budget of NTD160 million, which invited the Ministry of the Interior, Ministry of Finance, Ministry of Education, Ministry of Economic Affairs, Ministry of Transportation and Communications, Ministry of Health and Welfare, and Ministry of Labor to cooperate and build up a favorable environment for Taiwan's social enterprise innovation, entrepreneurship, growth, and development, according to the four strategies of amending regulations, building platforms, raising funds, and advocating development. When considering that social enterprises in Taiwan are still in the beginning stage, the Executive Yuan at that time decided to use administration-before-legislation as the overall policy guidelines, in order to set free the creativity of nongovernmental organizations. It did not presuppose any excessive legal restrictions; instead, it targeted the promotion of the development of social enterprise ecosphere.

In response to the limitations of current laws and regulations in Taiwan, and whether legislation of social enterprises should be put forward, in recent years, industrial, official, academic, and research circles have discussed such issues and have offered suggestions. Since President Ing-wen Tsai took office in May 2016, due to the beginning of company law amendments, a new wave of discussions regarding social enterprise legislation have occurred. While the company law amendment is still in progress, the amendment direction has slightly loosened the existing provisions of the company law and added new public welfare company chapters.

Social enterprises are flourishing in Taiwan's civil society by solving social problems with social innovations and business models. For the government, the contributions of social enterprises can be mainly categorized into the following three types: gathering power in crisis and reconstructing local industries; combining community management and creativity and setting up local economy models for rural areas; and, creating employment for all people and enabling self-sufficiency through empowerment. A review the implementation of past policies shows that, due to the ossification of administrative and operational procedures, policies will occasionally cause inconvenience to civil and social enterprises, meaning that the goodwill of policies is wasted. When reviewing the government's policy guidelines for supporting social enterprises, as seen from the perspective of social enterprises, future governments are expected to learn from past experience in general and not be kidnapped by the key performance indicators. In action, the private sector, the government, and private departments have their own fields, and they should focus their works in their fields.

"Something only the government can do" is actually creating a sound regulatory environment for social enterprises, as they can use innovative thinking to release and activate idle assets in order to support the development of social enterprises.

To utilize such resources, an economic process must be followed that always proceeds along a basic path: product, merchandise, service, experience, and then brand creation. Any industry can use these processes to increase its economic value and create a brand [30]. The Economic Process is illustrated in Figure 1.

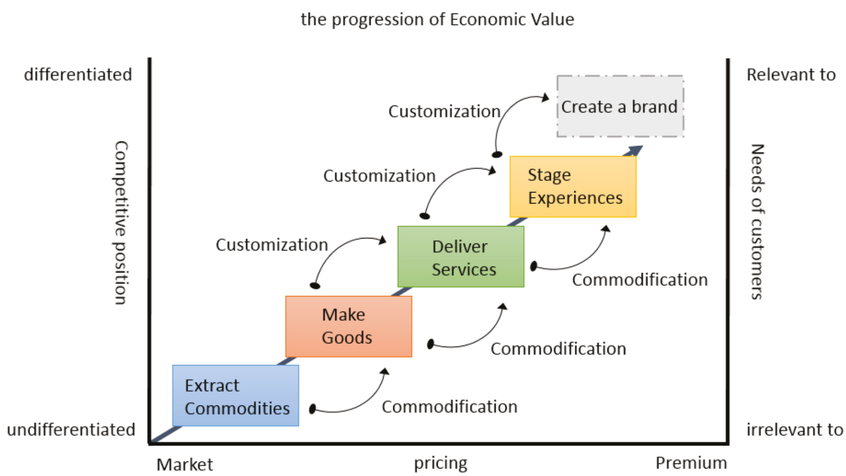

Figure 1. Economic Process. Source: Pine, B. J. II. And Gilmore, J. H. (1999) [30], revised in the present study.

After reviewing relevant literature regarding the planning and establishment of community industries and the development of the Multiple Employment Promotion Program, six major dimensions were identified for the successful development of community industries as SEs: core values, organizational management, key competencies, distinguishing features, strategic resources, and value-added design, as shown in Table 4, and the dimension map of community development industries in Figure 2.

Table 4. Six Major Dimensions of Community Industry Development.

Dimension	Content	Description
Core values	Organizational mission	Founding ideals and objectives of civil organizations.
	Social commitment	Proposals and social practices for improving society.
Strategic leverage	Links to resources	Establish links to local resources such as landscapes, ecosystems, festivals/ceremonies, cuisine, crafts, and people.
	Strategic Alliances	Regional alliances of homogeneous or heterogeneous organizations for community building or industrial development.
	Internet marketing	Based on people's right to internet access, use related tools to develop virtual stores and create business opportunities.
Value-added design	Cultural charisma	Local resources or culture that can be converted into value-added products.
	Creative design	Value-added designs that combines the knowledge economy, experience economy, and other innovative trends.
Key competencies	Primary product	Popular products with profitability.
	Customer service	Customer service and system implementation to promote product sales.
Distinguishing features	Social image	Public recognition or professional accreditation of civil organizations.
	Community resources	Various distinguishing community resources.
	Social capital	Diverse actions, mechanisms, and models to support social concerns.
Organization and management	Human resources	Cultivation of human resources such as grassroots volunteers, mid-level supervisors, and executive managers.
	Financial planning	Planning for fundraising, making profits, and venture capital to enhance financial autonomy.

Source: Chen, Yong Jin (2014) [25].

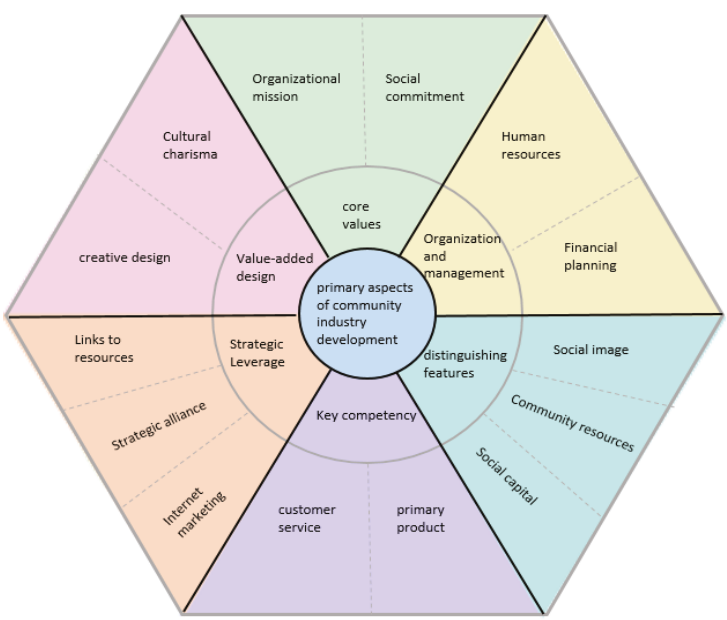

Figure 2. Industrial Dimensions of Community Development.

The development of the community industry aspect in Table 4 is similar to the Strategic Triangle of the social enterprises strategy management by Moore & Khagram. Moore's model can analyze social enterprises because it emphasizes the importance of defining the value of each organization's quest for creation. In this case, the social enterprise has a dual value, since it strives to achieve the organic combination of social value and economic value. When it comes to social enterprise, the implementation of the mission is equivalent to creating [31].

The items that are covered by organizational core values are social welfare, environmental protection, ecological conservation, cultural protection, and employment promotion, whereas action plans, such as environmentally friendly consumption, food miles, low carbon living, and employment diversity are social commitments. The core values can be considered to be the catalysts for shaping Taiwan's SE ecosystem and they have been shaped by research, training, guidance, publicity, and cooperation with SEs, NPOs, communities, governments, investors, incubators, and scholars. Beginning with the article "Creating Shared Value" that was published by Michael E. Porter in 2011, shared values are those that when dealing with societal needs and difficulties, create social as well as economic values. Shared values look to expand total economic and social value. Enterprises can create social value by redefining the productivity of traditional value chains, which in turn creates economic value [32].

Organizational management refers to the chief executive officer, project managers, and trained volunteers. Such management should actively seek to continue receiving social finance and fundraising while developing SEs. Organization type and focus continue to be selected based on profitability. To date, most SEs are focused on topics, such as technological innovation, culture, education, and fair trade, possibly because these are the easiest areas to turn a profit without relying on public donations. Organizations that promote CSR are mostly focused on environmental protection issues, partially because the trend toward environmentally sustainable practices is also an opportunity for future development. The commercialization of NPOs is not separate from their organizational mission, and these organizations mostly focus on disadvantaged groups [33].

Key competencies are based on local characteristics. Yang (2014) stated that SEs are defined by their nature, social influence, and operations; thus, SEs emphasize social issues that relate to their founding principles (e.g., environmental protection, care for disadvantaged groups, employment assistance, cultural preservation, and fair trade). However, SEs can also be defined during their operations, such as through a moving story, a luxurious product, or a dignified work [34]. Although their social influence comes from the social value that they create, the primary objective of SEs is ultimately to maintain continued operations. This is true across such varied examples as the Gaomei Wetlands experience and the Dajia Matzu Pilgrimage Procession, as well as local delivery services, guide services, visitor centers, and customer services.

Distinguishing features are vital to the success of communities or organizations, and these often take the form of accomplished individuals or unique cultural geography. By analyzing their thought patterns or psychological structures, elements that are crucial to SE successes can be extracted [35]. Examples of distinguishing features for SEs can be seen at the Joyce McMillan Erhlin Happy Christian Home in Changhua County, which has a reputation for professional care being gained from its dealings with disabled individuals; the L'olu tribal village in Heping District, Taichung, which has social capital from its joint kitchens; and, the Long-Yan-Lin Welfare Association in Zhongliao Township, Nantou County, which is known for its volunteer clinics.

Strategic resources link community resources to a common marketing strategy. If SEs have their own unique and innovative business models integrating strategic resources with sustainable development [36] or they pursue large-scale investment projects with a commitment to give back to surrounding communities, then it is possible for SEs and local communities to jointly share in successes [37,38]. Linking strategic resources can take many forms, such as: the resource linking of Taiwan ku fish, the Tanayiku River, the Formosan ku fish festival, and the Tsou-style cuisine of the Saviki village in Alishan; strategic alliances, such as the Right Bank Alliance of Linbian Stream and the

Seven Rainbow Villages of Jiujiu Feng; and, Internet marketing, such as the Taiwan Story Box with multiemployment and e-commerce shopping platforms.

Value-added design refers to the innovative ideas or practices of a single enterprise or organization that benefit all relevant stakeholders, which may serve as benchmarks or models for imitation. To facilitate ever-changing societal needs, knowledge is continuously generated and spread (O'Mahoney, 2007) [39]. Enterprises or organizations promoting their designs or activities will imitate, learn, and form alliances in order to determine the most effective means to communicate with other enterprises or organizations. A consequence of such exchanges is that business ethics spread and influence other enterprises to imitate and follow suit, which promotes a change in the ethical environment (Wu, 2016) [40]. Thus, SEs should have forward-looking designs to facilitate this diffusion effect.

The entrepreneurial designer William McDonough called for a production and consumption system that enables everyone to live a life where they are free to pursue happiness and no longer subject to excessive control; that is, oppression by poor design (Derry, 2002) [41]. In discussing how to reduce the human ecological footprint, McDonough said that human industrial civilization endangers nearly every ecosystem on Earth; there is no problem with the design of nature. The problem is with human design (McDonough, 2002) [42]. Community development organizations and civil organizations focus on their own strengths in the development of community industries. The Multi-Employment Promotion Program aimed not only to build supportive social mechanisms, but also to create sustainable local employment. Therefore, this study suggests that recruiting from diverse backgrounds serves as a pathway for the transition of community industries into SEs; that is, community industries lead to diverse employment, which in turn lead to SEs, and result in sustainable employment. The overall relational paths are illustrated in Figure 3.

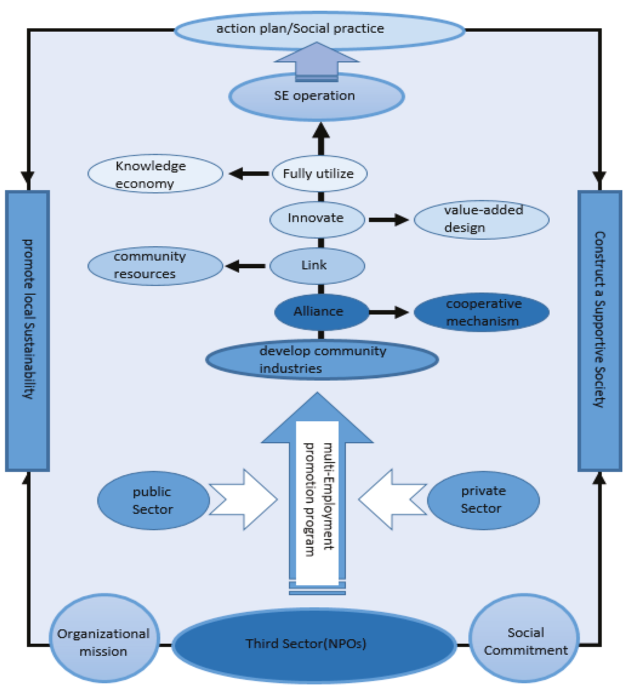

Figure 3. Overall Relational Paths of Social Enterprises.

In Figure 3, the overall relational paths of SEs are illustrated based on the interaction and the sequential progress of the six major dimensions of community industry development. Taken together, they promote the sustainable development of rural communities and construct supportive SEs. This is a virtuous cycle of progress that is driven by commitment to the core values of SEs alongside organizational management overseeing the cooperation of public and private sectors in the implementation of the Multi-Employment Promotion Program.

According to 2017 statistics by the Ministry of Labor and Ministry of Economic Affairs regarding the number of SEs in Taiwan, there are currently 384 SEs and 11,343 potential SEs, as listed in Table 5.

Table 5. Taiwan's social enterprises (SE) Ecosystem.

Organization Type		Number	Total
Current SEs	Corporate SEs registered with the SE registration platforms	106	384
	Noncorporate SEs involved in the Multiple Employment Program + talent cultivation + SE registration platforms	278	
Potential SEs	SEs under the guidance of the Ministry of Economic Affairs, excluding registered SEs	241	11,343
	Cooperatives	4348	
	Local development associations	6754	

Source: Ministry of Labor [18], Ministry of Economic Affairs (2017) [17].

The "2017 Survey of Social Enterprises" was conducted by the UDN survey center (2017) (Table 6) to discuss and examine SEs from the dimensions of "public awareness of SEs" and "the current status of SEs in Taiwan". It outlined the awareness of Taiwanese society toward SEs and potential directions for SE improvement and was the first opinion poll on the status of SEs conducted in Taiwan. The survey was performed through a dual-frame survey of landline and cell phone numbers using random sampling; 1077 valid responses were collected. The survey results indicated that nearly 60% of SEs in Taiwan have been established for less than five years and 40% were still experiencing losses. Primary challenges facing SEs in Taiwan were recorded as "human resource shortages" and "a lack of marketing channels". The awareness of the general public toward SEs did not increase in the two years between the surveys, with only 19.9% having heard of SEs. However, more people identified with the SE business model placing emphasis on both profit and public welfare. Specifically, 64% were willing to pay higher prices in order to purchase SE products or services, and 73% of people were happy to recommend SE products. In a further survey on the status of SEs in Taiwan, of interviewed SEs, 69.4% were registered as companies or trade names and 29.8% were NPOs, such as cooperatives, foundations, associations, and academic units. SEs in Taiwan are mostly young enterprises; 57.9% of interviewed SEs had been established for less than 5 years, 21.2% had been established for 6–10 years, and only 20% for more than 10 years. The social issues that are emphasized by SEs as important to them were extensive. Allowing for multiple responses, nearly 30% included food and agricultural innovation and services in rural areas or for disadvantaged groups. The percentages for environmental protection, promoting employment, and social concerns were all approximately 20%.

SEs in Taiwan are relatively low tech when compared with their counterparts globally. Most engage in host matching and can be easily imitated and replicated. Operations may become difficult for these SEs once well-funded enterprises enter the market. Table 6 summarizes the social enterprise survey. Table 6 shows that 2015 and 2017 have no significant impact on the increase or the decrease in social enterprise support and product consumption experience, which seems to coincide with the features of the small size of Taiwanese social enterprises and the lack of systematic experience.

Table 6. Social Enterprise Survey (2017), Unit: %.

Indicator Dimension	Item	Answer Options	2015	2017	Increase or Decrease
Social cognition	Have you heard of SEs?	Yes	18.9	19.9	1
Degree of support for SE concept	Do you agree with the SE business model of considering profit while pursuing public-welfare goals?	Agree	77.9	78.6	0.7
	Do you believe it is possible for SEs to consider profit while pursuing public-welfare goals?	Yes	64.1	64.7	0.6
SE product consumption experience	Have you used SE products before?	Yes	46	47.2	1.2
	(Have used SE products) Type of SE product or service used	Product manufacturing and sales	69.4	62.7	−6.7
		Dining services	37	43.9	6.9
		General cleaning services	9	7.5	−1.5
		Home services	3.8	3.4	−0.4
		Personal care services	3.5	3.0	−0.5

Source: UDN survey center (2017) [43].

3. Prospects and Limitations of Community Development

According to a survey by Dees (1998), 70% of SEs established within eight years are unable to maintain operations. This is because SEs lack detailed business models, which results in SEs being unable to overcome problems arising from finance, human resources, and market size insufficiencies [44]. The bottlenecks and response methods that were encountered during development were as stated by Evers and Laville. Because of the hybrid characteristic of SEs, they face crises of organizational mission, future positioning, organizational identification, and social capital. SEs must not only adapt to their environment, but must also propose appropriate response strategies to ensure sustainable operations [45].

According to a report by the Executive Yuan, six difficulties must be overcome for SEs to succeed in Taiwan: reinforcement of SE-related awareness and skills, expansion of channels for sourcing funds, development of SE marketing channels, amending SE development laws and regulations, integration of guidance resources, and external issues, such as human resource and research development [16]. Challenges facing SE human resources, services, products, and financial resources are outlined in the following subsections.

3.1. Human Resources

Disadvantaged employees that are employed by SEs are often in a weaker position in terms of mental, physical, or societal function, as well as in their work experience and production capacity; consequently, their work arrangements must be adjusted, which may affect SE operations. SEs are often established by people unfamiliar with business administration and may not know how to establish an appropriate entrepreneurial model to compensate for insufficiencies in resources, skills, or awareness. However, SEs are unlike regular firms that can provide higher pay levels; as a result, they find it difficult to recruit and retain professional management talents. Although Taiwan's government has provided subsidies for project manager personnel, these may still be unattractive to high-level management or marketing talents. Thus, existing personnel must learn new specializations and receive systematic education and training [46], which is an issue that must be addressed in the current development of SEs.

3.2. Services and Products

The core concepts of SEs are based on sustainable development and are aiming for financial self-sufficiency. The operational and managerial requirements of SEs are not only different from those of traditional NPOs, but are also inclined toward a corporate governance model. However, corporate governance and nonprofit governance are essentially different; differences exist between the two in terms of stakeholders, ownership, governance, and beneficiaries (Low, 2006) [47]. NPOs face the dual pressures of maintaining social image and market competitiveness, as well as a lack of marketing experience and funding. Most NPOs generally lack experience in strengthening production and marketing channels, and, as they have yet to locate a market segment to differentiate themselves from similar products, they cannot effectively promote products, which negatively affects their profitability. A holistic process of planning and implementing an idea, product, customer service, pricing, sales promotion, and distribution thus must be employed to satisfy individual and organizational goals [48].

3.3. Financial Resources

For entrepreneurs, the key element of entrepreneurship is not creativity itself, but rather it is the conditions for the marketization of creativity. However, transforming creativity into a product can be especially challenging for NPOs, which generally have limited resources. This is particularly so for small-scale SEs that cannot provide any collateral; banks are simply unwilling to undertake high-risk loans. Several studies have confirmed the difficulties that are faced by small- and medium-sized enterprises when seeking to obtain suitable financing services (Qureshi & Herani, 2011) [49]. Desa (2007) stated that during the early stages of development, SEs will inevitably encounter difficulties resulting from a severe environment and insufficient skill. Thus, SEs should employ multiple channels to integrate necessary resources, such as attracting relevant professionals, through having an attractive mission and vision, and utilizing the free resources of communities to reduce overheads [50]. SEs must obtain societal support, and this support derives from people identifying with organizational beliefs, which in turn leads to a willingness to purchase services or products and become donors or volunteers. Possibly due to their small scale, economic planning and implementation units have a limited scope of influence; however, they can help in cultivating communities and identification with local residents facilitates the gradual promotion of SEs [51].

4. Conclusions and Recommendations

4.1. Conclusions

Taiwan's social enterprise development trajectory can be said to be synchronized with the international community; it also has highlights and characteristics of its own. Taiwan's scale is smaller, and there is also a less systematic compilation of experience and explanation of the model. The operation of social enterprises, when selecting the system, tends to set legitimacy and company interest as priorities. Social enterprises additionally include social benefits, economic benefits, environmental benefits, cultural benefits, and other multiple goals. Cultural resources are the local identities of communities and also their cultural genes. These resources are unique, distinct, local, and irreplaceable, and they remain closely linked to local lifestyles. However, once communities have been empowered, the development and the innovation of community industries still requires cross-disciplinary support to establish an independent business entity that is capable of connecting with the world and mutually aiding others in the pursuit of social values. Taiwan's Multi-Employment Promotion Program can be one path to transforming community industries into SEs by promoting cooperation between all parties to assist community industry rebuilding and value-added development opportunities [52,53].

The development of sustainable employment can be considered as one of the primary purposes of the government sector. Over many years, Taiwan's government has cooperated with local civil groups to perform various social and economic activities to promote the development of SEs. Because SEs have both economic and social goals that promote values, such as social responsibility, empowerment, civic engagement, and social capital, they are a form of social engineering and an economic enterprise worthy of investment. Under such international trends and the current social atmosphere toward SEs, Taiwan's government should lead and use existing powers to integrate resources and to fully promote SEs, thereby realizing their potential. Such a policy would also promote social innovation and economic development.

4.2. Suggestions

Of the organizations in Taiwan that are considered to possess an "SE spirit", 70% are public interest groups and 30% are private enterprises. The percentage of private enterprises has continued to grow, which demonstrates that an increasing number of individuals and organizations are establishing SEs as a means of private investment, which indicates the unique inclination toward small- and medium-sized enterprises in Taiwan. Accounting for Taiwan's current state of development, the following policy recommendations are proposed in order to assist with the promotion of domestic SEs.

- Develop SEs from the perspective of economic policy and encourage social innovation.
- Establish a dedicated unit or communication platform at the department level or higher to integrate resources.
- Develop resource maps to provide a friendly development environment.
- Develop social enterprise incubation centers to encourage innovation and entrepreneurship among young adults.
- Strengthen the international links of SEs to develop benchmarking learning and international cooperation.

In the future, apart from exploring and demonstrating the characteristics of Taiwanese social enterprises, there are still many other factors that we can explore in the operation and value of the system of social enterprises. We look forward to the dialogue and links between practice and academia, and expect government departments to formulate supporting measures covering the legal system, policy, and overall development environment. Social innovation and social entrepreneurship have become the next wave of civic movement, and ecosystems based on these principles have quickly formed, thus marking a crucial milestone in SE development of Taiwan. If development can be sustained, then Taiwan's SEs may well be able to inspire society toward creating a brighter future.

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References

1. Mair, J. *Exploring the Intentions and Opportunities Behind Social Entrepreneurship*; Johanna, M., Jeffrey, R., Kai, H., Eds.; Social Entrepreneurship; Palgrave Macmillan: New York, NY, USA, 2006; pp. 89–94.
2. Nicholls, A. (Ed.) *Social Entrepreneurship: New Models of Sustainable Social Change*; Oxford University Press: Oxford, UK, 2006.
3. Bornstein, D. *How to Change the World: Social Entrepreneurs and the Power of New Ideas*; Oxford University Press: Oxford, UK, 2004.
4. Mair, J.; Marti, I. Social entrepreneurship research: A source of explanation, prediction and delight. *J. World Bus.* **2006**, *41*, 36–44. [CrossRef]
5. Austin, J.E.; Stevenson, H.; Wei-Skillern, J. Social entrepreneurship and commercial entrepreneurship: Same, different, or both? *Entrep. Theory Pract.* **2006**, *30*, 1–22. [CrossRef]
6. Gidron, B.; Yeheskel, H. (Eds.) *Social Enterprises: An Organizational Perspective*; Palgrave Macmilan: New York, NY, USA, 2012.
7. Battilana, J.; Dorado, S. Building sustainable hybrid organizations: The case of commercial microfinance organizations. *Acad. Manag. J.* **2010**, *53*, 1419–1440. [CrossRef]

8. Taiwan Social Enterprise Innovation and Entrepreneurship Society. Available online: http://www.seietw.org/knowledge.html (accessed on 10 February 2018).
9. Zhang, D.; Morse, S.; Kambhamptati, U.; Li, B. Evolving Corporate Social Responsibility in China. *Sustainability* **2014**, *6*, 7646–7665. [CrossRef]
10. Chen, D.-S. *Power of Good, How Social Enterprise Is Shaking The World!* 2nd ed.; Reveal Books Company: Taipei, Taiwan, 2016; pp. 8–10.
11. Hu, J.-S.; Chang, T.-Y.; Wong, H.-R. The Relations of Social Entrepreneurship, Models and Resources Integration in Social. *J. Entrep. Res.* **2012**, *7*, 1–25.
12. Lee, M.; Kim, H. Exploring the Organization Culture's Moderating Role of Effects of Corporate Social Responsibility (CSR) on Firm Performance: Focused on Corporate Contributions in Korea. *Sustainability* **2017**, *10*, 1883. [CrossRef]
13. Lin, Y.-J. The Development and Restriction of Social Enterprises in Taiwan—An Example of Diversified Employment Development Program Economic Projects. *Minis. Labor Employ. Secur. Semi-Annu.* **2008**, *7*, 63–67.
14. Kuan, Y.-Y. The Development of Social Enterprises in Taiwan—Concepts, Traits, and Types. In *Social Enterprise Governance*, 2nd ed.; Chu-Liu Book Company: Taipei, Taiwan, 2016; pp. 123–142.
15. Global Social Entrepreneurship Network (GSEN). Available online: http://www.gsen.global/report-2015/_pdf/GSEN-Report-2015-From-Seed-to-Impact.pdf (accessed on 28 February 2018).
16. The Executive Yuan Approved the Social Enterprise Action Plan (2013–2016). Available online: https://www.ey.gov.tw/Upload/RelFile/26/716149/8d8b6be7-0e21-4a37-9c72-871e28b325d2.pdf (accessed on 1 February 2018).
17. Economic Statistics Annual 2016. The Republic of China Dept. of Statistics Ministry of Economic Affairs. Available online: https://www.moea.gov.tw/Mns/dos/content/ContentLink.aspx?menu_id=9432 (accessed on 12 January 2018).
18. Major Labor Annual 2016. The Republic of China Dept. of Statistics Ministry of Labor. Available online: https://statfy.mol.gov.tw/statistic_DB.aspx (accessed on 12 February 2018).
19. Interior Statistics Annual 2016. The Republic of China Dept. of Statistics Ministry of Interior. Available online: https://www.moi.gov.tw/stat/node.aspx?cate_sn=&belong_sn=6463&sn=6465 (accessed on 12 January 2018).
20. Taiwan Health and Welfare Annual 2016. Ministry of Health and Welfare. Available online: https://www.mohw.gov.tw/lp-3196-1.html (accessed on 12 February 2018).
21. Ministry of Transportation and Communications Annual 2016. Available online: https://www1.stat.gov.tw/ct.asp?xItem=15464&CtNode=4761&mp=3 (accessed on 15 February 2018).
22. Statistics Annual 2016.Council of Agriculture, Executive Yuan. Available online: https://www.coa.gov.tw/ws.php?id=2506265 (accessed on 15 February 2018).
23. Kuan, Y.Y.; Wang, S.T. *The Governance and Social Impact of Taiwan's Social Enterprises*, 2nd ed.; Chu-Liu Book Company: Taipei, Taiwan, 2016; pp. 173–194.
24. Chan, K.T.; Kuan, Y.Y.; Wang, S.T. Similarities and Divergences: Comparison of social enterprises in Hong and Taiwan. *Soc. Enterp. J.* **2011**, *7*, 33–49. [CrossRef]
25. Chen, Y.J. *Outlet and Process of Rural Community Industrialization under the Social Enterprise Globalization, Water for Public Welfare: Theory and Practice of Social Enterprises in Taiwan*; Hu, W., Ed.; New Taiwanese Culture Foundation: Taipei, Taiwan, 2014; pp. 221–235.
26. Huang, Y.-K.; Zhuang, L.X. *New Trends in Community Development*; Publishing Community Development Journal (Quarterly), Ministry of Health and Welfare: Taipei, Taiwan, 2016; Volume 155.
27. Zhang, M.R. Taiwan's agricultural predicament and its response to the current situation. *Taiwan Econ. Res. Mon.* **2009**, *32*, 97–102.
28. Kuan, Y.-Y. The Development of Social Enterprise Organizations in Taiwan. *China Nonprofit Rev.* **2007**, *1*, 146–182.
29. Ries, Eric. *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*; Crown Business: New York, USA, 2011.
30. Pine, B.J., II; Gilmore, J.H. *The Experience Economy*; Harvard Business School Press: Boston, MA, USA, 1999.
31. Moore, M.; Sanjeev, K. *On Creating Public Value: What Business Might Learn from Government about Strategic Management*; Corporate Social Responsibility Initiative Working Paper No. 3; John F. Kennedy School of Government, Harvard University: Cambridge, MA, USA, 2004.

32. Yang, C.L. The Core of Social Enterprise, to Create Shared Value. 2014. Available online: http://archives.ey.gov.tw/01ey/20160110/www.ey.gov.tw/News_Content157cfa.html?n=22DE2FC89D3EE7DA&s=8389D6F2CFEB6BE2 (accessed on 15 February 2018).
33. Yang, J.Q.; Guo, X.Y. Social Enterprise Organization Type and Management Type. *Acad. Manag. Rev.* **2011**, *18*, 53–78.
34. Yang, C.L. Social Enterprise 3 Y to Create Unique Commodity Value. Taiwan Social Enterprise Innovation and Entrepreneurship Society (TSEIES) 2014. Available online: http://www.seietw.org/1285623103820225qa.html (accessed on 15 February 2018).
35. Chen, L.H.; Huang, Z.M. Research on the Business Model of Kobayashi Community Social Enterprise—Take "2021 Social Enterprise" as an Example. *Acad. Manag. Rev.* **2017**, *24*, 47–76.
36. Huang, Y.X.; Zhuang, L.X. New trend of community development. *Community Dev. J. Quart.* **2016**, *155*, 221–240.
37. Feng, Y.; Chen, H.H.; Tang, J. The Impacts of social Responsibility and Ownership Structure on Sustainable Financial Development of China's Energy Industry. *Sustainability* **2018**, *10*, 301. [CrossRef]
38. Yang, M.-H.; Wu, J.-T.B.; Su, C.-J.; Kao, T.-Y.K. Developing Business Model for Social Enterprises. *J. Entrep. Res.* **2009**, *4*, 57–83.
39. O'Mahoney, J. The diffusion of management innovation: The possibilities and limitations of memetics. *J. Manag. Stud.* **2007**, *44*, 1324–1348. [CrossRef]
40. Wu, C.-F. The relationship between Business Ethics Diffusion, Knowledge Sharing and Service Innovation. *Manag. Decis.* **2017**, *54*, 1343–1358. [CrossRef]
41. Derry, R. Seeking a Balance: Critical Perspective on Entrepreneurship and the Good Society. Business Ethics Quarterly (Ruffin Series No.3). *Ethics Entrep.* **2002**, *3*, 128–197.
42. McDonough, W.; Braungart, M. *Cradle to Cradle: Remaking the Way We Make Things*; North Point Press: New York, NY, USA, 2002.
43. 2017 Social Enterprise Survey. UDN Daily News Survey Center. 2017. Available online: http://p.udn.tw/upf/vision/2017/2017visionstory79004.pdf (accessed on 15 January 2018).
44. Dees, J.G. *The Meaning of Social Entrepreneurship*; Working Paper; Kauffman Center for Entrepreneurial Leadership: Kansas City, MO, USA; Palo Alto, CA, USA, 1998.
45. Evers, A. Mixed welfare systems and hybrid organizations: Changes in the governance and provision of social services. *Int. J. Public Adm.* **2005**, *28*, 737–748. [CrossRef]
46. Chao, T.-F. *Study of Talents Cultivation and Community Development: In Case of Pingjen City, Taoyuan County*; Yuan Ze University: Taoyuan, Taiwan, 2007.
47. Low, C. A framework for the governance of social enterprises. *Int. J. Soc. Econ.* **2006**, *33*, 376–385. [CrossRef]
48. Kotler, P. Strategies for Introduction Marketing into Nonprofit Organization. *J. Mark.* **1979**, *43*, 37–44. [CrossRef]
49. Qureshi, J.; Herani, G.M. The role of small and medium-size enterprises (SMEs) in the socio-economic stability of Karachi. *Indus J. Manag. Soc. Sci.* **2011**, *5*, 30–44.
50. DESA. World Economic and Social Survey 2007 Development in an Ageing World. Department of Economic and Social Affairs (DESA). 2007. Available online: https://www.un.org/development/desa/en/ (accessed on 15 January 2018).
51. Wang, B.J.; Zheng, S.F.; Wu, J.L. Research on Non-Profit Organizations' Social Enterpriseization in Taiwan. National Development Committee; 2013. Available online: https://www.ndc.gov.tw/News_Content.aspx?n=E4F9C91CF6EA4EC4&s=AC9E046F9622F160 (accessed on 15 January 2018).
52. Jin, J. *From Non-Profit Organizations to Social Enterprises Cannot Change the Drug: Role, Environment, Strategy and Thinking, Have Changed?* Social Enterprise Insights: Taipei, Taiwan, 2014.
53. Bidet, E. Achievements and Challenges for Social Enterprises in South Korea. In Proceedings of the 3rd International Seminar on Philanthropy and 2012 Conference on Social Enterprises in Eastern Asia, Tianjin, China, 8–9 December 2012.

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Article

Spatial Evolution of Producer Service Sectors and Its Influencing Factors in Cities: A Case Study of Hangzhou, China

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Abstract: Producer service industries are an important feature in the current development of a metropolis. Researchers from different countries are increasingly concerned about location changes and the motives of producer service sectors in cities. Given the rapid development of producer service sectors in developing countries, this study examines changes in the distribution of producer service sectors over the past decade and factors influencing them in a case study using the city of Hangzhou in China. Results show that Hangzhou's producer service sector is still mainly concentrated in the central business district (CBD). However, a distinct trend of diffusion to suburban areas was observed, which formed several secondary clusters on the periphery of the city. Locations of the CBD, sub-centers, and professional clusters of producer service sectors established by the government are the most important factors that affect the spatial distribution of producer service sectors. The main influencing factors for the spatial evolution of producer service sectors are: (1) the high development cost and residential suburbanization of the central areas of the city promote the development of producer service sectors toward the periphery; (2) city planning has guided the clustering of producer service sectors on the city's CBD and secondary city centers; (3) city renewal has provided personalized and diversified development space for producer service sectors; (4) incentive policies introduced by the government, such as rentals, and taxes have enhanced the orderly aggregation of producer service sectors.

Keywords: producer service sector; industry location; spatial evolution; influencing factors; Hangzhou

1. Introduction

Given the globalization of economic development, metropolises constantly spring up and significantly affect economies across the world [1]. The industrial structures of metropolises have been focused on producer service sectors since the 1950s. The productive service industry of China is developing rapidly in the 21st century. According to the Statistical Yearbook of China's Tertiary Industry 2017, the added-value of the productive service industry grew at an average rate of 15.91% from 2005 to 2016, but decreased to 8.67% in 2016. Nonetheless, the proportion of added-value of the productive service industry in GDP rose stably and reached 25.75% in 2016. From 2005 to 2016, total social fixed-asset investment in the productive service industry grew at an average rate of 19.49%. Moreover, the number of persons employed by the productive service industry in cities and towns, about 52,000,000, remained stable from 2004 to 2015. The proportion of foreign direct investment in the productive service industry surpassed that of the manufacturing industry for the first time in

2015. Specifically, productive services became the industry with the largest foreign direct investment, with its proportion reaching as high as 43.64% in 2016. These data amply signify that the productive service industry has achieved considerable progress in inviting foreign investment and improving its international competitiveness. Spatial changes in producer service sectors have distinct particularities in China. Moreover, the government adopts strict regulations in the process of economic development, in addition to market mechanisms similar to Western cities [2,3]. For the past three decades, China's reform and open-door policy have given rise to the rapid development of Chinese manufacturing and service sectors while significant changes have occurred in industrial structures [4]. At the same time, more central business districts (CBDs), sub-CBDs, and office blocks are rising in big cities in China [5,6]. The types of office space tend to be diversified. In addition to traditional office buildings, old factory buildings and warehouses have been converted into office space during urban renewal. In the context of diverse office-space types, multiple-center office space structures, mobile office modes, and office suburbanization, traditional office-location theory can no longer meet the requirements of current development needs [7,8]. Existing research on the productive service industry is mostly from the perspective of the world, nation, or urban agglomeration. Few studies have focused on the microscopic urban internal structure. Hence, understanding the spatial features, influencing factors and development patterns in the productive service industry in cities is essential for government agencies. These agencies could utilize scientific data in the preparation of incentive policies for office land-use planning, office-building construction, and rental. Consequently, effective programs could lead to sustainable development of the productive service industry and urban space.

Hangzhou, which hosted the 2016 G20 (Group of Twenty finance ministers and central bank governors) summit and the 2016 B20 (Business Leaders from the G20 countries) summit, is one of cities with the fastest development of service sectors in China. This study intends to explore the characteristics of spatial evolution of producer service sectors under the dual influences of market factors and governmental factors. Similarly, this study differentiates Hangzhou from other cities in the world by conducting research on the spatial pattern evolution of urban producer service sectors in Hangzhou from 2003 to 2013 and their influential factors. This study will adopt various models, namely, spatial density, spatial autocorrelation and spatial regression.

The rest of the study is organized as follows. The second section is a literature review of the spatial evolution of producer service sectors. The third section provides an introduction to research regions and research methods. The fourth section demonstrates spatial density analysis of producer service sectors, analysis of sub-industrial distribution characteristics, and analysis results of the effects of influential factors in the inner-city space location of producer service sectors. The fifth section discusses the evolution mechanisms of spatial patterns of producer service sectors under the influence of two aspects, namely, governmental guidance and market economies. The sixth section provides the conclusion, which is then compared with conclusions obtained in other studies on regional case cities.

2. Literature Review: Inner-City Locations of Producer Service Sectors

Spatial distribution modes of producer service sectors are influenced by a variety of factors of agglomeration and diffusion at different spatial scales by different industries [9–12]. In the early stage of development of metropolises, scholars studied the location characteristics of service industries from the perspective of accessibility, transaction cost, land rentals, and information services [13]. Several empirical studies were conducted with the advent of city globalization after the 1990s. For example, scholars studied the decentralization conditions of different service sectors and office space at regional scales [14–17], and the connection pattern of producer service sectors between different cities [11,12]. In the inner scale of cities, changes in service sectors in different CBDs were discussed [12]. However, the accelerated growth of producer service sectors was generally the research hotspot of macro-scale city space structures. Micro-scale research on the inner parts of cities is relatively limited [18–21]. First, producer service sectors embody strong spatial agglomeration characteristics, given the forward and backward relevance of agglomeration economies [22]. The availability of a diversified producer service sector attracts corporate headquarters to central positions, and requirements for "face-to-face" exchanges with agglomerated high-level services. This agglomeration forms service complexity [23], which can reduce intermediate service investments' market opportunities, production innovation, and labor costs [24,25]. Companies that benefit the most from "face-to-face" information exchanges are willing to pay the expensive land prices required for convenient locations [26].

Second, producer service sectors have exhibited a spatial trend of diffusion, particularly driven by the progress of information technologies, residential suburbanization, and the high cost of central areas [27–30]. The diffused and decentralized trend of producer service sectors started to gain attention in the 1980s as sub-centers of cities also developed the functions of producer service sectors [31–35]. Transformations in information technology and suppliers have forced an increasing number of companies in central areas to implement suburban expansion strategies [31,36]. Existing studies on metropolitan areas include New York, Atlanta, Los Angeles, Washington DC, Montreal [37], Sydney [38] and Seoul [39]. Many small cities that have good transport conditions and communication infrastructures and are within an hour's drive to a metropolis have also become a place to develop service sectors [40].

Spatial distributions of the producer service sectors also differ by industries. CBDs gradually become diffused production organizations and management and administrative hubs for companies with certain branches [15,18,41]. Market demands decide the location distribution of producer service sectors in cities. The sites of financial, legal and insurance offices of service corporate headquarters are chosen in the downtown area. Industries with mixed insurance, corporate and consumer markets place less focus on real estate and accounting. By contrast, departments that offer technical services, including computer services and research, are given a high concentration in high-tech suburban cities [11,15,34,42]. Several information exchange industries that are highly dependent on "face-to-face" exchanges can be appropriately concentrated in CBDs [15,24,43,44]. Several producer service sectors, such as advertising, accountancy, management and technical services, are separated from manufacturing enterprise. Thus, they prefer to be located in sub-CBDs which are closely related to the manufacturing sector [4,40].

This study uses spatial density models, spatial autocorrelation models, and spatial econometrics regression models in a geographic information system (GIS). These models are used to measure the spatial agglomeration and diffusion levels of the producer service sectors in Hangzhou for the past 10 years in order to explain the driving force in its formation. This approach can also verify whether the existing regularities of producer service sectors in the process of spatial evolution locally and internationally are applicable to Chines cities.

3. Data and Research Methods

The influencing factors that affect the spatial evolution of producer service sectors can be divided into three major categories: enterprises (market-driven), urban spatial structure (path dependence), and governments (spatial ordering). The enterprises provide location decisions for the spatial evolution of producer service sectors, and the governments provide policy guidance. Therefore, we construct a study framework (Figure 1) to assess the spatial evolution of producer service sectors and its influencing factors in cities using the case study of Hangzhou, China.

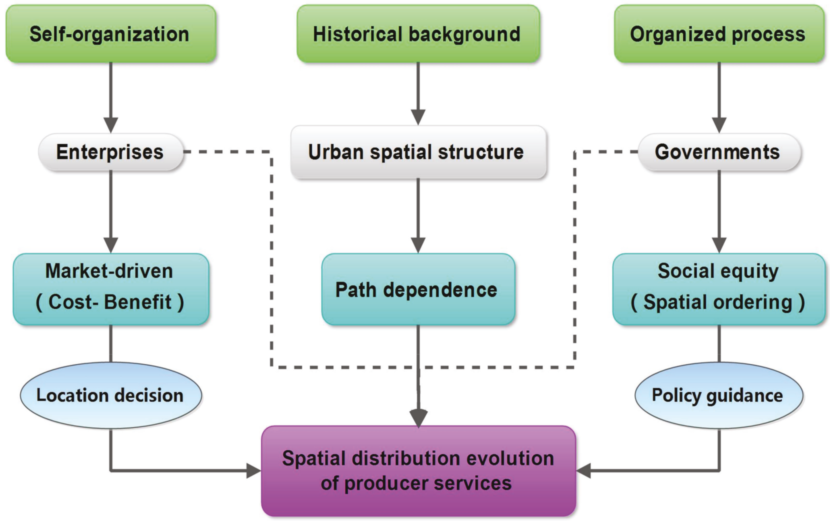

Figure 1. Study framework.

3.1. Study Area

Hangzhou is home to China's largest online retail trading platform, Alibaba Group, and a central city south of the Yangtze River Delta region. It is one of the most developed cities in China, and is advanced in tertiary industries. In 2014, Hangzhou accommodated 407 large office buildings mostly for producer service sectors, and the buildings accumulated a total amount of 25.347 billion Yuan in state and local taxes. Seventy-eight of these offices each accumulated more than 100 million Yuan in taxes. In the last few years, the government has also planned and built special types of producer service sector clusters, such as creative parks, hi-tech parks, city complexity, and pioneer parks, in addition to traditional CBDs.

In this study, 95 streets (areas) in the main urban areas of Hangzhou are divided into four groups, namely: CBD, sub-center, near suburban, and remote suburban (Figure 2). The current central city is the main built-up urban area of Hangzhou prior to 1949, the start of the People's Republic of China, and consistent with the urban administration management scope of 1982. This central city is considered as the CBD of Hangzhou today. The sub-center is determined in Hangzhou's 2004 version of overall planning. Rear and remote suburban areas are divided according to the density of the population, and the population density of near suburban areas is higher than that of remote suburban areas.

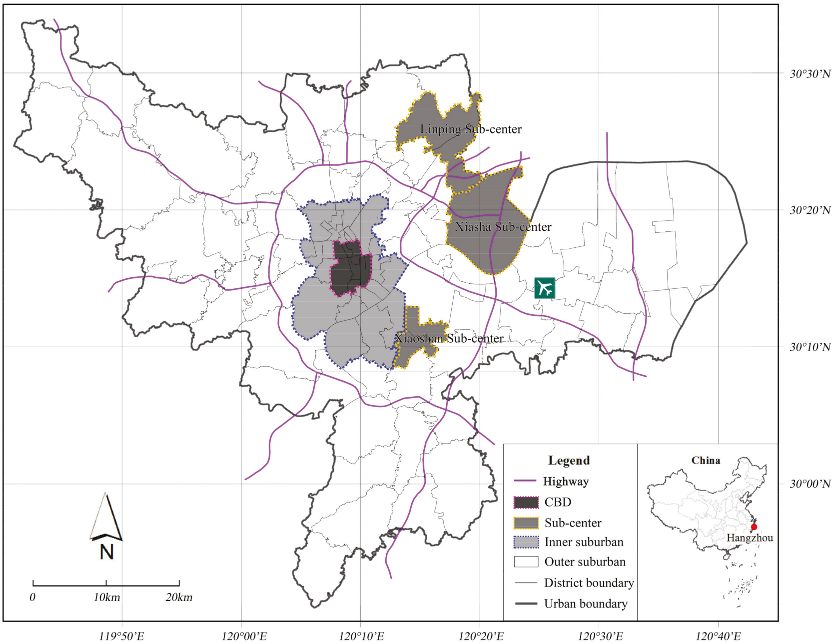

Figure 2. Map of research areas.

3.2. Data Sources

The sample data of producer service in this study is derived from official yellow pages, which are an internal common telephone directory for commercial and industrial enterprises compiled according to the nature of business and product categories. The name, address, and telephone number of registered businesses are the main content of this directory. Businesses comply with certain size requirements of the authorities, but the database does not provide specific data on employment and office scales. Lack of these data is one of the restrictions of this study and has resulted in the differences in the spatial distribution of enterprises after the scale is weighted. Therefore, the spatial forms that the present study explores refer to the concept of enterprise quantity distribution locations and not the agglomeration concept of employment and office scale referred to in previous research. The latest official yellow pages that we collected are the official yellow pages 2013. Therefore, the present study collected 21 enterprise data in producer service sectors, 8494 enterprise records in 2013, and 13,723 enterprise records in 2013 from the yellow pages. Given the lack of uniform classifications in producer service sectors, this study refers to previous research [45] and compares the Chinese National Standard Industrial Classification (CNSIC) of the National Bureau of Statistics of China and the industry classification of the North American Industry Classification System (NAICS). Twenty-one industries are then merged into five categories (Table 1).

Table 1. Comparisons of service sector classification.

Code	Category	North American Industry Classification System (NAICS)	Yellow Pages	Number of Enterprises in 2003	Number of Enterprises in 2013
IND1	Information, software and communication services	(51) Information	Information service; Computer service; Communication services	1023	3010
IND2	Finance and insurance services	(52) Finance and Insurance	Financial service; Insurance; Investment services; Security;	478	917
IND3	Rental and business services	(53) Real Estate and Rental and Leasing; (55) Management of companies and enterprises	Broadcasting; Advertising; Exhibition services; Accountancy; Professional services; Management of companies and enterprises; Rental service; Business services; Legal service;	5960	6694
IND4	Scientific and technical services	(54) Professional, Scientific, and Technical Services	Scientific research; Technical services;	379	1889
IND5	Transportation, warehousing and postal services	(48–49) Transportation and warehousing	Transportation; Logistics service; postal service;	654	1213

3.3. Research Methods

3.3.1. Spatial Density Analysis

This study uses the kernel density function (KDF) to calculate the magnitude per unit area based on points and polylines to fit each point and polyline into a smooth surface [46]. This approach helps prepare occurrence probability maps and identify agglomeration phenomena in research areas. This method is described in the study of Silverman [47]. This study utilizes the statistical values of producer service sectors in each street in Hangzhou in 2003 and 2013. Estimation and a smoothing treatment were conducted through KDF functions, and density values were divided into 10 grades. Changes in the spatial distribution of Hangzhou's producer service sectors were also explored.

3.3.2. Spatial Autocorrelation Statistics

This study calculates the overall and sub-industrial Moran's I of Hangzhou's producer service sectors in 2003 and 2013 to compare spatial agglomeration and diffusion levels of different industries in different periods. A positive Moran's I means that adjacent units have similar values, which indicates spatial agglomeration. A negative Moran's I means spatial diffusion [48]. The definition of global scale Moran's I is given as:

$$I(d) = \frac{N \sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} W(i,j)(x_i - \overline{x})(x_j - \overline{x})}{\left[\sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} W(i,j) \right] \sum_{i=1}^{N} (x_i - \overline{x})^2} \quad (1)$$

$$\overline{x} = \sum_{i=1}^{N} x_i / N \quad (2)$$

Representing a variable of unit I, $W(i,j)$ is a spatial weight matrix; if unit I and unit j is adjacent, $W(i,j) = 1$ or $W(i,j) = 0$. Moran's I fluctuates between -1 and 1; $I(d) < 0$ means negative spatial correlation; $I(d) > 0$ mean positive spatial correlation; and means no spatial correlation. High value means strong correlation.

This study then identifies hot regions of spatial agglomeration and diffusion of producer service sectors in different years and the changes they underwent using local indicators of spatial autocorrelation (LISA), which is the decomposition of the global scale spatial autocorrelation statistics of global Moran's I [49]. LISA statistics can further identify spatial position where agglomeration occurs, namely, a "hot-spot" [48]. The calculation method for the local indicators of spatial autocorrelation (LISA) is given as

$$\begin{aligned} \mathrm{I}_i &= \mathrm{z}_i \sum_j W(i,j) z_j \\ &= \frac{x_i - \overline{x}}{\frac{\sum_{j=1, j\neq i}^{N} x_j^2}{N-1} - \overline{x}^2} \sum_{j=1}^{N} W(i,j)(x_j - \overline{x}) \end{aligned} \tag{3}$$

Z_i is the standardized form of xi, and the meaning of W (i, j) is same as the global Moran index. The sum of all local Moran's indices is equal to the global Moran's index. Streets with significant LISA are divided into four categories and allocated in four quadrants in the Moran scatter plot [49]. These categories are high–high, low–low, low–high, and high–low. High–high and low–low denote the height of enterprise density values of the street itself, whereas low–high and high–low denote the height of enterprise density values of adjacent streets. Identified streets denote the height of enterprise density values of the street itself and adjacent streets have significant correlation.

3.3.3. Spatial Regression Models

This study used spatial regression models to explain the influences of influencing factors of different locations on producer service sector distribution. The spatial regression model brings in spatial constant coefficient regression models for spatial effects (spatial correlation and spatial differences) [49,50]. This model includes the spatial lag model (SLM) and spatial error model (SEM). The maximum likelihood method is normally used to conduct estimation.

The influencing factors of city space are underscored from the perspectives of history, current status, and government [51]. Historical inertia and cumulative causation have a significant influence on the spatial process of producer service sectors [36,51,52]. Historical factors reflect the domicile, sunk costs, and unmovable resources of workers related to the development of producer service sectors [53]. Current status factors mainly refer to access to customers and the availability of different types of services. Governments guide site decision making of enterprises through special preferential policies [54]. This study considers the availability of variables. Twelve spatial influencing factors were selected as an explanatory variable (Table 2), and the degree of agglomeration of producer services were used as a dependent variable to establish a spatial regression model. The degree of agglomeration of producer services is calculated by the number of producer services in a street area in 2003 and 2013, that is, the enterprise densities. Although these variables are precisely related with distance (except some dummy variables), the geographical distribution with the econometrics models needs to be controlled since the distances in variables only reveal the relationships among points of enterprise location, and the spatial dependences cannot be solved in an ordinary econometrics models. Faced with a similar situation, Zhang (2016) selected a spatial regression analysis to reveal the impact of flood hazards on neighborhood house prices [55].

Table 2. Variable table of location influencing factors.

Perspective of Impact	Variable	Variable Models	Unit	Description
History	HWY	Ln	m	Distance between the street center and expressway exit and entrance
	RWS	Ln	m	Distance between the street center and the nearest railway station
	SCE	Ln	m	Distance between the street center and the nearest scenic spot
	POP	Ln		The resident population density of the street is totally divided into 7 grades, with 7 as the highest grade, 1 as the lowest grade.
	PLAND	Ln	Yuan/m^2	Average land price level of the street
Current status	CBD	Ln	m	Distance between the street center and central business district (CBD) in current status.
	SCEN	Ln	m	Distance between the street center and the city's sub-center in current status.
	COLL	Ln	m	Distance between the street center and universities.
	COMM	Ln	m	Distance between the street center and the commercial center.
Market system	INDUS	Dummy variable	1/0	Whether the street is within the scope of the industrial zone, Yes, 1; No, 0.
	SCIP	Ln	1/0	Distance between the street center and the nearest Hi-Tech park
	CPR	Dummy variable	1/0	Whether the street is located within the scope of the creative park, Yes, 1; No, 0.

Anselin et al. (2006) put forward a spatial regression model selection decision rule among ordinary least squares (OLS) models, spatial lag models (SLM), and spatial error models (SEM) [56]. If the Lagrange multiplier (lag) is significant, but the Lagrange multiplier (error) is not, run the spatial lag model, and vice versa. If both Lagrange multiplier (lag) and Lagrange multiplier (error) are significant, check Robust LM (lag) and Robust LM (error). If Robust LM (lag) is significant, but Robust LM (error) is not, run the spatial lag model, and vice versa. If both Robust LM (lag) and Robust LM (error) are significant, choose the one with the biggest test value. R^2, Log likelihood and Akaike information criterion (AIC) are adopted to compare the model performances. The model with greater R^2 and log likelihood values and a lower AIC indicates better performance (Weng et al., 2016; Voss et al., 2006) [57,58], and is selected for regression analysis. If there is a conflict between the indication given by Moran's I and that given by the Lagrange multiplier test statistics (Anselin, 2005), we also select the model with best model performance for regression analysis.

4. Results

4.1. Spatial Distribution Pattern of Producer Service Sectors

4.1.1. Spatial Pattern and Hotspots

Hangzhou's producer service sectors showed a diffusion spatial pattern from 2003 to 2013, with differences in industries of different service sectors (Table 3). The increased Moran's I of information, software and communication services from 2003 to 2013 indicates that service sectors of Information, software and communication services underwent an agglomerated trend. However, Moran's I of Rental and business services and Transportation, warehousing and postal services from 2003 to 2013 decreased, which means that the two types of service sectors showed a diffused trend. The industry with the highest agglomeration level in 2003 is Transportation, warehousing and postal services, which had a value of 0.635. The industry with the lowest level of agglomeration is Information, software and communication services at 0.299. The industry with the highest agglomeration level in 2013 is also Transportation, warehousing and postal services with a value of 0.635. The industry with the lowest level of agglomeration is Scientific and technical services at 0.366.

Table 3. Index table of spatial agglomeration of producer service sectors.

	All		**IND1 Information, Software and Communication Services**		**IND2 Finance and Insurance Services**		**IND3 Rental and Business Services**		**IND4 Scientific and Technical Services**		**IND5 Transportation, Warehousing and Postal Services**	
Year	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013
Moran's I	0.627 ***	0.562 ***	0.299 ***	0.472 ***	0.532 ***	0.573 ***	0.631 ***	0.518 ***	0.535 ***	0.366 ***	0.635 ***	0.595 ***
z-score:	10.834	9.710	5.905	8.535	9.377	10.382	11.034	9.388	9.324	6.958	10.957	10.296

Note: * represents significance in the level of 10%; ** represents significance in the level of 5%; *** represents significance in the level of 1%.

To further understand the spatial distribution features of service sectors, this study identifies the hotspot region distribution of agglomeration and diffusion by the LISA statistics (Figure 2) and the spatial density distribution patterns of producer service sectors (Figure 3). The values of overall Moran's I, 0.627 in 2003 and 0.562 in 2013 imply that producer service sectors showed significant spatial autocorrelation.

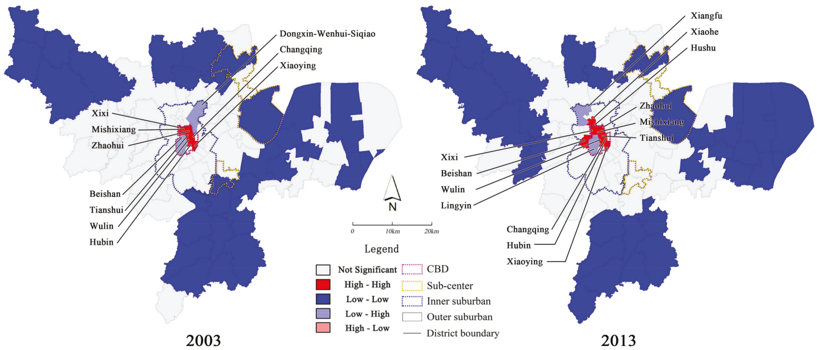

Figure 3. Diagram of the density of local indicators of spatial autocorrelation (LISA) agglomeration of producer service sectors.

Areas with a "high–high" value for agglomeration are mainly located in the central area of the city. The main agglomeration hotspot regions of 2013 mostly includes eight streets, which are largely the scope of the main urban area of Hangzhou city in 1990s. The typical regions are the Hubin and Wulin Square areas, and the main agglomeration hotspot areas in 2013 were more enlarged than that in 2003, which reached streets with the addition of Hushu Street, Xiaohe Street, and Lingyin Street. These added areas are mainly located in the periphery of former agglomeration areas.

Low–high area mainly refers to areas that are significantly different from their peripheral neighbors, which mostly were Shiqiao–Wenhui and Dongxi Street. These streets are the main areas expanded by the city over the past few years, and Beishan Street, which has scenic spots and parks in 2003. In 2013, this area also included Xiangfu Street, which is a commercial and economic agglomeration area that emerged in recent years.

Low–low areas are mainly sprinkled in the remote area of the city, which are largely rural areas without urban economic development.

4.1.2. Spatial Density Distribution Pattern of Producer Service Sectors

The spatial density of Hangzhou's producer service sectors in 2013 is broader than that in 2003 (Figure 4). This finding shows a pattern of agglomeration in the city's central area and some remote areas. Compared with 2003 values, the top four grades (density range: 7.0–11.0) with the highest value in 2013 expanded outward from the central area. Similarly, the fifth grade and the sixth grade showed a form of peripheral dot-shaped agglomeration. The main areas in the density distribution expansion of the central area are the southern and northern regions of the city, as well as the CBD area of Qianjiang. Peripheral dot-shaped agglomeration areas are mainly the Linpin sub-center, Xiaoshan sub-center, Binjiang area, Jiubao, and East railway station. These areas are largely the sub-center and important external transport hub areas of the city.

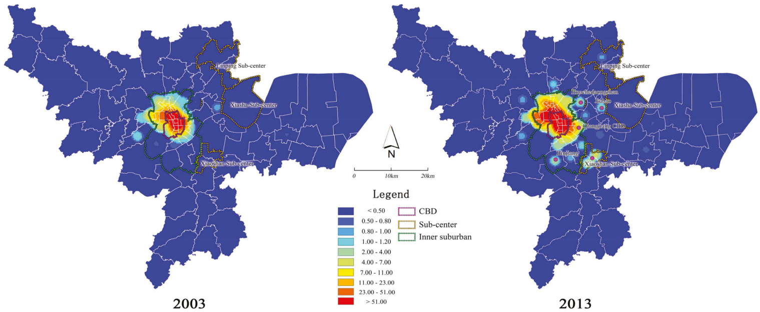

Figure 4. Kernel density function (KDF) density diagram of producer service sector.

Areas with a growth rate in enterprise density of producer service sector growth, which are the highest in Hangzhou, are mainly on the periphery of the city's central area, followed by the sub-center and near suburban. Figure 5 shows that areas with a growth rate of more than 15% are mostly Wulin Street, Caihe Street, Gudang Street and Cuiyuan Street, Hushu Street, Sijiqing Street, Xiaohe Street, Hemu Street, Wenxin Street and Gongchenqiao Street. Areas with a growth rate between 5% and 15% are near suburban in the south and north of the city, as well as Linping and Xiaoshan sub-centers. Areas with a growth rate of over 10% are mainly Tianshui Street, Changqing Street, Xiaoying Street, and Qingbo Street. Areas with most reduction are largely central areas with the highest density of urban pollution, and the periphery of scenic area of Xihu. Figure 6 shows areas with the largest quantity of distribution in 2003, which are the city's central areas, followed by near suburban. Areas with the largest quantity of distribution in 2013 are near suburban. An apparent increase was also observed in sub-center areas. From 2003 to 2013, the proportion of enterprise number in the central areas decreased from 41.82% to 22.99%, and the proportion of enterprise number in the sub-center areas increased from 35.67% to 38.69%.

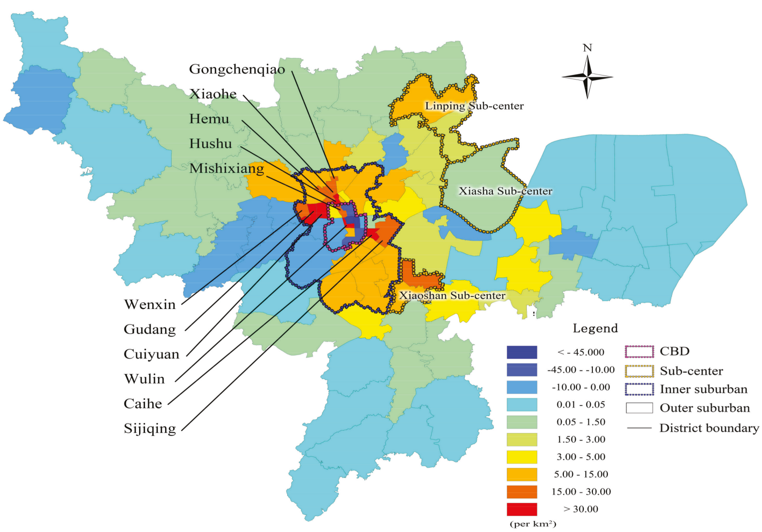

Figure 5. Diagram of changes in spatial density of producer service sectors from 2003 to 2013.

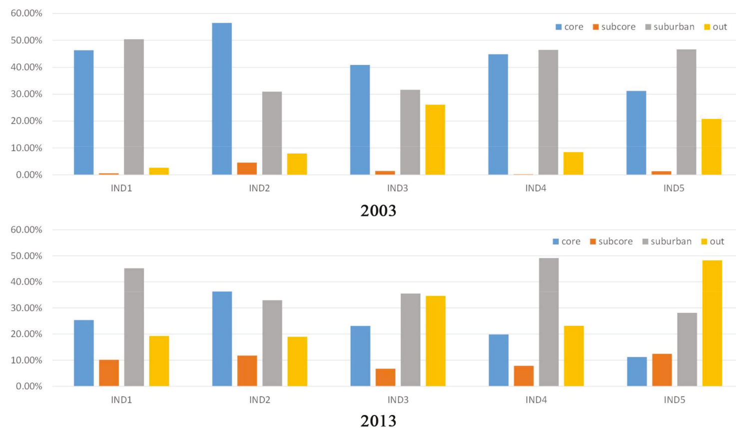

Figure 6. Statistical chart of differences in spatial distribution of different industries.

4.2. Differences in Spatial Distribution of Producer Service Sectors

Differences also exist among industries (Figure 6). Industries, such as Transportation, warehousing and postal services, that do not require face-to-face communication diffused the fastest, whereas industries that are heavily dependent on face-to-face communication and customers' personal business, such as Finance and insurance services, tend to be concentrated in central areas. The industry with the largest proportion of distribution in the central areas is Finance and insurance services, the largest in near areas is Scientific and technical services, and the largest in sub-center areas and peripheral areas is Transportation, warehousing and postal services. Transportation, warehousing and postal service's relative suburbanization level is the highest, whereas Scientific and technical services diffuses the fastest. The proportion of Rental and business services distribution in near suburban areas exceeds central areas, and the proportion of Transportation, warehousing and postal services distribution in the periphery goes beyond the central areas and near suburban. The industry with a proportion in the central areas decreasing the fastest is Scientific and technical services, the industry with proportion in the sub-center increases the fastest is transportation, warehousing and postal services, and the industry with a proportion in the peripheral areas decreasing the fastest is Transportation, warehousing and postal services.

4.3. Influencing Factors of Spatial Distribution of Producer Service Sectors

This study selects seven models to estimate the regression models of buildings. This approach was employed to investigate the relations between the distribution pattern of overall and sub-industrial producer service sectors and the city's other types of spatial influencing factors. The comparisons among OLS models, SLMs and SEMs are shown in Tables 4 and 5. The OLS models' goodness-of-fit test values are lower than those of the spatial regression models. SLMs and SEMs have greates R^2 than OLS models. Meanwhile, R^2 and log likelihood in SEMs are greater than those in SEMs. SEMs have lower AIC than SLMs. Therefore, SEMs are selected for spatial regression analysis.

Models 1–4 assessed the impacts of influencing factors on spatial distribution of producer service sectors in 2013 and 2003. Models 5–14 assessed the impacts of influencing factors on five industrial categories. Two spatial weight matrices including Queen contiguity and Euclidean distance were applied in spatial regressions in Table 6. The robust of significances of regression coefficients that were assessed by Queen contiguity and Euclidean distance in one regression model is fine. It reveals that the different spatial weight matrices do not have significant influence on the results of the regression coefficient estimation.

Table 4. The comparisons among ordinary least squares (OLS) models, spatial lag models (SLM), and spatial error models (SEM) (part 1).

	2003All						2013All						IND1						IND2		
Spatial Weight Matrix	Queen Contiguity			Euclidean Distance			Queen Contiguity			Euclidean Distance			Euclidean Distance			Queen Contiguity			Euclidean Distance		
Model	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag
R2	0.856	0.859	0.856	0.856	0.853	0.853	0.886	0.893	0.889	0.886	0.908	0.906	0.367	0.367	0.385	0.367	0.448	0.418	0.450	0.438	0.439
Log likelihood	−179.021	−178.584	−179.021	−179.109	−178.405	−178.405	−116.731	−115.062	−115.873	−116.731	−109.718	−109.634	−307.892	−307.882	−307.14	−307.892	−303.921	−305.224	−185.574	−184.870	−184.87
AIC	386.042	383.169	386.042	384.219	382.811	384.811	259.462	256.125	259.746	259.462	245.437	247.269	641.783	641.764	642.28	641.783	633.842	638.449	397.148	395.74	397.74
Moran's I	0.305			25110.630 ***			−0.240			−27393.581 ***			1.169			−1.328			37456.723 ***		
Lagrange Multiplier (lag)	0.191			1.359			1.621			0.052			0.856			4.277 **			0.0003		
Rubust LM (lag)	6.382 *			5.300 **			0.176			0.021			6.776 ***			0.193			4.737 **		
Lagrange Multiplier (error)	0.841			0.108			1.924			0.091			0.000			5.414 **			0.031		
Rubust LM (error)	7.032 **			4.050 **			0.479			0.060			5.920 ***			1.329			4.768 **		
Lagrange Multiplier (SARMA)	7.223 **			5.409 *			2.099			0.112			6.776 **			5.607 *			4.768 *		

Note: * represents significance in the level of 10%; ** represents significance in the level of 5%; *** represents significance in the level of 1%.

Table 5. The comparison among ordinary least squares (OLS) models, spatial lag models (SLM), and spatial error models (SEM) (part 2).

	IND2			IND3						IND4						IND5					
Spatial Weight Matrix	Queen Contiguity			Euclidean Distance			Queen Contiguity			Euclidean Distance			Euclidean DISTANCE			Queen Contiguity			Euclidean Distance		
Model	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag	OLS	Error	Lag
R2	0.450	0.511	0.510	0.242	0.247	0.263	0.242	0.420	0.353	0.431	0.431	0.454	0.431	0.457	0.467	0.379	0.391	0.381	0.379	0.485	0.409
Log likelihood	−185.574	−182.256	−182.047	−412.697	−412.543	−411.976	−412.697	−407.017	−407.953	−285.075	−285.062	−284.004	−285.075	−283.832	−283.021	−172.74	−172.350	−172.666	−172.74	−167.657	−171.284
AIC	397.148	390.512	392.094	851.394	851.086	851.951	851.394	840.034	843.906	596.15	596.125	596.007	596.15	593.664	594.042	371.48	370.701	373.333	371.48	361.313	370.569
Moran's I	−1.381			0.898			3.414 ***			1.135			−0.413			2.000 ***			−1.672 *		
Lagrange Multiplier (lag)	4.467 **			0.634			7.094 ***			1.159			2.980 *			0.007			1.974		

Table 5. *Cont.*

	IND2			IND3						IND4						IND5					
Spatial Weight Matrix	**Queen Contiguity**			**Euclidean Distance**			**Queen Contiguity**			**Euclidean Distance**			**Euclidean DISTANCE**			**Queen Contiguity**			**Euclidean Distance**		
Model	**OLS**	**Error**	**Lag**	**OLS**	**Error**	**Lag**	**OLS**	**Error**	**Lag**	**OLS**	**Error**	**Lag**	**OLS**	**Error**	**Lag**	**OLS**	**Error**	**Lag**	**OLS**	**Error**	**Lag**
Rubust LM (lag)	0.393			3.598 *			15.474 ***			7.316 ***			1.831			0.051			4.741 **		
Lagrange Multiplier (error)	4.227 **			0.050			3.124 *			0.000			1.496			0.005			5.316 **		
Rubust LM (error)	0.154			3.013 *			11.505 ***			6.157 **			0.347			0.049			8.082 ***		
Lagrange Multiplier (SARMA)	4.620 *			3.647			18.599 ***			7.316 **			3.327			0.056			10.056 ***		

Note: * represents significance in the level of 10%; ** represents significance in the level of 5%; *** represents significance in the level of 1%.

Table 6. The results of spatial regression models.

	2013ALL		2003ALL		IND1		IND2		IND3		IND4		IND5	
Spatial Weight Matrix	**Queen Contiguity**	**Euclidean Distance**	**Queen Contiguity**	**Euclidean Distance**	**Queen Contiguity**	**Euclidean Distance**	**Queen Contiguity**	**Euclidean Distance**	**Queen Contiguity**	**Euclidean Distance**	**Queen Contiguity**	**Euclidean Distance**	**Queen Contiguity**	**Euclidean Distance**
Model	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**	**Model 11**	**Model 12**	**Model 13**	**Model 14**
CONSTANT	43.763 ***	33.051 ***	63.209 ***	60.836 ***	48.734	43.645	4.415	16.901	81.223	−101.519	−64.103	−63.28	−6.681	−4.410
lnHWY	5.251 ***	4.545 **	5.396	5.301	45.552 ***	50.189 ***	0.552	2.693	−132.559	−90.950	15.492	15.843	−7.471	−6.322
lnRWS	3.713	3.489	−7.797	−7.685	29.369	26.199	11.937	11.873	−94.271	−127.609	−8.216	−7.390	−0.479	−3.531
lnSCE	1.669 **	1.535 *	3.121 **	3.128 *	10.183 **	26.035 **	−1.661	−1.640	−4.054	120.969	12.026 **	11.847 **	0.552	0.812
lnPOP	0.450 ***	0.533 ***	−0.363	−0.296	1.409 *	1.092	0.203	0.253	2.471	2.095	0.836	0.788	−0.036	−0.073
lnPland	−0.821 *	−0.401	1.146	1.152	−3.325	−2.597	−0.931	−1.597	−5.119	3.250	1.829	1.901	0.604	0.566
lnCBD	−0.466 **	−0.392 *	−0.716 *	−0.712	1.126	2.311	−2.709 ***	−2.507 ***	−13.671 **	−8.884 *	−2.560 *	−2.602 *	1.363 ***	1.466 ***
lnSCEN	−2.795 **	−2.647	5.922 **	5.286 *	21.319 **	11.898 *	−2.655	−1.392	−156.422 ***	−74.171 *	−8.795	−8.506	−3.056	−3.564
lnCOLL	−1.685	−1.034	−39.021 ***	−37.631 ***	−50.485 **	−58.064 *	8.520	5.326	150.156	12.946	−10.919	−11.436	9.859	8.206
lnCOMM	−4.673	−4.260	14.554	14.715	−62.913 *	−65.702 *	−12.708	−13.991	320.465 *	232.25	19.654	18.332	4.152	7.820
Industry	−0.300	−0.166	0.599	0.553	−0.854	−0.359	−0.111	−0.133	−3.718	−0.733	0.195	0.070	0.185	0.202
lnSCIP	−4.937 ***	−4.535 **	11.225 ***	10.46 8 **	3.166	4.520	−1.031	−0.784	−74.653	−76.768	−12.617	−12.128	−4.764	−4.899
CPR	0.385	0.248	1.437 ***	1.225 **	2.494	2.545	0.394	0.448	−8.637 *	−9.064 *	4.271 ***	4.101 ***	0.115	0.131
LAMBDA	−0.394 **	1.044 ***	−0.183	1.044 ***	−0.533 ***	−0.038	0.336 **	1.044 ***	0.725 ***	1.044 ***	−0.105	−0.043	0.288 **	−0.790
R^2	0.893	0.884	0.859	0.853	0.448	0.367	0.481	0.438	0.420	0.224	0.434	0.432	0.405	0.391

Note: * represents significance in the level of 10%; ** represents significance in the level of 5%; *** represents significance in the level of 1%.

Based on the regression coefficients of all industries, CBDs, sub-centers, land prices, and hi-tech parks are the most remarkable factors that affect the spatial distribution of producer service sectors. lnCBD, lnSCEN, and lnSCIP are notable negative influencing factors, which indicate that the evolution of producer service sectors from 2003 to 2013 show outward spatial diffusion. A high density in areas close to CBDs and sub-centers indicates that the city center has significant agglomeration effects. Given the advantages of economic preferential policies and convenient innovation alliances, hi-tech parks attract a high number of producer service sectors. The regression coefficient of lnSCE are positive, meaning a scenic spot is not suitable for the development of producer services. However, the regression coefficient of lnHWY of 2013 is positive, while it is not significant in 2003, which means that most producer service sectors are not sensitive to transport infrastructures. On the contrary, lnCOLL and CPR is significant in 2003, but they are not significant in 2013, which means producer service sectors had a close relationship with universities in the past; and there were few creative parks built in 2003, so the producer service sectors are not sensitive to them.

The analysis results of sub-industries show that differences exist in the key location influencing factors of different industries. Information, software and communication services is closely located to the business circle and higher education zone. This type of industry is highly dependent on the support from large crowds. Finance and insurance services is appropriately located close to the CBD, which illustrates that this type of industry tends to be agglomerated and relies on "face-to-face" communication and support of related industries. Rental and business services tends to be city's CBD, sub-center and creative parks. This industry is also dependent on "face-to-face" communication and relevant industries. Scientific and technical services tend to be closely located in CBD and creative parks. Creative parks are special policy areas set up by the government exclusively for research and development and art-like service sectors to enable industries that meet the requirements to enjoy preferential policies in tax and rental. Transportation, warehousing and postal services tend to be distant from the CBD. Moreover, logistics and warehousing require a large warehouse close to the urban external transport hub. Thus, they are mostly distributed in the peripheral areas.

5. Discussion

5.1. Synchronized Development of Urban Spatial Expansion and Suburbanization of Producer Service Sectors

Our findings indicate that overall, several service sectors gradually back away from "face-to-face" communication because of urban spatial expansion, polycentered development, and the advancement of communication technology. High costs in central areas also promote the suburbanization of enterprises in producer service sectors. Producer service sectors show a diffusing trend, and the global Moran index in 2013 decreased from 0.562 to 0.627. The average population density of Hangzhou's central areas in 2013 reached 20,000 people/square kilometers, with a constant increase in land prices and a decrease in traffic conditions and environmental quality. The land that can be developed in this area is limited. Thus, many service sectors that do not need frequent "face-to-face" communication, such as research and technical service sectors, are willing to be located near suburban and sub-centers. For example, Alibaba, a representative of a large e-commerce service sector, is not dependent on a "face-to-face" mode of communication. In 2009, Alibaba moved to the Binjiang block in the near suburban area from the cultural and educational block in the west of the city, and then moved to the remote suburban in the west of city, which is farther than the remote suburban. At present, in addition to the CBD in the traditional central area, Qijiang CBD, East railway station, Cuiyuan, Gudang in the near suburban have become the agglomeration areas of more emerging producer service sectors. The main industrial types in those blocks include research, technical services, leasing, and commercial services. An innovation alliance was developed by combining the higher education zone in the near suburban area. The innovation alliance was developed into an agglomeration area for producer service sectors, such as Xiasha sub-center, Binjiang, Jiubao, and other blocks.

5.2. City Planning Guides Agglomeration of Producer Service Sectors in Specific Space

Hangzhou's city planning has guided relocations of producer service sectors from the city centre to peripheral regions with development space and a supportive environment. In the 1980s, Hangzhou municipality defined that urban functions of the city shall be shifted from industries to modern service sectors and tourism. However, until the early 2000s, many factories were still located in the scope of Hangzhou's central urban area, which is a heavily polluted environment that affects office work and the living environment. In the city's overall planning program of 2004, mass industrial lands in the central urban area were adjusted as service-use lands. Relocated industrial enterprises entered the peripheral industrial zone. The government formulated the Plan of Relocation of Industrial Enterprises in Urban Areas of Hangzhou and Research on Integration of Industrial parks in Urban Areas of Hangzhou. In addition, the government published a series of development strategies and incentive policies, such as "Building a City of Quality Life", "Suppress the Second Industry and Develop the Third Industry", and "Vacating the Cage for Better Birds". "Vacating the Cage for Better Birds" is one of the China's current economic development strategies, which is moving out the traditional manufacturing industry of the central city, then moving in advanced industry, in order to achieve the purpose of economic transformation and industrial upgrading. Environmental quality has improved in recent years given the completion of office buildings. Enterprises in producer service sectors have increased remarkably in numbers, especially in Xiaohe, Shiqiao, Wenhui, and Dongxin Streets.

Agglomeration areas for producer service sectors are established, and professional function areas for service sectors have gradually formed. The master plan of 2004 determined the new main center of the city (Qiangjian CBD) and three sub-centers (Linping, Xiasha, and Xiaoshan) as a peripheral agglomeration area for producer service sectors [59] (Figure 7). Many professional agglomeration areas for producer service sectors, such as Cuiyuan and Xixi streets, were planned in the near suburban area. These streets are centered on information and computer services, Jiubao and East railway station focused on transportation and a number of university research parks that are distant in CBD are based on science research and technical services, such as logistics, Liuxia, Gudang, Binjiang. In addition, the government proposed a plan in 2008 to build "100 city complexes", which are all distributed in the near suburban area, including high-proportion office buildings. After nearly a decade, the construction of the planed office buildings has been basically completed. For example, streets in the near suburban area, such as Dongxin, Xiangfu, Beishan, are areas in which mass office buildings have been completed over the past few years.

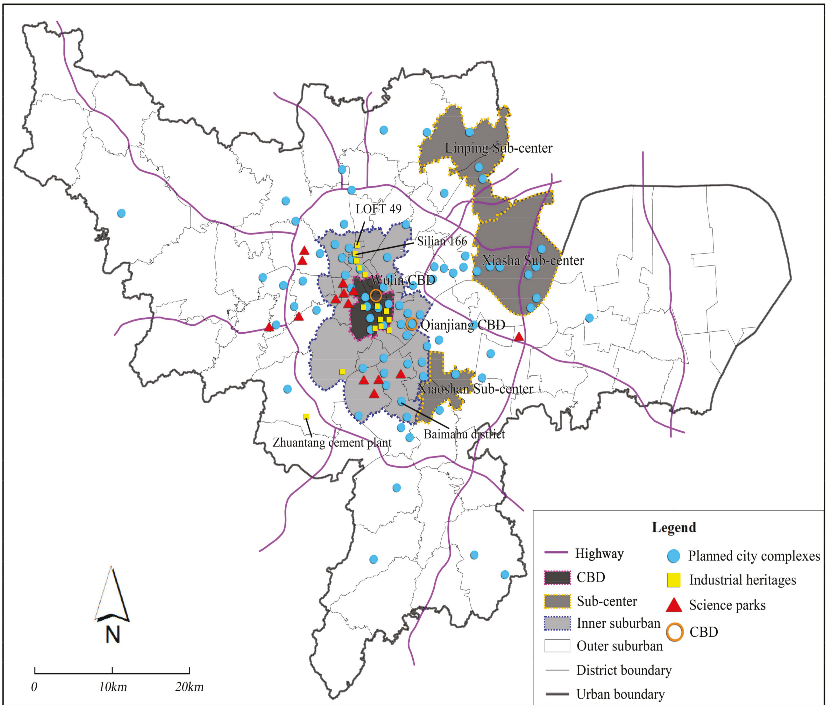

Figure 7. Distribution map of city complexity (planned), industrial heritage, and science parks.

5.3. City Renewal Offers Personalized and Diversified Development Space to Producer Service Sectors

City renewal in many areas of Hangzhou converts existing production and residential buildings into office space and guides producer service sectors to cluster in these renewed areas through the provision of preferential policies in the aspect of rentals and taxes.

Reconstruction of industrial heritage and historical buildings provides characteristic space for the development of produces service sectors. In 2009, the Hangzhou government devised the Plan of Protection of Industrial Heritage (Buildings) in Urban Areas of Hangzhou that mainly used existing old factories and warehouses in the near suburban area. This plan combines service sector development with the protection of industrial and historical buildings and cultural tourism. For example, the "Silian 166 (Figure 8)", LOFT 149, and Zhuantang Cement Plants are former industrial heritage buildings that have been converted into an agglomeration area for creative design service sectors (Figure 7). These conversions not only provide space for the development of producer service sectors, but also enrich the city's historical heritage landscapes and cultural characteristics.

Figure 8. Agglomeration area of Silian 166 creative design service sectors. (**A**) Hangzhou Silk Printing and Dying United Factory in the 1950s; (**B**,**C**) reconstucted Silian 166 Creative Industrial Park.

With the development of urban business circles and complexity modes, office space and supportive services are offered for the development of producer service sectors. In 2013, many buildings on both sides of the most important Yan'an business street inside Hangzhou's Wulin CBD were reconstructed. Underground commercial space with an area of 99,910 square meters was newly created to provide diversified support services. Moreover, the Citizen Center in Qianjiang CBD, which has a gross floor area of more than 500,000 square meters, includes various cultural, entertainment, educational, and catering facilities, in addition to office space forming an office agglomeration area of "one-stop" services.

Village SOHO, which is another new spatial mode for service sectors, provides office space for producer service sectors in the city's near suburban area. The Hangzhou government started to reconstruct villages' residential houses in the Baimahu area into an experience-type agglomeration area for creative service sectors with the characteristics of rural scenes in 2007, where considerable science research, business, and design-like service sectored are clustered (Figure 9). Enterprises that are currently settled in the park numbered over 200. They also offer jobs to the local rural natives.

Figure 9. Hangzhou Baimahu Nong Ju (Small Office/Home Office) SOHO creative industrial park. (**A**,**C**): villages' residential buildings before the reconstruction; (**B**,**D**,**E**): creative industrial park after the reconstruction.

5.4. Governmental Incentive Policies on "Filtering Effects" Guarantee Orderly Agglomeration of Producer Service Sectors

Government policies have guided the distribution of producer service sectors in space. First, to promote balanced development incorporating social equality and regional economies, the government emphasized the well-balanced spatial distribution of producer service sectors and planed agglomeration areas for producer service sectors in multiple areas. Second, the government set up policies to guide office buildings to conduct "selective" and "professional" investment invitations through preferential policies of tax. These policies only choose related or similar enterprises on the industrial chains for sales and leasing. For example, Xixi and Cuiyuan streets are the information industrial zone of Hangzhou. Thus, businesses of computer and software service sectors are welcome. Preferential policies are offered to renowned or multinational enterprises, similar to the process of implanting a "magnet" to attract other related supportive service sectors on different production chains to cluster there. For example, after Alibaba Group migrated to the western suburban area under the guidance of the government, many medium- and small-sized Internet enterprises related to its existing industries agglomerated in its surroundings. Finally, the government has invested or planned to invest in improvement of infrastructure and supportive services to attract service sectors that were previously scattered in various locations of the city. These include the evaluation of the potential of land development in the city's central area, expanded parking lots, construction of metro outlets, pedestrian-type reconstruction of business circles, and promotion of the agglomeration of service sectors that are dependent on "face-to-face" customer markets and crowd scales, such as leasing and business sectors. The government also planned service sectors in the surroundings of the external transport hub equipped with warehousing and logistics for mass cargo dispatches.

6. Conclusions

Hangzhou shows an agglomeration pattern for spatial distribution of producer service sectors, but with an apparent trend of suburbanization in the past decade. The spatial evolution of producer service sectors can be understood by the self-organization process of the sector under the dual influences of market factors and governmental control. The results of the self-organization process are mainly reflected in outward expansion trends driven by insufficient space in the city centre. The process of being organized is mainly embodied in the government's overall plan for urban spatial structures and construction of mass agglomeration areas for producer service sectors in multi-type city renewal [60]. The approximation to CBD and sub-centers, science parks, and other special policy areas have the largest influence on site selection for producer service sectors. The results of this study confirm the research conducted by scholars from other countries as follows. First, this work confirms that the employment concentration of producer service sectors in space and productivity improvement effects that resulted from "face-to-face" communication [61]. The characteristics of high agglomeration in financial and insurance service sectors are consistent with the conclusions in the cases of Paris and Atlanta [15]. The findings of the relative diffusion of Scientific and technical services verifies the research results for Atlanta [62], that is, professional technicians in these types of services are not dependent on the externality of the CBD. These results also indicate the frequent use of communication technology sectors [63]. Near suburban and sub-center areas are those where producer service sectors increased mostly over the past few years because these areas can harness the benefits of agglomeration economies, reduce high costs, and the non-economy of agglomeration in the development of the central areas [64,65]. However, the particularity of the spatial evolution of producer service sectors in Chinese cities is reflected by special policy areas for producer service sectors set up by the government and the guidance effects of city planning.

Understanding regularities in industrial evolution and urban spatial development is the primary importance of research on the producer service sectors of cities. In China, where the government dominates social economies and spatial development, this finding facilitates the formulation of spatial plans to adapt to changes in social economies. Differences also exist in the development of different cities. Future studies can explore spatial relations between departments inside the same enterprise located in different regions, or between the same enterprise and enterprises that have business relationships from the perspectives of enterprise connections and labor division relations.

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References

1. Sassen, S. *The Global City: New York, London, Tokyo*; Princeton University Press: Princeton, NJ, USA, 1991.
2. Su, S.; Liu, Z.; Xu, Y.; Li, J.; Pi, J.; Weng, M. China's megaregion policy: Performance evaluation framework, empirical findings and implications for spatial polycentric governance. *Land Use Policy* **2017**, *63*, 1–19. [CrossRef]
3. Zhang, Q.; Su, S. Determinants of urban expansion and their relative importance: A comparative analysis of 30 major metropolitans in China. *Habitat. Int.* **2016**, *58*, 89–107. [CrossRef]
4. Ke, S.; He, M.; Yuan, C. Synergy and Co-agglomeration of Producer Services and Manufacturing: A Panel Data Analysis of Chinese Cities. *Reg. Stud.* **2014**, *48*, 1829–1841. [CrossRef]
5. Zhou, Y.; Huang, X.; Chen, Y.; Zhong, T.; Xu, G.; He, J.; Xu, Y.; Meng, H. The effect of land use planning (2006–2020) on construction land growth in China. *Cities* **2017**, *68*, 37–47. [CrossRef]
6. You, H.; Yang, X. Urban expansion in 30 megacities of China: Categorizing the driving force profiles to inform the urbanization policy. *Land Use Policy* **2017**, *68*, 531–551. [CrossRef]
7. You, H. Characterizing the inequalities in urban public green space provision in Shenzhen, China. *Habitat Int.* **2016**, *56*, 176–180. [CrossRef]
8. You, H. Quantifying megacity growth in response to economic transition: A case of Shanghai, China. *Habitat Int.* **2016**, *53*, 115–122. [CrossRef]
9. Bennett, R.J.; Graham, D.J.; Bratton, W. The Location and Concentration of Businesses in Britain: Business Clusters, Business Services, Market Coverage and Local Economic Development. *Trans. Inst. Br. Geogr.* **1999**, *24*, 393–420. [CrossRef]
10. Yang, F.F.; Yeh, A.G.O. Spatial development of producer services in the Chinese urban system. *Environ. Plan A* **2013**, *45*, 159–179. [CrossRef]
11. Yeh, A.G.O.; Yang, F.F.; Wang, J. Producer service linkages and city connectivity in the mega-city region of China: A case study of the Pearl River Delta. *Urban Stud.* **2015**, *52*, 2458–2482. [CrossRef]
12. Zhao, M.; Liu, X.; Derudder, B.; Zong, Y.; Shen, W. Mapping producer services networks in mainland Chinese cities. *Urban Stud.* **2015**, *52*, 3018–3034. [CrossRef]
13. Daniels, P.W. *Service Industries: A Geographical Appraisal*; Methuen: London, UK, 1985.
14. Yi, H.; Yang, F.F.; Yeh, A.G.O. Intraurban Location of Producer Services in Guangzhou, China. *Environ. Plan A* **2011**, *43*, 28–47. [CrossRef]
15. Shearmur, R.; Alvergne, C. Intrametropolitan Patterns of High-order Business Service Location: A Comparative Study of Seventeen Sectors in Ile-de-France. *Urban Stud.* **2002**, *39*, 1143–1163. [CrossRef]
16. Aelst, S.V. Assessing the Functional Polycentricity of the Mega-City-Region of Central Belgium Based on Advanced Producer Service Transaction Links. *Reg. Stud.* **2014**, *48*, 1939–1953.
17. Yeh, A.G.O.; Yang, F.F.; Xu, Z. Will rural urbanization produce a new producer service space in China? *Habitat Int.* **2017**, *67*, 105–117. [CrossRef]
18. Duranton, G.; Puga, D. From sectoral to functional urban specialisation. *J. Urban Econ.* **2005**, *57*, 343–370. [CrossRef]
19. Arzaghi, M.; Henderson, J.V. Networking off Madison Avenue. *Rev. Econ. Stud.* **2008**, *75*, 1011–1038. [CrossRef]
20. Ke, S. Agglomeration, productivity, and spatial spillovers across Chinese cities. *Ann. Reg. Sci.* **2010**, *45*, 157–179. [CrossRef]
21. Ke, S.; Edward, F. Count on the Growth Pole Strategy for Regional Economic Growth? Spread–Backwash Effects in Greater Central China. *Reg. Stud.* **2010**, *44*, 1131–1147. [CrossRef]
22. Keeble, D.; Nachum, L. Why do business service firms cluster? Small consultancies, clustering and decentralization in London and southern England. *Trans. Inst. Br. Geogr.* **2002**, *27*, 67–90. [CrossRef]
23. Coffey, W.J.; Shearmur, R.G. Agglomeration and Dispersion of High-order Service Employment in the Montreal Metropolitan Region, 1981–96. *Urban Stud.* **2002**, *39*, 359–378. [CrossRef]
24. Gad, G. Downtown Montreal and Toronto: Distinct Places with Much in Common. *Can. J. Reg. Sci.* **1999**, *22*, 142–147.
25. Holmes, T.J.; Stevens, J.J. Geographic Concentration and Establishment Scale. *Rev. Econ. Stud.* **2002**, *84*, 682–690. [CrossRef]
26. Mills, E.S.; Luan, S.L. Inner Cities. *J. Econ. Lit.* **1997**, *35*, 727–756.

27. Ogawa, H.; Fujita, M. Equilibrium land use patterns in a nonmonocentric city. *J. Reg. Sci.* **1980**, *20*, 455–475. [CrossRef]
28. Boiteux-Orain, C.; Guillain, R. Changes in the Intrametropolitan Location of Producer Services in Île-De-France (1978–1997): Do Information Technologies Promote A More Dispersed Spatial Pattern? *Urban Geogr.* **2004**, *25*, 550–578. [CrossRef]
29. Gong, H.; Keenan, K. The Impact of 9/11 on the Geography of Financial Services in New York: A Few Years Later. *Prof. Geogr.* **2012**, *64*, 370–388. [CrossRef]
30. Yuan, F.; Gao, J.; Wang, L.; Cai, Y. Co-location of manufacturing and producer services in Nanjing, China. *Cities* **2017**, *63*, 81–91. [CrossRef]
31. Martinelli, F. Producer services' location and regional development. In *The Changing Geography of Advanced Producer Services*; Daniels, P.W., Moulaert, F., Eds.; Belhaven Press: London, UK, 1991; pp. 70–90.
32. Schwartz, A. Corporate Service Linkages in Large Metropolitan Areas A Study of New York, Los Angeles, and Chicago. *Urban. Aff. Rev.* **1992**, *28*, 276–296. [CrossRef]
33. Schamp, E.W. The geography of APS in a goods exporting economy: The case of West Germany. *Prog. Plan.* **1995**, *43*, 155–171. [CrossRef]
34. Wernerheim, C.M.; Sharpe, C. 'High Order' Producer Services in Metropolitan Canada: How Footloose Are They? *Reg. Stud.* **2003**, *37*, 469–490. [CrossRef]
35. Kloosterman, R.C. Polycentric Puzzles—Emerging Mega-City Regions Seen through the Lens of Advanced Producer Services. *Reg. Stud.* **2008**, *42*, 1055–1064.
36. Daniels, P.W. Service sector restructuring and metropolitan development: Processes and prospects. In *Services and Metropolitan Development: International Perspectives*; Daniels, P.W., Ed.; Routledge: London, UK, 1991; pp. 1–25.
37. Coffey, W.J. The geographies of producer services. *Urban. Geogr.* **2000**, *21*, 170–183. [CrossRef]
38. Searle, G.H. Changes in producer services location, Sydney: Globalisation, technology and labour. *Asia Pac. Viewp.* **1998**, *39*, 237–255. [CrossRef]
39. Park, S.O.; Nahm, K.B. Spatial structure and inter-firm networks of technical and information producer services in Seoul, Korea. *Asia Pac. Viewp.* **1998**, *39*, 209–219. [CrossRef]
40. Ženka, J.; Novotný, J.; Slach, O.; Ivan, I. Spatial Distribution of Knowledge-Intensive Business Services in a Small Post-Communist Economy. *J. Knowl. Econ.* **2015**, *8*, 1–22. [CrossRef]
41. Truman, A.H.; Peter, O.M. Suburban downtowns and the transformation of metropolitan Atlanta's business landscape. *Urban Geogr.* **1989**, *10*, 375–395.
42. Li, J.; Zhang, W.; Yu, J.; Chen, H. Industrial Spatial Agglomeration Using Distance-based Approach in Beijing, China. *Chin. Geogr. Sci.* **2015**, *25*, 698–712. [CrossRef]
43. Stanback, T.M. *The New Suburbanization: Challenge to the Central City*; Westview Press: Boulder, CO, USA, 1991.
44. Taylor, P.J.; Derudder, B.; Hoyler, M.; Pain, K.; Witlox, F. European cities in globalization. In *Global Urban Analysis. A Survey of Cities in Globalization*; Taylor, P.J., Ni, P., Derudder, B., Hoyler, M., Huang, J., Witlox, F., Eds.; Earthscan: London, UK, 2011; pp. 114–136.
45. Yeh, A.G.O. Producer services and industrial linkages in the Hong Kong–Pearl River Delta region. In *Service Industries and Asia-PacificCities: New Development Trajectories*; Daniels, P.W., Ho, K.C., Hutton, T.A., Eds.; Rutledge: London, UK; New York, NY, USA, 2005; pp. 150–172.
46. Portnov, B.A.; Dubnov, J.; Barchana, M. Studying the association between air pollution and lung cancer incidence in a large metropolitan area using a kernel density function. *SOCIO Econ. Plan. Sci.* **2009**, *43*, 141–150. [CrossRef]
47. Silverman, B.W. *Density Estimation for Statistics and Data Analysis*; Chapman & Hall/CRC: London, UK, 1998.
48. Longley, P.A.; Goodchild, M.F.; Maguire, D.J.; Rhind, D.W. *Geographic Information Systems and Science 3e*; Wiley: Hoboken, NJ, USA, 2001.
49. Anselin, L. *Spatial Econometrics: Methods and Models*; Kluwer Academic: Boston, MA, USA, 1988.
50. Su, S.; Lei, C.; Li, A.; Pi, J.; Cai, Z. Coverage inequality and quality of volunteered geographic features in Chinese cities: Analyzing the associated local characteristics using geographically weighted regression. *Appl. Geogr.* **2017**, *78*, 78–93. [CrossRef]
51. Han, S.S.; Qin, B. The Spatial Distribution of Producer Services in Shanghai. *Urban Stud.* **2009**, *46*, 877–896.

52. Hanssens, H.; Derudder, B.; Witlox, F. Are advanced producer services connectors for regional economies? An exploration of the geographies of advanced producer service procurement in Belgium. *Geoforum* **2013**, *47*, 12–21. [CrossRef]
53. Jakobsen, S.E.; Onsager, K. Head office location: Agglomeration, clusters or flow nodes? *Urban Stud.* **2005**, *42*, 1517–1535. [CrossRef]
54. Parnreiter, C. Managing and governing commodity chains: The role of producer service firms in the secondary global city of Hamburg. *DIE ERDE* **2015**, *146*, 1–15.
55. Zhang, L. Flood hazards impact on neighborhood house prices: A spatial quantile regression analysis. *Reg. Sci. Urban Econ.* **2016**, *60*, 12–19. [CrossRef]
56. Anselin, L.; Syabri, I.; Kho, Y. Geoda: An introduction to spatial data analysis. *Geogr. Anal.* **2006**, *38*, 5–22. [CrossRef]
57. Weng, M.; Pi, J.; Tan, B.; Su, S.; Cai, Z. Area deprivation and liver cancer prevalence in Shenzhen, China: A spatial approach based on social indicators. *Soc. Indic. Res.* **2017**, *133*, 317–332. [CrossRef]
58. Voss, P.R.; Long, D.D.; Hammer, R.B.; Friedman, S. County child poverty rates in the US: A spatial regression approach. *Popul. Res. Policy Rev.* **2006**, *25*, 369–391. [CrossRef]
59. Zhu, Q. Building Hangzhou's new city center: Mega project development and entrepreneurial urban governance in China. *Asian Geogr.* **2011**, *28*, 3–19.
60. Wu, Y.; Fan, P.; Li, B.; Ouyang, Z.; Liu, Y.; You, H. The effectiveness of planning control on urban growth: Evidence from Hangzhou, China. *Sustainability* **2017**, *9*, 855. [CrossRef]
61. Wei, Y.D. Globalization, institutional change, and industrial location: economic transition and industrial concentration in China. *Reg. Stud.* **2008**, *42*, 923–945.
62. Gong, H.; Wheeler, J.O. The Location and Suburbanization of Business and Professional Services in the Atlanta Area. *Growth Chang.* **2002**, *33*, 341–369. [CrossRef]
63. Rubalcaba, L.; Gallego, J.; Gallo, M.T.; Garrido, R. Business services location and market factors in major European cities. *Cities* **2013**, *31*, 258–266. [CrossRef]
64. Coe, N.M.; Townsend, A.R. Debunking the Myth of Localized Agglomerations: The Development of a Regionalized Service Economy in South-East England. *Trans. Inst. Br. Geogr.* **1998**, *23*, 1–20. [CrossRef]
65. Jacobs, W.; Koster, H.R.A.; Oort, F.V. Co-agglomeration of knowledge-intensive business services and multinational enterprises. *J. Econ. Geogr.* **2014**, *14*, 433–475. [CrossRef]

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Article

The New Pyramid of Needs for the Digital Citizen: A Transition towards Smart Human Cities

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Abstract: This article analyzes the cultural transition towards postmodernity or a knowledge society and its impact on the changing needs of cities. This transition is characterized by a growing diversification of the use of technologies in most of the economic, political, educational, social, and cultural activities of different human groups. The concept of smart cities emerges, in which the roles and behaviors of citizens are redefined in physical spaces and in their interactions, as well as the function of institutions and interpersonal relationships. Emerging models of social and cultural behavior are required to analyze and systematize these realities, to understand how to increase effectiveness in action, and to rethink education and new ways of teaching and learning. All these processes are based on phenomena of innovation and management, mediated by technology. We proposed an analysis of the new digital skills of these individuals. The elements that shape the reformulation of roles and reference models, as well as an analysis of the postmodern cultural changes and the formation of a holistic, human-community-technology vision, are based on a new pyramid of training needs in which technologies are placed at the service of people's development, organizations, society, and culture.

Keywords: ICT skills; smart human cities; digital gap; knowledge society; bi-dimensional identity; needs pyramid

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1. Introduction

In the current era, great changes are being experienced in which interconnected societies are demanding new ways to reformulate society, human interactions, and education. Authors such as Martinez [1] express that we are facing a crisis of the fundamentals of thinking, philosophical knowledge, and scientific knowledge as they are demanding new definitions. These changes will relentlessly affect the cultural uniqueness and some aspects of the global culture. According to Morin [2], this process is related to action ecology, considering that as soon as an individual carries out an action, this process starts to escape from its original intention and enters a complex plot that gives it a new dynamism.

In the social current, characterized by an increasing demand of goods and services, it is worthwhile to ask if human beings will have the capacity to revert the actions that are carrying the planet to a point without return with regard to the natural and ecological heritage of future generations and the entire human species. This problem requires a complex solution: a new utopian city that modifies its metabolism by significantly reducing the waste produced [3]. New concepts are needed to help citizens in order to understand the consequences of their actions and omissions. In this context arises a new conception of city known as a smart city. A smart city is mainly characterized by the demographic explosion of the suburbs and the growth of information and communication technologies (ICT) in most human activities. As stated by Conesa [4], the essence of the smart city lies in the capacity that cities have always had to reinvent and innovate. Said condition needs to connect with the current challenges of cultural transition, as it urgently requires focusing on its efforts in the sustainability of the same, since, according to the projections for the year 2050, the worldwide urban population will reach the 6.4 million inhabitants [5].

From this stage, it becomes possible to consider ICTs a factor that influences both the understanding of how the city works and the attitude citizens are taking towards diminishing the negative effects of the climatic change and towards social equity. That is, ICTs can influence attitudes towards citizen participation, transportation, education and employment, and developing politics that could improve the life quality of its citizens. In fact, the ways of gathering data or information about the city are changing our way of understanding it [6].

As defined by Harrison, Eckman, Hamilton, Hartswickm, Kalagnanam, Paraszczak et al. [7] the smart city is (a) equipped, through the use of sensors and personal devices, to capture real-life data; (b) interconnected, by the integration of the data captured in computer platforms; and (c) intelligent, and processes, models and visualizes the information to make future decisions. Although this definition bases the concept of intelligence on the city rather than on computer decisions, this does not necessarily mean its inhabitants will complete all their paperwork online [8]. There are differences between a digital city and a smart city, since the first seeks to cater a broadband computer infrastructure to attend the requests of the companies, citizenship, and governments [9], and the second shows up as a consequence of the intersection between the society of the knowledge and the digital city [10].

This concept has been made by humans, little by little. For example, it is associated with the resolution of the public problems. These mean that the solutions are based on the technology in the frame of an association between different participants. These two are private and public [11]. In this same perspective, The Digital Country Foundation in Chile defines smart cities as the following:

> "Through the application of technology in different fields, places are changing to become more efficient regarding the use of resources, energy-saving, improving the services delivered and promoting a sustainable development, solving the main problems citizens have to face". [12] (p. 3)

According to the Committee of Digital and Knowledge-Based (Comisión de Ciudades Digitales y del Conocimiento) Cities, a smart city is one that includes ICTs in its critical infrastructure, and its components and public services are offered in order to make them more interactive, efficient and to make the citizenship more aware of them [13]. The same commission proposes six key fields and indicators that every smart city must take into consideration: the economy, citizenship, management, mobility, surroundings, and quality of life.

In sum, an intelligent city must stand out with as an efficient performance in said dimensions and have as a basis a combination of communication, infrastructure, economic development, and activities of the citizenship that allow a rational use of the natural resources by means of a participatory government [13]. However, Olmedo and López [14] pose that two new dimensions should be incorporated, as they are of equal or higher importance than the previous: versatility and the accessibility to users. The first refers to the capacity that objects or places need to be used by any user, whereas the second focuses on the possibility that smart cities can provide services adapted to all its inhabitants, especially to those that are disadvantaged by physical circumstances, for example, sensory, economic, among others.

Another interesting concept is the smart human city. It arises from the need to generate inclusive spaces inside the cities to avoid the differences between people. By prioritizing citizen rights over technology use, the smart human city incorporates a more humane vision of the smart city.

In the literature, there is a wide range of related concepts, such as the sharing cities. This includes knowledge-exchange platforms and exchange of resources among citizens, assumed like social agents between themselves and/or with the institutions; circular economies that promote a social and economic model based on the recycling and the optimization of the efficient use of resources or products throughout its life cycle, increasing its value and reducing the environmental impact and the generation of waste; and the concept of WeGovernment, which evolves from the understanding of citizens like customers or consumers to consider them partners, empowering them so as to have a more active role in management of the city. All these concepts pretend to increase the capacity of participation of the citizenship to influence, decide and contribute to the development and management of the city [4].

The new tendencies conceive that citizens are those that give the city the possibility to be considered smart. These citizens promote sustainability through its interaction in real and digital spaces. But who are these citizens? How do they conceive reality? What are their sources of information, and how do they administer it? Which is the border between the information and knowledge? How do they generate and transfer knowledge? How are they taught, and how do they learn? These questions have not been tackled sufficiently in the literature because they require new models of reference. Therefore, this article aims to reach the answers to these questions, proposing a new pyramid of the needs of the digital citizen in the transition to the postmodern world.

2. Framework

2.1. Bi-Dimensional Identity: The Concept of a Holistic and Eclectic Citizen

The widespread growth of social networks has increased the possibility for people to express their opinions regarding diverse subjects of public or private matter while under the anonymity that the internet offers. However, this participation is not equal to that found in presidential or local elections of a country or city. Who, then, are these citizens?

Aristotle defines man as a rational and political animal. Therefore, humans are separated from other animals because of their ability to think and reflect about what they do and because of their political involvement. That is to say, as humans we have to live in a society (city, polis) with other beings. Individuals cannot live alone because they all have a language, are symbolic beings, and therefore need others to share this world of symbols with them [15].

Citizenship is a process that gets stronger as people become conscious of their role as political subjects and get involved in personal and collective problems. Thus, to suffocate a city with technology is worthless if its inhabitants do not face the challenges of their society. However, in addition to the fact that cities are moving towards an ideal of sustainability, what should citizens do in order to take advantage of the technology and information available?

Reasonably, the first step is to generate conditions of transformation of the archetype typical of the modern man: an individualistic citizen, whose conception of success is supported by what he/she can buy and consume. As restated by Fromm, "the main goal of human culture is to have more and more" [16] (p. 11).

In this sense, it is worthwhile to analyze whether it is possible to change the focus and work to develop a holistic citizenship, whose principles are supported, according to Salazar [17], by a bigger community than the total of citizens that compose it, with virtues based on freedom, an emancipating willingness, and the autonomic and social vocation. Moreover, it is important to comprehend if it is possible to form new generations of eclectic citizens that can perform effectively in the dimensions of tangible things and in the virtual world, to take care of the natural surroundings, managing information for good purposes, and manage knowledge to contribute to a better world. In other words, these citizens would need to work proactively to create more smart cities, because they work for the real world and virtual world. For this, it is necessary to understand man's good qualities and his own contradictions and limitations manifested in the real and virtual world, changing only his behavior. The transition to the postmodern society or knowledge society incorporates the fifth dimension of the virtuality that has changed the forms of human interaction. The bi-dimensional identity demands citizens' behavior and in this new dimension that requires holistic and eclectic abilities.

From the view point of the behavior of knowledge, according to Careaga and Avendaño [18], arises the need of a reconceptualization, incorporating the notion of virtual epistemology. Virtual epistemology, a postmodern proposal about new notions related to the behavior of knowledge in virtual contexts, requires the approximation of theoretical notions that explain the phenomenon. Among those, the following stand out: (a) a split in the understanding of the modern concept of knowledge; (b) the axiom expands to the relation subject-object-subject which involves a substantial change in the way to conceive the sources of knowledge; (c) postmodern knowledge would be rooted in comprising the relations that constitute the sources of said truth; (d) the cybernetic resides in the efficiency of man's interaction with the sources of knowledge; (e) man's creations reveal to it transforming it; (f) the possibility to manage knowledge, representing and transferring one's own intellectual constructors through cyberspace, and; (g) mutual modification as effect.

In the case of education, this approach caters to a vision that involves the need for reconsidering roles, especially the educational one, and the modalities that are adopted in the pedagogical relation in the current cultural stage. These would have to move from a rationalist-academic conception, in which it assumes a function of cognitive filter, to a more proactive conception of the autonomy of learning, sustained by a horizontal conception of the pedagogical relation [18].

This new vision about the behavior of knowledge given by virtual epistemology involves a clear differentiation between the administration of information (access and representation) and the management of knowledge (creation and transfer), which requires a redesign of roles. In agreement with Careaga [19], and Careaga and Barnes [20], where is the epistemological border between the administration of information and the management of the knowledge?

The administration of information involves basic competencies that allow the efficient access to the information sources and to its processed representation the data. The management of knowledge involves creation and transfer of knowledge, competencies that allow transferring the intellectual and practical constructs through the conceptual mediation of some language, as it is appreciated in Figure 1.

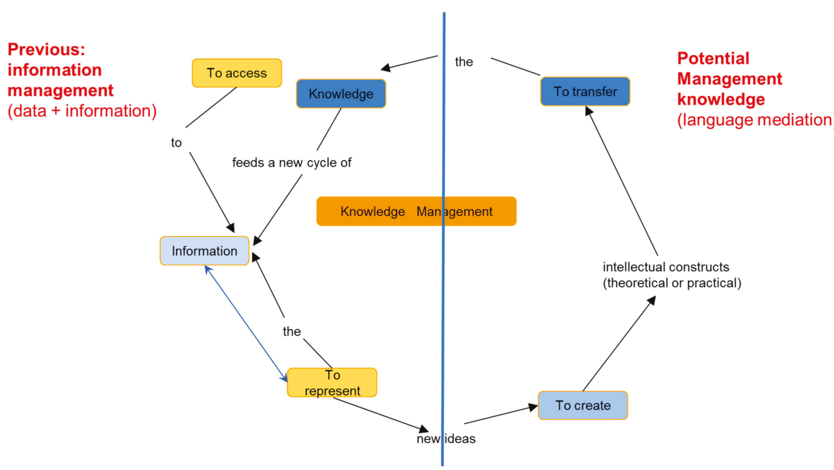

Figure 1. The Knowledge Management Pedagogical Circuit. (Source: Careaga and Barnes, 2015).

In this context, the challenge consists in trying to comprise, from the theory, the identity of these bi-dimensional cyber-citizens and the spaces where they move and learn. In this regard, Reig and Vilchez [21] propose that, with the rise of internet and the social networks, we are confronted with a paradigm change and with the evolution of a new type of individual, a hyper individual or connected individual who is difficult to surprise. Because of the reciprocal influence between the cultures like the consequence of globalization [22], there have been an increased number of people who have seen too many things to be surprised easily [23].

According to Morin [24], there is an existing holographic relation between the individuals and society. That is to say, these individuals create the society with their interactions, but this influences in the social area by means of its culture and norms. In the current stage of cultural transition, what is the hologram between the individuals and the society? Are there still three worlds, as described by Popper [25]? The material world, composed of rivers, clouds, stones, plants and animal; the subjective world, composed of feelings, beliefs, thoughts, and the wishes of each person; and the intellectual world, defined by notions, thoughts, theorems, hypothesis, theories, symphonies, paintings and beliefs? The analysis indicates that the hyper individual or bi-dimensional citizen would live in three dissimilar worlds that coexist and surpass the ones posed by Popper. Each one of these worlds provided by its own identity: identity 1, the one made in the physical world (real); identity 2, the one who links the virtual and real world (virtual-real); and an identity 3, the one who configures exclusively in the virtual world (virtual-virtual).

These identities that coexist in distinct worlds move in a complex way without necessarily connecting the real world with the virtual world. Tendencies can show up in bi-dimensional citizen actions that take them to show organized performances that are understood like cyber organisms [26]. Since they unchain complex decisions from very simple ones, they exert control without having to realize the mechanisms that operate to give results. In relation to cybernetics, many meanings and implications are awarded to the scientific discipline that operates with a technological base linking it to the rational science of the machines, to an informational technique, or to the art of giving efficiency to the action.

This last approach gets closer to the eventual implications of the cybernetics in education, as Couffignal [27] pointed out in the 1960s. Based on these cybernetic concepts, it is possible to enter into human communication, attending to the interrelationships established between the individuals and the modalities that acquire these relations when they are made through artificial systems. These systems base their action on the operation of complex systems of automated control and operate to guarantee a determined purpose or end (direction, in a cybernetic sense) without users necessarily knowing the operation of said systems (notion of a black box). In this way, the new development of communication models, defined in virtue of the forms of concretion of said interrelationships, is observed when communication is perfected through networks of machines, which in reality are networks of people.

These systems act as a form of communicational control in smart cities, finding that humans communicate between themselves through technologies. Through the activation of computerized systems, these controls make it possible for them to work efficiently to fulfill the purposes of processing according to the standards with which they were designed. Cybernetics presents specific control techniques. A system behaves like a dynamic model that changes states, flowing in the behavior data and information, both in its modalities of internal communication, and in its interactions with the environment that surrounds it.

Then, the virtual-virtual dimension of bi-dimensionality identity is related to the active presence on the internet and to the interactions of communicational control that develop there by means of Facebook likes, Twitter retweets, photos, and viral videos. The reason to exist is to be on Google, configuring representations of information and knowledge that does not necessarily relate to the objective world of things. McLuhan and Powers [28] would say that this is a result of the presence of a resonant interval, since it has acquired consciousness of two different worlds, the real world and the virtual world situated in cyberspace. This requires accepting that both worlds experience an initial crash, to surface a new environment for human beings: virtual objective ecology.

How can this bi-dimensional citizen, who moves between what is real and virtual in a natural way, understand in its different world's reality, learning and uncertainty of knowledge? Figure 2 represents this scenario in two loops. Loop 1 (blue) denotes the interaction between bi-dimensional citizens and different spaces of formal and informal multidimensional experiences, like cyberspace, school, family, social networks, or friends. In loop 2 (green), these interactions generate learning that, as it is being adapted to the bi-dimensional reality of citizens, turns into knowledge that feeds the smart city. "The territory is therefore the network, embodied in an archipelago of joined points by lines that allows the traffic" [29] (p. 49).

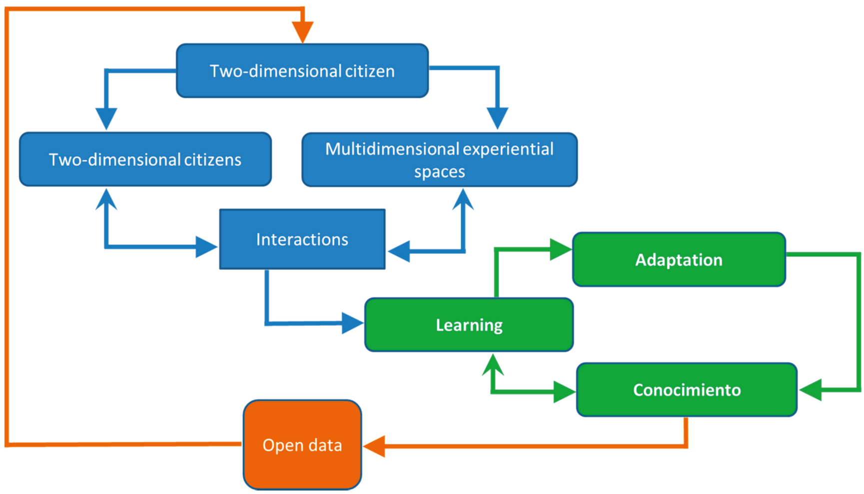

Figure 2. The reality and the contribution of knowledge of the bi-dimensional citizen in a smart human city (Source: Own authorship).

The interesting part of this representation is that the traditional educational system is maintained as a stage of experiences of learning. The school stops being the exclusive center for learning, since in the mixed reality (real + virtual) the formal and informal components complement each other to generate learning. The educational system requires a reformation, posing new modalities in the ways of teaching and learning. It requires reformulating the experiences of learning by means of interactions and adaptations involving diverse multidimensional spaces to improve the training of holistic and eclectic citizens.

Similarly, citizenship and education go together according to the new tendencies of change in the smart human city. At the beginning of the 20th century, Rousseau made this association between the citizen and his education, indivisible "in a weighted synthesis of both inalienable appearances, the one of the liberal individual and the republican citizen" [30] (p. 212). At the same time Gimeno sustained the same questions, stating, at the beginning of this century, that "the citizenship (what makes possible the exercise of democracy, of the republican version of Athenian origin) and the education need and invigorate reciprocally" [31] (p. 155).

It is important that the holistic and eclectic citizen is conscious of the impacts that globalization has on the citizenship because "if people remain unsatisfied with the role that citizens have, the stability of the democratic political systems could erode" [32] (p. 373). This empowerment or citizen intelligence is described by Sarmiento [3] through a series of responsibilities that the holistic citizen assumes in the smart city: commitment to the environmental politics of the city, commitment to energy efficiency and recycling.

2.2. Challenges for Education in the Smart Human City

Education is facing a historical moment that demands reformation. The digital revolution has impregnated the classical forms to teach and learn. Its main function of educating useful people for society has been affected. The formal educational system is not able to answer the new demands of smart human cities, society, and culture. The Foundation Education 2020 in Chile proposes that Latin America has been transformed into a continent of functional illiterates, where, although the levels of coverage have increased, it continues to coexist in a process of including exclusion [33], in which the inclusion without quality continues to deny the right to education [34].

In this regard, Foucault [35] posits that disciplinary organizations organize and distribute time with diverse activities to change the behavior of the individuals regarding previously established criteria, measuring through examinations how governable a person is and how they could be classified in society.

This increase of the distance between the education and the needs of the people, together with the imbalance between what is received and what is needed, is what De Corte [36] defines as the educational gap. This has been explained from another point of view by Robles [37], the one who poses three paradoxes:

1. Education decides to contribute to the success of the individual career of all the students, but is forced to evaluate the learning of the contents that it communicates, and its results are always uneven.
2. On the one hand, education needs to consider the individualities of the students and take precautions with the diversity of aptitudes, vocations and expectations. Yet students must be treated like equals.
3. The class is made collectively within the context of the classroom. It is made up of an indefinite quantity of individuals with different experiences, from different families, and with enclosed consciousness and, therefore, must follow the same content of the class.

These paradoxes are the opposite of what it happens outside the classroom. The educational system transforms into a time catcher where students, during a determinate number of daily hours, live in an analog parallel world. Afterwards, they go back to their multidimensional and mixed spaces, where the real world and the virtual world coexist. The latter is still insufficiently incorporated in the educational classrooms. How can education in the context of the new intelligent cities be re-taught? To answer to this question, the following premises must be established:

(a) The educational system is one space of multidimensional experiences of holistic citizens, and is not the center, but has the capacity to influence the rest of space.
(b) Learning occurs in multiple real and virtual dimensions.
(c) The educational system must adapt and answer to the learning needs of the holistic and eclectic citizen.
(d) To diminish the educational gap, it is necessary to design inside the educational system multidimensional experiences of learning that recognize the personal surroundings of learning and management of knowledge of holistic and eclectic citizens.
(e) It is necessary to consider three conceptions: 1. A new epistemological condition, in which the digital citizens know to resolve the border between how to access and represent information of how knowledge is created and transferred; 2. The recognition of a new digital citizen identity based on the notion of bi-dimensionality, that is, a citizen remitted to the real and to the virtual space, and; 3. The notion of a complex redesign of a new citizen that, according to Morin [24], is understood by its autonomy/dependency, individuality, and self-production.

Thus, lifelong learning with the following attributes is proposed: multidimensional; holistic; eclectic; situated; interactive (related to classroom and distributed learning); self-regulated; autonomous; connective; adaptable (in any place and by means of any format or space, real or virtual), and; recursive.

For this re-significance of the bi-dimensional learning, one must work in the following meta-concepts: adaptation; the holistic and eclectic vision in the training of the digital citizen, and; the new pyramid of needs for the digital citizen.

2.3. The Adaptation

The skill of adaptation "involves the wish and the skill to change central competences and expand continuously the degree and depth of the skill" [38] (p. 223). Similarly, it is possible to transfer one's own knowledge and skills to the new tasks and contexts of learnings to a lifelong state [39,40]. This is especially true in this time, as designated by Bauman [41], which is like liquid modernity, that moves to the individuals by the uncertainty rather than by the certainties.

Álvarez [42] posits that examples like Wikipedia and the massive open courses online (MOOC) relate to the autonomous learning competence anytime, in the network, openly, massively, and ubiquitously. The epistemological foundation that sustains this possibility of adaptation and learning anytime and in any place is based on the connectivism theory [43] that maintains that learning can reside in artificial devices.

For Zapata-Ros [44], this connectivity premise contradicts the theories and conceptions of learning, arguing that it corresponds to an exclusively human activity linked to the faculties to know, represent, relate, transmit, and execute. However, why would it have to reside only in the human mind? Siemens [43] offers some clarity when affirming that learning is fundamentally a process of training networks. A subject then forms part of a network of nodes connected between them, being itself one of these nodes that contributes to those connections. Therefore, learning is a process of the creation of thousands of new connections that connect with contents, people, groups, services and repositories [45]. Likewise, the epistemological frame of connectivism is related to an emergent knowledge, connected and adaptive [43], where the knowledge remains in the individual, but resides in the community.

Siemens explained how the theories of analog or modern learning did not consider identity 3 (explained in Section 2) [43]. When he affirmed that these were obsolete, perhaps he should have explained a bit more about how learning online could fit perfectly with this new human identity. Cyberspace is the mind of identity 3 (where the distributed learning is produced); the databases and searchers are versions of the inferior brain, half and upper, fed by thousands of connections. When Siemens created the first MOOC, perhaps he suspected that internet users were newborns with identity 3 that were not yet conscious of it. Ruíz-Velasco [46] defends this idea when affirming that learning is a process that can occur in multiple environments outside of people's control. This process can reside outside of the human being, either inside of an organization or in a database.

The possibility to learn anytime and anywhere requires management of learning spaces and knowledge.

2.4. The Holistic and Eclectic Vision for Training the Digital Citizen

A holistic approach can be appreciated in the model of research, creation, and re-thought of contents in personal surroundings of learning (see Figure 3). This proposal incorporates an eclectic look at the real world and the virtual world. It then considers two circuits: one related to the consumption of information, and the other to the collaborative production of knowledge.

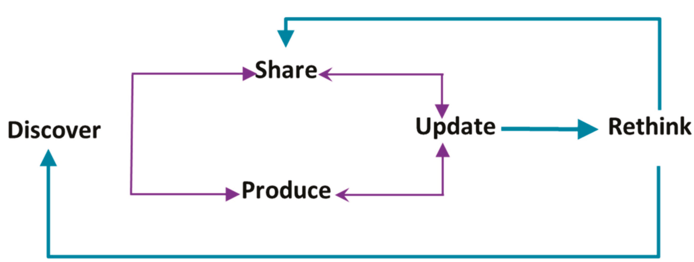

Figure 3. Model of nonlinear learning and rethinking of contents in virtual environments (Source: Own authorship).

The relationship between the model's different verbs show a sequence of research and re-construction of knowledge based in the hypertextual, not sequential theory. Hypertextual theory pretends to reflect nonlinear learning that is typical of the digital bi-dimensional citizens. In relation to the hypertext, Corona [47] indicates that it refers to the forms in which a user visits, sails, moves, and interacts with data on internet.

Nonlinear learning associates the notion of distributed and flexible curriculum that does not correspond to the rationality of a traditional curriculum, mostly rigid, academically rational, formal and prescribed, as it is nowadays. Nonlinear learning is self-regulated, formal, informal, face to face, virtual and temporal. Nonlinear learning implies making connections between things people already knew and new knowledge. This meant that persons actively constructed the knowledge as they needed it, in a subjective and individual way, because each individual experiences distinct social and psychological phenomena in an entirely unique phenomenon.

Together with the hypertextual theory, the model makes evident the collaborative production of knowledge through the production of intellectual constructs and digital devices.

3. The New Pyramid of Needs for the Digital Citizen: A Proposal for Analysis

These new interactive scenarios called resounding spaces by Castells [48], and places or resonant intervals by McLuhan and Powers [28], require citizens with bi-dimensional identities to be capable of managing face-to-face or virtual contexts. It seems interesting to highlight that it is necessary to differentiate between a bi-dimensional identity and a bi-dimensional context. Even though the penetration of ICT has contributed to the face-to-face duality, it does not necessarily mean that, a priori, two-dimensional identities are configured. In fact, Prensky [49] disdained his own idea of being digital native, arguing that they do not exist, and that they really are not as skilled as thought. Although they know how to use technology, they do not know how to learn with it. Negroponte [50] would say that this confusion is related to the concepts of identity, that it is related to the transformation, from atom culture to a bits culture. This is about a process of construction of a hologram representation of humans in virtuality, through small circuits to be seen and complex codes to be understandable [51]. In fact, according to Sibilla [52], this process of construction about identity or this mix between organic and technology requires new theoretical guides that search about how virtuality has been started or to configure a new bi-dimensional identity, that inquire into singular identities in human aggrupation and their link with culture according to human scale.

Therefore, new theoretical guides are required to inquire about this term of virtuality. This concept has been creating new necessities in users, such as in groups of human identity and their interactions with human scale culture.

To design the proposal of this new pyramid of needs for the digital citizen (see Figure 4), it seems interesting to make a contrast with Maslow's hierarchy of needs [53]: new postmodern needs do not deny the permanent needs of the modern citizen. What happens is that permanent needs incorporate new needs based in a mixed reality that involves the real and virtual worlds. These new needs surface with the increasing ability for people to connect, society and the culture. In the measure that a greater quantity of subjects, understood technologically like natural systems excessively complex and probabilistic, relate with other people or institutions using automated means of communication, in this new communicational interactions, new decisions and control decisions for purposes are produced. These processes, proper to the postmodern world, require new skills and the increasing satisfaction of new needs to create the bi-dimensional profile of a digital citizen. These levels of complexity increase from the subjects to the local culture to the global culture.

Figure 4. Pyramid of needs for the digital citizen (Source: Own authorship).

The formulation of the new pyramid of needs for the digital citizen emerges in the postmodern; these are dynamic transculturation processes that make the relationship in the interconnected world complex. This requires satisfying emerging necessities of bi-dimensional citizens (face-to-face or virtual), which complement Maslow's pyramid. This is because it requires a new dimension and definitions at the level of the cultural user, singular cultures and the interaction between them and the human scale.

The new pyramid of needs incorporates the complexity of the cultural transition to postmodernism, giving the new dimension of virtuality and new dynamics that are in cyberspace and the connection with the objective. Therefore, the inverted pyramid does not deny Maslow's pyramid validity (postmodern new necessities do not deny permanent necessities of the modern citizen), otherwise, it places a new rationality by its side, which complements and increases according to the emerging necessities related to the digital citizen, smart city and human scale. This creates a new referent that is theoretically formulated; however, it will be looked for in the implications of its dimensions, categories, standards and indicators that account for every level of complexity.

Some of these new necessities are evident, for instance, in the results of the last report gathered by Project Tomorrow [54], that made a survey with more than 400,000 students in primary, secondary and high school in the United States, finding around a quarter of students already took some virtual classes in math, science and English. More than a half of the total (56%) of the students declared that they use technology to learn outside the classroom. Around 79% of students in high school and 69% in secondary school use the internet at least once per week in order to support their homework. On the one hand, around a half of the students in high school use the internet every day to do their school homework. On the other hand, 14% of teachers declare that they use the internet to assign homework. This report recommends that students are using mobile devices for their own learning processes, online courses are popular, and there are gaps between generations in terms of students in secondary and high school related to the use of technology and the restrictive consequences associated to the use of technology.

In the first level of individual needs, we find the need for digital literacy, which allows individuals to use ICTs in an effective way, so they can access information sources, as well as administer and represent the information. These processes are linked to the development and the management of the individual talents that contribute to the production of a collective identity. The ways of learning are modified because of the new need for self-regulated and autonomous learning, which goes beyond the limits of time and space of modern educational institutions. The bi-dimensional identity of these digital citizens poses the need to develop a holistic and eclectic vision of reality. The holistic need origins in that the digital citizen must integrate the elements of the real world (tangible reality), the idea world (immanent reality), and cyberspace (virtual reality). Moreover, it must be able to develop an eclectic capacity (a) when confronted with the need to identify and decide on the real components, ideal and virtual, that better contribute to the definition of its identity as a bi-dimensional subject, (b) when developing its individuality, like a member of a specific human grouping, and (c) in determining the positive and ethical characteristics of its transfers of knowledge to human culture.

The second level of the singular needs refers to the dynamic between the subjects, understood as cultural agents, and the identity formation of the human grouping to which it belongs. The most remarkable need is of epistemological character since the digital citizen needs to surpass the existent border between the administration of information and the management of knowledge to perform efficiently in smart human cities. The capacity to create intellectual and/or practical constructs and to make them transferable requires the mediation of learning and knowledge through some abstract expression of language. Once this is achieved, this individual will be considered a dimensioned citizen at the level of his/her singular culture. He/she will be an agent generator of knowledge that positively influences the processes of creating a local cultural identity. Digital citizenship surfaces from smart cities by means of the management of knowledge of its cultural agents, and those who are able to link with other human groupings.

The third level of the global needs is based on digital inclusion. It is only possible to be a citizen of the world if one has the technological skills and access to technology in order to communicate. It creates the need for adaptation to real, mixed, and virtual contexts. This creates the need to re-think what is known because the categories of the modernity have been altered. It is necessary to add virtuality to the four categories of modernity, namely, length, plus width, plus height, plus time. The digital citizen is no longer just dimensional with the objective reality but also with virtual reality. This forces us to re-think these categories of thought. This new need is absolutely necessary, and is proper to the postmodern world that is transformed gradually into a cultural pattern. Similarly, the need to transfer knowledge arises. The cultural singularity of human groups is questioned by the new dynamics of culture on a human scale. The singular epistemology, situated locally, extrapolates to a virtual epistemology that is formed by all the digital citizens that can participate actively in the global culture. This is because the citizens have gradually satisfied their basic digital needs at the level of the subjects. That is, they have managed their own culture mediated by technologies and have begun to experience intense processes of intercultural illustration, transculturation, and acculturation.

4. Conclusions

The smart city is a consequence of two phenomena of the human history [55]. On one hand, urbanization has increased around the world and, on the other, there is the digital revolution, which is characterized by the use of ICT in every sort of human activity.

The exposed analysis allows us to conclude that computerized and hyperconnected cities do not necessarily involve the creation of smart cities. The technological implementation in itself does not bring like consequence the creation of networks of digital citizens empowered with their role in the real or virtual world, neither has it secured local or global impacts.

We finally argue that in order to be considered as a smart city, a city must improve citizens' quality of life, making them part of decisions, such as government or city planning. Related to this topic, Bakici, Amirall and Wareham [56] propose a smart city as a live laboratory in which citizens can interact via ICT.

It is possible to find an effect of smart cities in the project that Bill Gates is developing, who acquired 100 km^2 of desert near Phoenix (Arizona) in order to develop his vision of the city of the future. According to Belmont Partners [57] (the real estate company in charge of the project), the vision that Gates wants to develop includes a city with digital network, with huge high-speed data centers, new manufacturing technologies and distribution models, vehicles without drivers, with logistics working autonomously. Even though, currently, there are few people living in this area, the idea is that the smart city will incrementally grow its population through years until it has a population of 182,000. A few years ago the use of touchscreen to control the light, music or temperature was something unthinkable for the era; now it is common that houses have home automation of various control. In the same way, it is highly probably that the analysis of this experimental experience and its impact will come later.

The cities need campaigns of digital literacy and digital illumination to guarantee accessibility. They also need intellectual development and technological talents to generate digital inclusion within citizens that contribute to make cities smarter. This does not exclusively mean in function of its own development, but in relation to the talents of citizens, the singular identity of the human groupings that inhabit them and its links with culture on a human scale.

In this sense, digital citizens of future generations will have to develop a cybernetic-intuitive consciousness that allows them to perform according to a bi-dimensional identity. The objective reality is the reality of tangible objects; and the virtual reality is the reality of cyberspace that moves with other rhythms and distinct categories to the ones of modernity. We can affirm then that the mixed coexistence of both realities is the typical stage of smart human cities.

In the transition to the postmodern world, learning occurs in multiple real and virtual dimensions. The modern educational system has to adapt to the needs of a new citizen in training with the goal of diminishing the educational gap, moving to the design of multidimensional experiences in education, and learning to recognize the personal surroundings of learning and the surroundings of management of knowledge of holistic and eclectic citizens.

The required education is based on self-regulated and autonomous learning that promotes the training of capable intelligent citizens to identify and surpass the epistemological border that separates the administration of information from knowledge management. Said citizens will learn in the formal educational systems and will learn about their own knowledge, making it transferable to their local and global cultures.

It is necessary to re-think the categories of thought, moving from linear, characteristic of modernity, to a holistic and eclectic thought that promotes effective and ethical performance in the real and virtual worlds. In this context, a new pyramid of needs for the digital citizen arises in a mixed real-virtual reality, mediated by the cybernetic characteristic of individuals and social groups and with a local and global cultural impact.

The virtual world is not different from the real world in its contents; it only behaves with different dynamics and categories. Both worlds are the reflection of man's intelligence, goodness, virtues, capacities, and talents, as well as his weaknesses, contradictions, passions and misfortunes. In order to be an intelligent digital citizen, it is necessary to recognize that, although nature is man's home which he must respect, virtuality is the new dimension of the postmodern man. This man must take care filling the dimension with contents that, apart from healthy digital fun, would have to be impregnated with an ethical sense, aesthetics, knowledge, education, art, science, society, humanity and culture.

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References

1. Martínez, M. *Epistemología y Metodología Cualitativa en las Ciencias Sociales*; Editorial Trillas: Ciudad de México, Mexico, 2008.
2. Morin, E. *El Método III: El Conocimiento del Conocimiento*; Ediciones Cátedra: Madrid, Spain, 1999.

3. Sarmiento, J. Ciudades y Ciudadanos Inteligentes. El Componente Humano de las Smart Cities. *Telos Cuad. Comun. Innov.* **2016**, *105*, 76–83.
4. Conesa, P. Smart cities: Una visión integral para acelerar la innovación urbana, un camino a recorrer. *Rev. Telos* **2016**, *105*, 6–8.
5. Organización de las Naciones Unidas, Departamento de Asuntos Económicos y Sociales. Más de la Mitad de la Población Vive en Áreas Urbanas y Seguirá Creciendo. Available online: http://www.un.org/es/development/desa/news/population/world-urbanization-prospects-2014.html (accessed on 19 November 2017).
6. Ratti, C. Smart cities: Lo que de verdad importa. *MIT Technol. Rev.* **2013**. Available online: https://www.technologyreview.es/s/3749/smart-cities-lo-que-de-verdad-importa (accessed on 19 November 2017).
7. Harrison, C.; Eckman, B.; Hamilton, R.; Hartswickm, P.; Kalagnanam, J.; Paraszczak, J.; Williams, P. Foundations for smarter cities. *J. Res. Dev.* **2010**, *54*, 1–16.
8. Colado, S.; Gutiérrez, A.; Vives, C.; Valencia, E. *Smart City. Hacia la Gestión Inteligente*; Marcombo: Barcelona, Spain, 2014.
9. Ishida, T.; Isbister, K. *Digital Cities: Technologies, Experiences, and Future Perspectives*; Springer: Berlin, Germany, 2002.
10. Albino, V.; Berardi, U.; Dangelico, R. Smart Cities: Definitions, dimensions, performance, and initiatives. *J. Urban Technol.* **2015**, *22*, 3–21. [CrossRef]
11. Arizmendi, S.; Navío, J.; Portilla, J. Smart cities: ¿Cómo determinar el estado de desarrollo de una ciudad inteligente? *Telos Cuad. Comun. Innov.* **2016**, *105*, 49–65.
12. Cohen, B.; Obediente, E. Estudio Ranking de Ciudades Inteligentes en Chile. Centro de Estudios Digitales, Fundación País Digital. 2014. Available online: http://dg6223fhel5c2.cloudfront.net/PD/wp-content/uploads/2014/06/Ranking-Ciudades-Inteligentes-en-Chile.pdf (accessed on 19 November 2017).
13. Comisión de Ciudades Digitales y del Conocimiento. Estudio Internacional Sobre la Situación de las TIC, la Innovación y el Conocimiento en las Ciudades. 2012. Available online: http://www.uclg-digitalcities.org/la-comision-presenta-el-smart-cities-study-en-la-reunion-anual-celebrada-en-dakar/ (accessed on 1 October 2017).
14. Olmedo, E.; López, A. De la smart city a la smart human city. Inclusión digital en aplicaciones. *Rev. Fuentes* **2015**, *17*, 41–65. [CrossRef]
15. Savater, F. *La Aventura del Pensamiento*; Penguin Random House Grupo Editorial S. A: Santiago, Chile, 2014.
16. Fromm, E. *¿Tener o Ser?* Fondo de Cultura Económica: Ciudad de México, Mexico, 1978.
17. Salazar, R. Quién es el Sujeto Insumiso. 2008. Available online: http://conceptos.sociales.unam.mx/conceptos_final/478trabajo.pdf (accessed on 19 November 2017).
18. Careaga, M.; Avendaño, A. *Currículum Cibernético y Gestión del Conocimiento. Fundamentos y Modelos de Referencia*; RIL, Ed.; Editorial UCSC: Santiago, Chile, 2017.
19. Careaga, M. Circuito Pedagógico de Gestión del Conocimiento. 2008. Available online: http://www.ucsc.cl/wp-content/uploads/2013/09/educacion-parte-2.pdf (accessed on 19 November 2017).
20. Careaga, M.; Barnes, S. Actualización Circuito Pedagógico de Gestión del Conocimiento. 2015. Available online: http://marcelocareaga.blogspot.com/ (accessed on 19 November 2017).
21. Reig, D.; Vílchez, L. *Los Jóvenes en la Era de la Hiperconectividad: Tendencias, Claves y Miradas*; Fundación Telefónica: Santiago, Chile, 2013. Available online: https://www.fundaciontelefonica.com/arte_cultura/publicaciones-listado/pagina-item-publicaciones/itempubli/182/ (accessed on 19 November 2017).
22. García, N. *Lectores, Espectadores e Internautas*; Editorial Gedisa: Barcelona, Spain, 2007.
23. Hannerz, U. *Conexiones Transnacionales*; Frónesis Cátedra Universitat de Valencia: Madrid, Spain, 1996.
24. Morin, E. *La Cabeza Bien Puesta. Repensar la Reforma. Reformar el Pensamiento*; Nueva Visión: Buenos Aires, Argentina, 2002.
25. Popper, K. *Objective Knowledge: An Evolutionary Approach*; Oxford University Press: Oxford, UK, 1972.
26. Wiener, N. *Cybernetics or Control and Communication in the Animal and the Machine*; John Wiley and Sons: New York, NY, USA, 1961.
27. Couffignal, L. *Cibernética y Educación*; Édition de Minuit: Paris, France, 1964.
28. McLuhan, M.; Powers, B.R. *La Aldea Global. Transformaciones en la Vida y Los Medios de Comunicación en el Siglo XXI*; Editorial Gedisa: Barcelona, Spain, 1989.

29. Wachter, S. *La Ville Interactive: L'architecture et L'urbanisme au Risque du Numérique et de L'écologie*; L'Harmattan: Paris, France, 2010.
30. Rubio, J. Educar ciudadanos: El planteamiento republicano liberal de rousseau. *Contrastes. Rev. Int. Filos.* **2003**, *8*, 211–227.
31. Gimeno, J. *Educar y Convivir en la Cultura Global. Las Exigencias de la Ciudadanía*; Morata: Madrid, Spain, 2001.
32. Kymlicka, W. *La Política Vernácula: Nacionalismo, Multiculturalismo y Ciudadanía*; Paidós: Barcelona, Spain, 2003.
33. Waissbluth, M. América Latina, un Continente de Analfabetos Funcionales. Fundacion Educacion 2020. 2016. Available online: http://www.flacso.edu.mx/sites/default/files/ponencia_mexico_final_abril_2016.pdf (accessed on 19 November 2017).
34. Gentili, P. Marchas y Contramarchas. El Derecho a la Educación y las Dinámicas de Exclusión Incluyente en América Latina. *Rev. Iberoam. Educ.* **2009**, *49*, 19–57. Available online: https://dialnet.unirioja.es/servlet/autor?codigo=35994 (accessed on 19 November 2017).
35. Foucault, M. *Power Know Ledge: Selected Interviews and Other Writings 1972–1977*; Pantheon Books: New York, NY, USA, 1981.
36. De Corte, E. Una perspectiva innovadora de enseñanza y aprendizaje en la educación superior. In Proceedings of the Conferencia Presentada en el Lanzamiento de la Unidad de Innovación Educativa de la Universidad Nacional Agraria la Molina, Lima, Peru, 2011. Available online: http://www.lamolina.edu.pe/innovacioneducativa/images/files/libros/Art%C3%ADculo%20Peru%20Educa-%20Ambientes%20de%20aprendizaje%20-%20conferencia%20de%20Erik%20de%20Corte%20en%20la%20UNALM%20(Mayo%202011).pdf (accessed on 19 November 2017).
37. Robles, F. *Las Paradojas de la Educación Chilena y la Apología de las Máquinas Triviales. ¿Ha Llegado la Hora del Cambio en el Sistema Educacional?* Facultad de Ciencias Sociales, Departamento de Antropología, Universidad de Chile: Santiago, Chile, 2010. Available online: http://www2.facso.uchile.cl/postgrado/mad/docs/Robles_Educacion_Chile.pdf (accessed on 19 November 2017).
38. Bransford, J.; Stevens, R.; Schwartz, D.; Meltzoff, A.; Pea, R.; Roschelle, J.; Vye, N.; Kuhl, P.; Bell, P.; Barron, B.; et al. Learning theories and education: Toward a decade of synergy. In *Handbook of Educational Psychology*, 2nd ed.; Alexander, A., Winne, P.H., Eds.; Lawrence Erlbaum Associates: Mahwah, NJ, USA, 2006; pp. 209–244.
39. De Corte, E. Learning from Instruction: The Case of Mathematics. *Learn. Inq.* **2007**, *1*, 19–30. [CrossRef]
40. Hatano, G.; Oura, Y. Commentary: Reconceptualizing school learning using insight from expertise research. *Educ. Res.* **2003**, *32*, 26–29. [CrossRef]
41. Bauman, Z. *Liquid Modernity*; Polity Press: Cambridge, UK, 2000.
42. Álvarez, D. Entornos personales de aprendizaje para la gestión del conocimiento en tiempos líquidos. ikasnabar. *Open Educ. Technol.* **2014**. Available online: http://ikasnabar.com/papers/wp-content/uploads/2014/12/DavidAlvarez.pdf (accessed on 19 November 2017).
43. Siemens, G. Connectivism: Learning as Network-Creation. 2006. Available online: http://www.elearnspace.org/Articles/networks.htm (accessed on 19 November 2017).
44. Zapata-Ros, M. Teorías y Modelos sobre el Aprendizaje en Entornos Conectados y Ubicuos. Bases para un nuevo modelo a partir de una visión crítica del conectivismo. *Teoría Educ. Educ. Cult. Soc. Inf.* **2015**, *16*, 69–102. [CrossRef]
45. Bartolomé, A. Conectivismo: Aprender em rede e na rede. In *Tecnologias na Educaçao: Uma Abordagem Crítica para Uma Atuaçao Práctica*; Brito, M., Ed.; UFRPE: Recife, Brasil, 2011; pp. 71–86.
46. Ruíz-Velasco, E. *Cibertrónica: Aprendiendo con Tecnologías de la Inteligencia en la Web Semántica*; Díaz de Santos: Ciudad de México, Mexico, 2013.
47. Corona, J.M. La Construcción Social de Internet: Estrategias de Uso y Significación de la Información. *Rev. Tecnol. Soc. Redes Soc. Divers.* **2012**, *3*, 1–14. Available online: http://www.udgvirtual.udg.mx/paakat/index.php/paakat/article/view/176/244 (accessed on 19 November 2017).
48. Castells, M. Flujos, redes e identidades: Una teoría crítica de la sociedad informacional. In *Nuevas Perspectivas Críticas en Educación*; Castells, M., Flecha, R., Freire, P., Giroux, H., Macedo, D., Willis, P., Eds.; Paidós: Barcelona, Spain, 1994; pp. 13–54.

49. Prensky, M. Nativos e Inmigrantes Digitales. 2010. Available online: http://www.marcprensky.com/writing/Prensky-NATIVOS%20E%20INMIGRANTES%20DIGITALES%20(SEK).pdf (accessed on 19 November 2017).
50. Negroponte, N. *Ser Digital*, 1st ed.; Ediciones B, S.A.: Barcelona, Spain, 1995; ISBN 84-406-5925-3.
51. Dery, M. *Velocidad de Escape*; Síruela: Barcelona, Spain, 1998; pp. 9–10.
52. Sibilla, P. *El Hombre Postorgánico: Cuerpo, Subjetividad y Tecnologías Digitales*, 1st Electronic ed.; Fondo de Cultura Económica: Buenos Aires, Argentina, 2012.
53. Maslow, A. A theory of human motivation. *Psychol. Rev.* **1943**, *50*, 370–396. [CrossRef]
54. Project Tomorrow. Speak Up 2016 Research Project For Digital Learning. 2016. Available online: http://www.tomorrow.org/speakup/index.html (accessed on 19 November 2017).
55. Bouskela, M.; Casseb, M.; Bassi, S.; De Luca, C.; Facchina, M. *La Ruta Hacia las Smart Cities: Migrando de una Gestión Tradicional a la Ciudad Inteligente*; Banco Interamericano de Desarrollo: Washington, DC, USA, 2016. Available online: https://publications.iadb.org/bitstream/handle/11319/7743/La-ruta-hacia-las-smart-cities-Migrando-de-una-gestion-tradicional-a-la-ciudad-inteligente.pdf?sequence=10 (accessed on 19 November 2017).
56. Bakici, T.; Almirrall, E.; Wareham, J.A. Smart city initiative: The case of Barcelona. *J. Knowl. Econ.* **2013**, *4*, 135–148. Available online: https://econpapers.repec.org/article/sprjknowl/v_3a4_3ay_3a2013_3ai_3a2_3ap_3a135-148.htm (accessed on 29 September 2017). [CrossRef]
57. Pascual, A. Así es la Smart City Que Quiere Construir Bill Gates en Estados Unidos. Available online: http://www.quo.es/tecnologia/asi-es-la-smart-city-que-quiere-construir-bill-gates-en-estados-unidos (accessed on 11 November 2017).

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County-Rural Transformation Development from Viewpoint of "Population-Land-Industry" in Beijing-Tianjin-Hebei Region under the Background of Rapid Urbanization

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Abstract: In recent years, rural transformation has gradually become the focus of scholars and governments in the context of global sustainable development; it is of great significance to achieve urban-rural integration and coordinated development through studying the spatial-temporal characteristics and driving mechanism of rural transformation development. This paper analyzes the spatial-temporal characteristics of county-rural transformation development through drawing into the transformation degree (TD) and coordination degree (CD) from the viewpoint of "population–land–industry" (PT-IT-LT) in the Beijing-Tianjin-Hebei region. It explores the mechanism of PT-IT-LT on the rural transformation in different stages through multi-element positioning in the same space coordinate system and carries out functional regionalization on the basis of transformation and coordination research. The results showed that: (1) The CD and TD were divided into four types, namely, the lower-level, low-level, middle-level and high-level, and had a similar changed tendency from 1990 to 2015, where the middle- and high-level were in the central counties of the Beijing-Tianjin-Hebei region and the lower- and low-level were in the other parts of the region. (2) According to the mechanism analysis, stages A and B were mainly influenced by industry transformation; stage D was affected by population transformation; and stage E was influenced by land transformation. (3) The Beijing-Tianjin-Hebei region was divided into an ecological conservation area, a key development area and a core leading area, according to the study, which would provide a scientific basis to achieve integration of the Beijing-Tianjin-Hebei region and regional strategic optimization.

Keywords: rural transformation; population-land-industry; coordination degree; Beijing-Tianjin-Hebei region

1. Introduction

Since reform and opening up, China has experienced a rapid urbanization process with rapid socioeconomic development. Great changes have also taken place in the countryside at the same time, including changes to the peasant living standard and rural living environment [1–3]. Rural transformation has been the main form of rural development driven by rapid industrialization and urbanization, and the government has taken many reforms and policies to promote rural economic development and improve the infrastructure [4,5]. The rural transformation has included the spatial organization structure of villages and towns, developmental patterns of rural industry, employment ways, consumption structure, land-use patterns and urban–rural relations [6–8]. Thus, rural transformation is an important link to promote urban and rural integration in the process of rapid urbanization.

However, there are many problems during the process of rural transformation, including weakening farmers, environmental pollution, village hollowing and the occupation of cultivated land in China [9–11]. To pursue higher wages and better employment opportunities offered by cities, young rural laborers have moved to work in the cities, leaving the aged at home in agriculture roles, or whole families have moved to the cities, leaving empty houses in the countryside. With the development of industrialization, a large number of polluting substances have also been discharged into the village, which has brought about serious impacts on the rural environment [12]. The uncoordinated phenomenon in rural development has become increasingly obvious. Thus, coordination has been an important part of the rural transformation and an important criterion to measure whether rural development has been sustainable or not. Meanwhile the research of rural transformation and coordination development has gradually attracted the attention of scholars over recent years [13,14].

The study of rural transformation has mainly focused on the population, land and industry, and it has had a great deal of research to analyze the coordination of rural development [7,13,15,16], but the question of how to explain the development of rural transformation systematically and comprehensively and how to explore the mechanism of "population-land-industry" (PT-IT-LT)—which consists of three factors, population, land and industry—scientifically has still been difficult. To solve these problems, this paper puts forward the coordination degree (CD) and TD, and combines them with PT-IT-LT in the same space coordinate system in different stages. The TD refers to the transition scale of the rural population, land and industry to the non-agricultural factors and the CD refers to the coordination and conformity of the population, land and industry to the non-agricultural transformation. Then this paper discusses the mechanism of PT-IT-LT on rural transformation in depth, and carries out the functional regionalization to rural development innovatively on the basis of a mechanism analysis and the spatial–temporal characteristics of transitional development in the Beijing-Tianjin-Hebei region. The study is significant for the rural sustainable development and the integration of the Beijing-Tianjin-Hebei region in the future, and it provides method references for the study of rural development.

2. Methods and Materials

2.1. Study Area

The Beijing-Tianjin-Hebei region is the "capital circle" in China, which includes 13 cities and 200 counties (Figure 1). It is one of the most developed and prosperous regions and attracts worldwide attention. By the end of 2015, the total population of the Beijing-Tianjin-Hebei region was 111 million, and the urban population was 69.7 million; its urbanization rate was 62.5%. The gross domestic product (GDP) was about $1 trillion and the per capita GDP had already exceeded $9000 in 2015. Ever more rural people were attracted to work in the city as a result of the socioeconomic development, and the urban and industrial extension led the rural economy surrounding the city to develop rapidly. More farmers abandoned traditional agriculture and turned to modern agriculture for higher earnings; great changes have taken place in the rural areas of the Beijing-Tianjin-Hebei region over the past 30 years. Thus, the region was a typical case area to study rural transformation over the past 20 years.

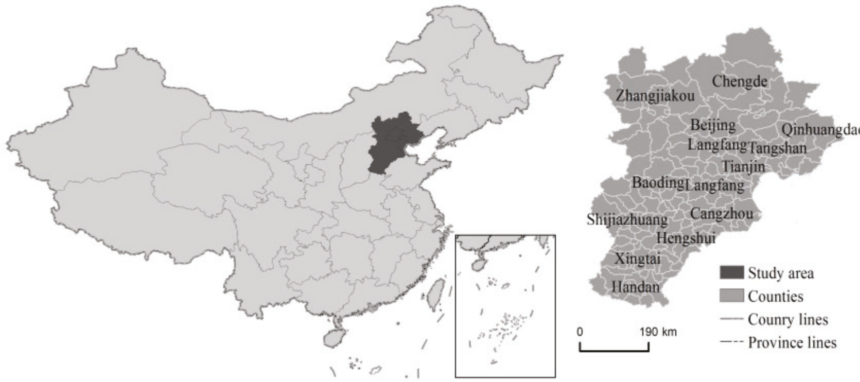

Figure 1. Study area.

2.2. Data and Methods

The urban-rural system is made up of the population, land and industry. The population is the main body of the system, whose behavior can change the system by using other factors. Land is the carrier of the system, which can supply the living and working space for the population and guarantee industrial development. Industry is the power supply of the system, which can improve the living standard of the population and promote the system to rise to a higher level [17,18]. Thus, the population, land and industry are the essential factors of rural transformation [7,13]. These factors are interactive with each other in the process of transformation, and their coordination relationship has promoted the development of the urban-rural system. With socioeconomic development, the second industry and the tertiary industry have expanded their scale continuously; ever more of the rural population has been attracted to the city for its high living standard, which has accelerated the process of urbanization in recent years and increased the demand for living-space land [3,14]. Meanwhile, the external population has made a great contribution to the urban economy and expanded the scale of cities. The population, land and industry have been interactive with each other to form a development cycle system. Therefore, studying the rural PT-IT-LT has aided the understanding of the developing law of the rural system and has been of great significance to promote the coordinated development of urban and rural areas.

Population, land and industry are regarded as important factors in the process of rural transformation. Population transformation refers to farmers moving into towns to engage in non-agricultural employment or to live; land transformation refers to farmland becoming construction land; industry transformation refers to agriculture turning into the second and tertiary industries, which produces rural development. Thus, this study uses these three indicators to analyze the rural transformation degree (TD). This includes the proportion of agricultural labor with non-agricultural employment accounting for the total agricultural labor (*PT*) and the proportion of non-agricultural output value accounting for the GDP (*IT*), which came from the statistical yearbook of Beijing, Tianjin and Hebei [19–21], and the proportion of urban-industrial and mining land accounting for the total land area (LT), which was provided by the Resource and Environment Science Data Center of Chinese Academy of Sciences (http://www.resdc.cn) [22–24]. Two important indicators, the CD and TD, have been defined to describe the development of the rural transformation in the county.

All data had to be dimensionless to control the indicator value, which was from 0 to 1, allowing it to be calculated easily, and the indicators were given weights by mean deviation (Table 1). The CD with three indicators was acquired by Equation (1), which was improved by the formula for coupling coordination [25]; the formula aimed to test the consistency of change in PT-IT-LT, and its value was between 0 and 1. The closer to 1 the value was, the better the coordination relationship of the three indicators. The TD was obtained by adding three indicators with different weights (Equation (2)) [23,26]. The counties in the Beijing-Tianjin-Hebei region were seen as sample points to study the characteristics of rural transformation development by cluster analysis. The cluster analysis regarded the TD as basic ordered data, and added the CD and PT-IT-LT to the unified coordinate system; then the study divided the transformation development types according to the variation trend of the TD, CD and PT-IT-LT; in the last, the study named the transformation development types by multidimensional elements: "population-land-industry" + "coordination degree" + "transformation degree".

Table 1. Indicators of rural transformation.

Criteria Layer	Index Layer	Weights
Population	The proportion of agricultural labor with non-agricultural employment accounting for the total agricultural labor.	0.387
Land	The proportion of urban-industrial and mining land accounting for the total land area.	0.239
Industry	The proportion of non-agricultural output value accounting for gross domestic product.	0.374

$$\mathrm{CD} = \frac{\mathrm{PT} \times \mathrm{IT} \times \mathrm{LT}}{\left(\frac{\mathrm{PT}+\mathrm{IT}+\mathrm{LT}}{3}\right)^3} \tag{1}$$

$$\mathrm{TD} = \alpha \times \mathrm{PT} + \beta \times \mathrm{IT} + \gamma \times \mathrm{LT} \tag{2}$$

3. Results

3.1. Coordination Degree

The study used the improved Equation (1) to obtain the CD of the PT-IT-LT (Figure 2). It used the quartering method to analyze the result in different periods: the first stage was the lower-level coordinate whose degree was from 0.0 to 0.25; the second stage was the low-level coordinate whose degree was from 0.25 to 0.50; the third stage was the middle-level coordinate whose degree was from 0.50 to 0.75; the last stage was the high-level coordinate whose degree was from 0.75 to 1.0.

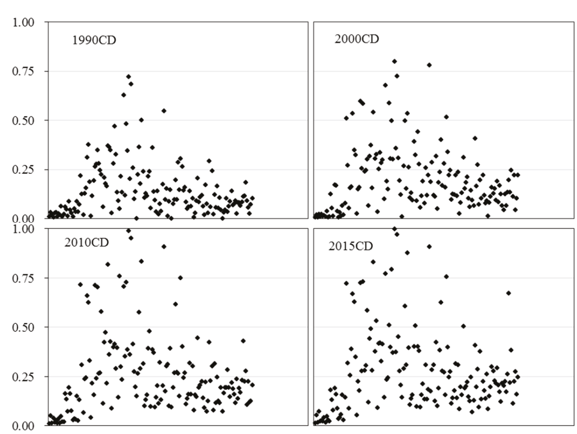

Figure 2. Coordination degree (CD) from 1990 to 2015.

In time, the CD of the PT-IT-LT changed to high-level from low-level, and the mean value of the CD was 0.14, 0.20, 0.26 and 0.28 from 1990 to 2015. From 1990 to 2015, the CD was generally lower-level, but the proportions accounting for the total counties decreased gradually, and the values were 83.44%, 70.70%, 61.78% and 56.69%. The proportions of the low-level, middle-level and high-level CD accounting for the total counties increased from 1990 to 2015, which showed that the CD of rural PT-IT-LT in the Beijing-Tianjin-Hebei region continuously improved. With the economic development, ever more farmers gave up agriculture and left rural areas to work in factories; the demand for land increased, and the government had to take measures to alleviate the conflict between population and land.

In terms of space, most counties belonged to the lower-level CD from 1990 to 2015, but they had great spatial differences. The high-level CD of PT-IT-LT applied to Beijing and Tianjin; few counties occurred in the center of the Beijing-Tianjin-Hebei region (Figure 3). A circle structure from southeast to northwest Beijing-Tianjin-Hebei was clear; the CD of coastal counties was greater than for those far from the sea, which reflected the order of socioeconomic development in the region. The CD of some southeastern counties had reached the middle-level in 2015, while the northwestern counties were still at the lower-level, compared with 1990, because the economic development in the southeast with more advantages was faster than for the northwest, and its economy promoted the rural areas to develop in a more coordinated manner.

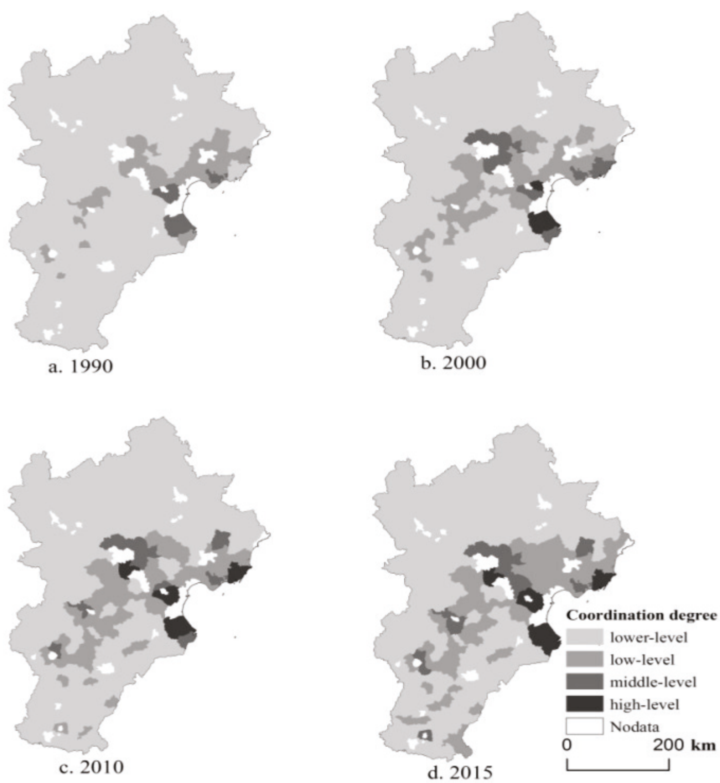

Figure 3. Coordination degree (CD) in Beijing-Tianjin-Hebei region.

3.2. Transformation Degree

The study obtained the rural TD of different counties by the linear weighting of three indicators from 1990 to 2015. According to the value of the TD, the study divided rural transformation into four types: lower-level transformation (0–0.25), low-level transformation (0.25–0.50), middle-level transformation (0.50–0.75), and high-level transformation (0.75–1.0). From Figure 4, no counties in the region achieved the high-level transformation, and most of the counties remained at the lower-level transformation (52.86%) in 1990. The proportion of high-level transformations increased, and the proportion of lower-level transformations decreased from 1990 to 2015; there were 10 counties with high-level transformation in 2015, while the number with lower-level transformation was only 3, accounting for 1.91% of the total counties. The result reflected that the level of the TD in the Beijing-Tianjin-Hebei region gradually became better from 1990 to 2015, and there was a great difference in these counties because of their different bases in different periods.

In terms of space, there was a spatial development trend similar to that of the CD from 1990 to 2015. Beijing and Tianjin were the cores of this region, and the TD of their counties was always higher than for other counties, reaching high-level transformation in 2015 (Figure 4). However, the northwestern area of the Beijing–Tianjin–Hebei region was at the lower-level from 1990 to 2015. This shows that regional differences were a serious problem that hindered the development of urban and rural integration.

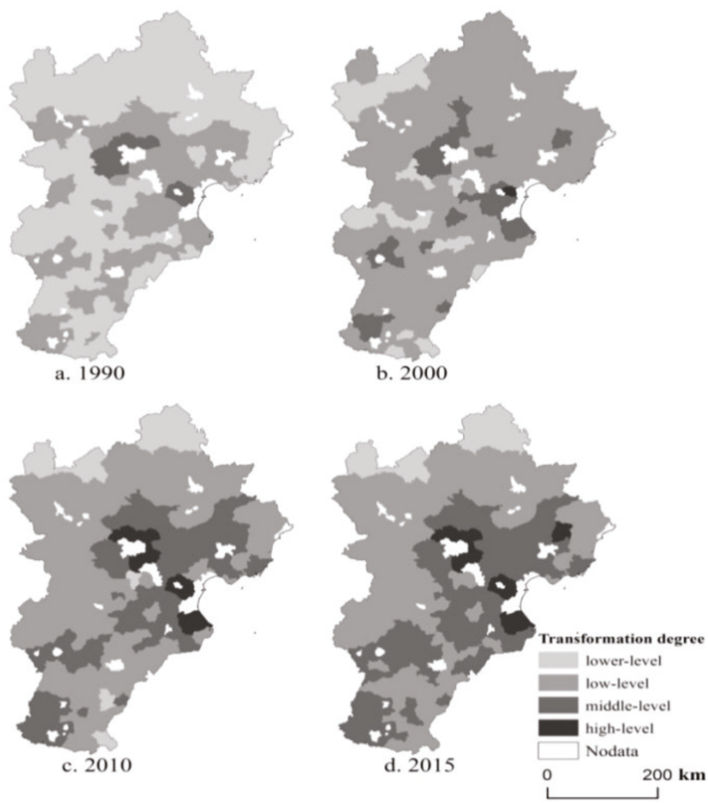

Figure 4. Rural transformation degree (TD) from 1990 to 2015.

To analyze the differences in the TD, this study obtained the speed of transformation for the periods of 1990–2000, 2000–2010 and 2010–2015 (Figure 5). The speed for 1990–2000 was higher than that for 2000–2010 and 2010–2015, and the speed for 1990–2000 and 2000–2010 did not follow an obvious trend, but the speed for 2010–2015 in the southeast of the Beijing-Tianjin-Hebei region was faster than for other regions. However, the speed decreased gradually from 1990 to 2015, and its change trend was opposite to that of the TD. Thus, the higher the transformation level was, the lower its speed.

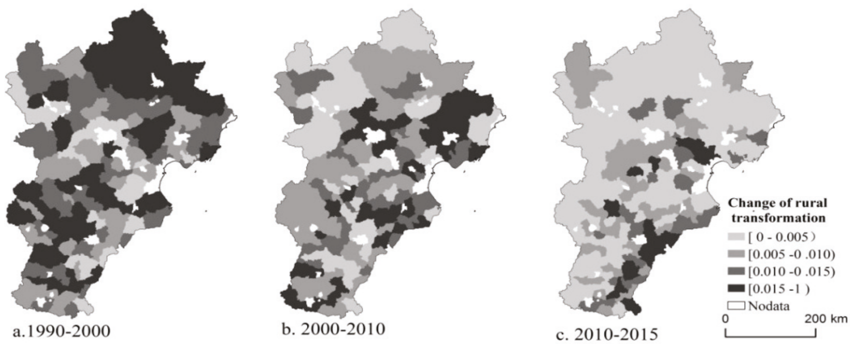

Figure 5. Change of transformation degree (TD) from 1990 to 2015.

3.3. Rural Transformation—Coordination Development

The study obtained the fitting curves of the PT-IT-LT, CT and TD by disturbance translation with 18 iterations, which avoided the volatility of the sample counties' data. Then, according to the coupling results of all the factors, the rural transformation–coordination development was divided into five types: fast industry lower-level coordination and transformation development (A), fast industry and population lower-level coordination and low-level transformation development (B), high factors lower-level coordination and low-level transformation development (C), fast population low-level coordination and middle-level transformation development (D) and fast land middle- and high-level coordination and transformation development (E) (Figure 6).

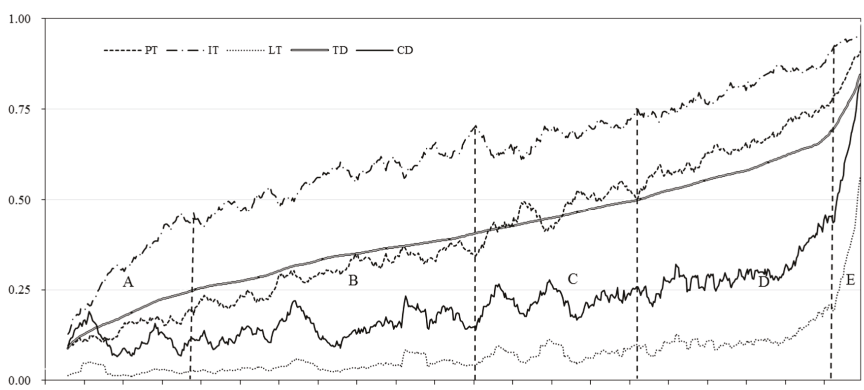

Figure 6. Rural transformation-coordination and population-land-industry (PT-IT-LT).

(1) The fast industry lower-level coordination and transformation development (A) described the industry transformation increasing continuously with rapid growth and was higher than the population and land transformation. The CD and land transformation had lower-level stability, and the TD was lower-level but increased slowly. This reflected that the industry transformation had an influence on the rural TD but had no effect on the rural CD.

(2) The fast industry and population lower-level coordination and low-level transformation development (B) described the industry and population transformation growing quickly, but the land transformation and CD increasing very slowly. The TD was low-level and improved with the change of industry and population transformation. Thus, this showed that the industry and population had a larger impact on the rural TD than the land but a smaller function for the rural CD.

(3) The high factors lower-level coordination and low-level transformation development (C) was a type for which the population, industry and land were relatively stable and without significant change. However, the coordination was still lower-level and it had a high volatility similar to the change of the land transformation. It is clear that the land transformation was promoting the change of the rural CD, and the rural TD was affected by population, land and industry together in these counties.

(4) The fast population low-level coordination and middle-level transformation development (D) showed that the TD was middle-level and increased rapidly with the change of population. Meanwhile, the CD had reached the lower-level and its growth was slower than that of the TD. The amplitude for the land transformation and industry was also lesser than that of the population transformation. Thus, the population was the main factor influencing the rural transformation in the regions.

(5) The fast land middle- and high-level coordination and transformation development (E) was the most highly developed type, whose TD and CD were middle- or high-level and whose population transformation and industry transformation were also high-level in these regions. However, the increase of land transformation was more than other types and arrived at the high-level, as for the population and industry in the previous sample points. Accordingly, land was the most important factor for the rural transformation in these counties.

According to the characteristics of different rural transformation types, we found the developing state of different counties from 1990 to 2015, and detected the leading factors influencing the TD and CD, which would provide support for the functional subzones of the rural transformation development in the Beijing-Tianjin-Hebei region and greatly enlighten the study of rural development.

4. Discussions

4.1. Mechanism of Population–Land–Industry to Rural Transformation

This paper uses the CD and TD to describe the spatial and temporal characteristics of rural transformation development from the view of PT-IT-LT in Beijing-Tianjin-Hebei. It shows the difference among these counties from 1990 to 2015. The rural transformation development has been divided five types by cluster analysis and multidimensional element naming, which revealed the development characteristics of different counties easily because of the different influences of population, land and industry. Thus, it was very necessary to further analyze the mechanism of PT-IT-LT on the rural transformation development (Figure 7). The study has important value for achieving urban and rural integration and coordinated development of the Beijing-Tianjin-Hebei region in the future.

The population mainly refers to the rural population, which is subject to the rural system. These people live in the countryside with their own land and have engaged in agriculture for a long period of time. With the social development, cities have appeared gradually and their economies have boomed rapidly. Many in the rural population have been attracted to the cities for a high quality of life. However, the cities have continued to expand at a higher speed in modern times, and more from the agricultural population have moved into cities and become part of the urban population. There have also been many surplus rural labors becoming migrant workers for a higher income without farming, and the living standard of the rural population has gradually improved. The rural population migration and non-agricultural employment has been better for relieving the employment pressure of surplus rural labors; it has had important effects as shown in the rural transformation development in Figure 6 (D). However, there have been lots of problems, such as agriculture subject weakening and village hollowing, in the Beijing-Tianjin-Hebei region.

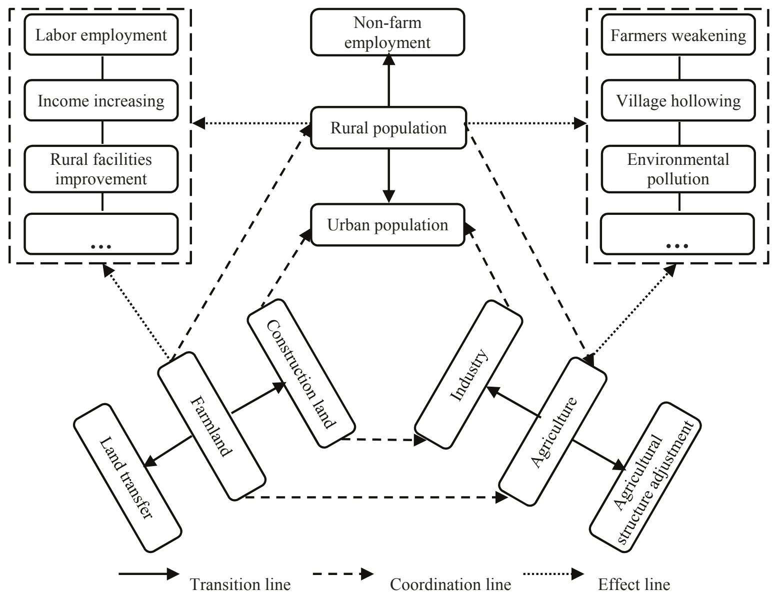

Figure 7. Mechanism of population-land-industry (PT-IT-LT) transformation in Beijing-Tianjin-Hebei.

Land is the material base for human living and is the object of the rural system. Rural transformation has mainly been the change between farmland and construction land, which were the important forms bearing human production and life, but the two were usually antagonistic. The expansion of urban environments has required lots of construction land, which often occupied large areas of farmland before the farmland protection was formulated. Now, the land transfer has become popular in villages; the rural labor has been outflowing, especially in the developed areas. The land transformation has had a great influence on rural development with the rise of land prices, as shown in Figure 6 (E); the high-speed growth of land transformation has promoted the rural transformation and coordination to reach high-level. The quality of farmland has decreased, although the quantity of farmland has been protected without preventing urban sprawl, and the adjustment of production structure as a result of land transfer may also threaten food safety in the future.

Industry is a necessary link between population and land, and it provides a guarantee for social development. In the early stages of human society, agriculture was the only industry, but cities boomed little by little with the development of secondary industries and tertiary industries. The development of industry was the main cause of population migration and land transfer. Thus, the study selected non-agricultural industry for rural industry transformation. The industry greatly improved the living standard of farmers, and eliminated the rural poverty and back-warded to form new countryside, as shown in Figure 6 (A and B). However, the secondary industry brought lots of pollution to the village; the rural environment was damaged and more serious illnesses occurred in recent years than in the early years because of the soil and water pollution.

Through an analysis of the effect of population, land and industry on the rural transformation, the study found that there were also many problems in the process of factor transformation as a result of no coordination among these three factors. Thus, in the study of transformation development, coordination must be considered. The study used a quartering method to obtain a different level of the CD and TD, which was lower than for other studies. However, this made the mechanism of PT-IT-LT on rural transformation development clear to analyze; it was more scientific to divide the types of rural transition development and diagnose the problems of regional differences.

However, an important factor was policy influencing on the rural transformation development in China. The policy had a guiding function to the rural development and promoted transformation of the PT-IT-LT, such as new countryside construction and modern agriculture development, which formed typical villages as the pilot to build new rural communities and form many famous rural brand industries in China. This paper mainly analyzed the rural transformation development from the perspective of PT-IT-LT; it did not describe rural development policies in detail. However, policy was essential for rural development, and further research is needed in the future.

4.2. Functional Regionalization of Rural Transformation Development

According to the results of discussions on the relationship between the TD and CD, the counties in the Beijing-Tianjin-Hebei region were divided into five types. The study gave each type a different score: "A" was 1, "B" was 2, "C" was 3, "D" was 4 and "E" was 5; then, each county acquired a score for its rural transformation–coordination development from 1990 to 2015. The study developed the county-rural transformation by dividing the functional regionalization by the mean score of the transformation–coordination development, which included the ecological conservation area, key development area and core leading area (Figure 8).

The core leading areas were mainly located in the center of the Beijing-Tianjin-Hebei region, and belonged to the counties of Beijing and Tianjin; these included 11 counties. The region was one of the most densely populated areas and was the political and economic center in China. The rural TD and CD were middle- and high-level, and their rural area reached the higher development level with high urbanization and industrialization. Thus, the land transformation was the major leading factor to promote village development, but land price in the region was much higher than for other regions, which was a resistance for the rural development of the future. However, the rural development had been at a high level in the region; it should keep the development state and lead other regions to form sustainable and scientific rural development as the guidance core.

The key developing areas included 79 counties accounting for 50% of the total, laying to the south and central parts of Beijing-Tianjin-Hebei. These regions' TD and CD were middle- and low-level, and their rural development was still lower than that of the core leading area. However, the region had large development drivers, including the population and industry. With the socioeconomic development, many heavy factories in Beijing or Tianjin moved to the counties in Hebei, which improved the local economic development and promoted more of the rural population to work at the factory. Meanwhile, the rural population of the counties around Beijing, Tianjin and Shijiazhuang was attracted to the urban areas for high earnings; some people became part of the urban population and some worked in the city for a long period of time. Thus, the driving factors in the region were the population and industry transformation. However, there were some serious problems with the rural transformation development in the region, such as farmers weakening, environmental pollution and village hollowing in recent years, because the CD of the population, land and industry was lesser than for Beijing and Tianjin. However, the region should continue to develop and build the new sustainable rural areas, whilst also considering the factors in the process of rural development.

The ecological conservation area was in the north and west of the Beijing-Tianjin-Hebei region and included 67 counties, whose TD and CD were low- and lower-level. These counties were also near Beijing and Tianjin, but their rural development was worse than that of the core leading area and the key developing area because of their poor natural conditions. The population was also attracted to Beijing and Tianjin without local industry support, which formed the "siphon effect", and many poor counties and poor villages appeared around Beijing. Thus, the rural development in the region clearly lagged behind other areas. However, there were also rich natural eco-tourism resources and cultural deposits; the industry transformation promoted rural development in the region for tourism and leisure services, but far away from environmental pollution. Thus, the region had great development potential and needed to wait for the help of the key developing area and core leading area. Now it should uptake the task of environmental protection in the Beijing-Tianjin-Hebei region as an ecological conservation area.

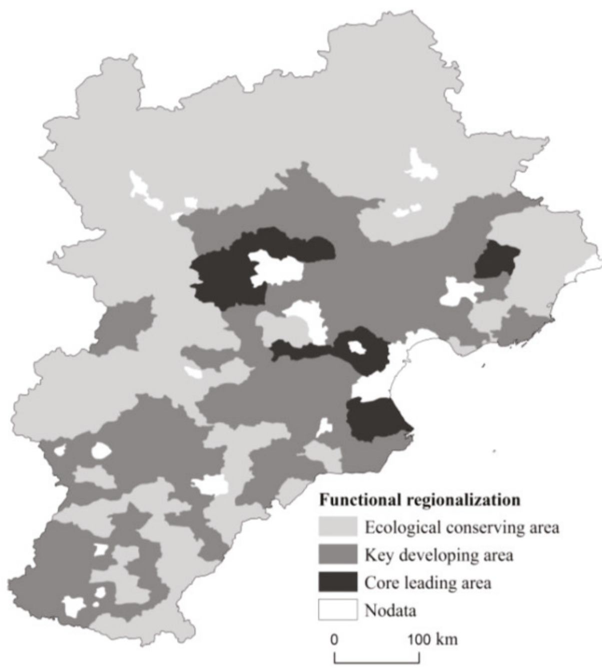

Figure 8. Functional regionalization of rural transformation development in the Beijing-Tianjin-Hebei region.

5. Conclusions

This paper analyzed the county-rural transformation development in the Beijing-Tianjin-Hebei region from 1990 to 2015 from the perspective of PT-IT-LT, and obtained the TD and CD using a coupling method with multi-indicators. The rural transformation—coordination development was divided into five types and the functional areas were divided into three types, including the ecological conservation area, key development area and core leading area, which provided reference and research methods for the coordinated and sustainable development in Beijing-Tianjin-Hebei.

(1) The CD and TD were divided into four types: lower-level (0–0.25), low-level (0.25–0.5), middle-level (0.5–0.75) and high-level (0.75–1.0). These had similar changing tendencies from 1990 to 2015. Middle- or high-level counties were located in the central area of the Beijing-Tianjin-Hebei region, and lower- or low-level counties were located in the other regions. There were a large number of differences among the counties because of the influence of the population, land and industry.

(2) The rural transformation—coordination development was divided into five stages: fast industry lower-level coordination and transformation development (A), fast industry and population lower-level coordination and low-level transformation development (B), high factors lower-level coordination and low-level transformation development (C), fast population low-level coordination and middle-level transformation development (D) and fast land middle- and high-level

coordination and transformation development (E). Each stage had its own characteristic. The results showed that according to the mechanism analysis of PT-IT-LT to rural transformation, stages A and B were mainly influenced by industry transformation, stage D was affected by population transformation, and stage E was impacted by land transformation.

(3) The study carried out functional regionalization of rural transformation development in the Beijing-Tianjin-Hebei region on the basis of coupling of the CD and TD and the mechanism of PT-IT-LT. The functional areas were segmented into three areas, which were the ecological conservation area, the key development area and the core leading area. The core leading area included 11 counties, which were already of high-level rural development; the key development area included 79 counties, whose priority needed to be given to rural development; the ecological conservation area consisted of 67 counties, which should promote rural development in the region for tourism and leisure services. The functional regionalization of rural development could provide a scientific basis to achieve the integration of the Beijing-Tianjin-Hebei region and regional strategic optimization.

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References

1. Nyberg, A.; Rozelle, S. Accelerating China's rural transformation. In *Accelerating Chinas Rural Transformation*; World Bank Publications: Washington, DC, USA, 1999; pp. 13–18.
2. Long, C.Y. The Mechanisms of Cropland Conservation in Chinese Rural Transformation. *Sci. Geogr. Sin.* **2001**, *187*, 91–103.
3. Keith, B. From proletarian to peasant: Rural transformation in the state of Acre, 1870–1986. *J. Dev. Stud.* **2007**, *24*, 141–160.
4. Abam, F. Developing the Biofuel Industry for Effective Rural Transformation in Nigeria. *Eur. J. Sci. Res.* **2010**, *40*, 441–449.
5. Desai, S.; Vashishtha, P.; Joshi, O. *Mahatma Gandhi National Rural Employment Guarantee Act: A Catalyst for Rural Transformation*; National Council of Applied Economic Research: New Delhi, India, 2015.
6. Julie, C. Concentration and decentralization: The new geography of freight distribution in US metropolitan areas. *J. Transp. Geogr.* **2010**, *18*, 363–371.
7. Li, T.T.; Long, H.L. Rural development from viewpoints of transformation and coordination: A case in Shandong Province. *Prog. Geogr.* **2014**, *33*, 531–541.
8. Liu, Y.S.; Yang, R. The spatial pattern measure of urban-rural development transformation in the Bohai Rim region in China. *Acta Geogr. Sin.* **2015**, *70*, 248–256.
9. Long, H.L. Land use transition and rural transformation development. *Prog. Geogr.* **2012**, *31*, 131–138.
10. Li, F.R.; Wang, Y.S.; Hu, Y.L.; Yao, X. Research on Yancheng Coastal Beach Reclamation Development and Ecological Environment Protection. *J. Green Sci. Technol.* **2013**, *9*, 155–157.
11. Liu, Y.S. Integrated land research and land resources engineering. *Resour. Sci.* **2015**, *37*, 1–8.
12. Reddy, A.A.; Rani, C.R.; Cadman, T.; Reddy, T.P.; Battarai, M.; Reddy, A.N. Rural Transformation of a Village in Telangana, a Study of Dokur since 1970s. *Int. J. Rural Manag.* **2016**, *12*, 143–178. [CrossRef]
13. Yang, R.; Liu, Y.S.; Long, H.L. The study on non-agricultural transformation co-evolution characteristics of "population-land-industry": Case study of the Bohai Rim in China. *Geogr. Res.* **2015**, *49*, 972–975.
14. Liu, Y.S.; Long, H.L.; Chen, Y.F.; Wang, J.Y.; Li, Y.R.; Li, Y.H.; Yang, Y.Y.; Zhou, Y. Progress of research on urban-rural transformation and rural development in China in the past decade and future prospects. *J. Geogr. Sci.* **2016**, *26*, 1117–1132. [CrossRef]

15. Fichera, C.R.; Modica, G.; Pollino, M. GIS and Remote Sensing to Study Urban-Rural Transformation during a Fifty-Year Period. In Proceedings of the International Conference on Computational Science and its Applications, Santander, Spain, 20–23 June 2011; Springer: Berlin, Germany, 2011; pp. 237–252.
16. Hu, Z.C.; Wang, Y.L.; Liu, Y.S.; Long, H.L.; Peng, J. Spatio-Temporal Patterns of Urban-Rural Development and Transformation in East of the "Hu Huanyong Line", China. *ISPRS Int. J. Geo-Inf.* **2016**, *5*, 24. [CrossRef]
17. Gibson, C. Rural Transformation and Cultural Industries: Popular Music on the New South Wales Far North Coast. *Geogr. Res.* **2010**, *40*, 337–356. [CrossRef]
18. Oleti, G. Effects of internal migration on poverty reduction, income and gender inequality, rural transformation (including urbanization of towns) and agricultural productivity. *Appl. Geochem.* **2017**, *38*, 82–91.
19. Xia, Q.F. *Beijing Statistical Yearbook*; Beijing Statistics Bureau: Beijing, China, 1990/2000/2010/2015.
20. Wu, J.D.; Peng, Z.L. *Tianjin Statistical Yearbook*; Tianjin Statistics Bureau: Tianjin, China, 1990/2000/2010/2015.
21. Wu, X.H.; Meng, X.Y.; Peng, J.Q. *Hebei Economic Yearbook*; People's Government of Hebei Province: Shijiazhuang, China, 1990/2000/2010/2015.
22. Zhou, H.; Wang, B.J. Analysis of the coupling rurality index and rural transformation development of Jiangsu province in China in the early 21st century. *China Popul. Resour. Environ.* **2013**, *23*, 48–55.
23. Li, T.T.; Long, H.L. Analysis of rural transformation development from the viewpoint of "population-land-industry": The case of Shandong Province. *Econ. Geogr.* **2015**, *35*, 149–155.
24. Wang, Y.F.; Liu, Y.S.; Li, Y.H. The Spatial Disparity of Rural Transition Development and Regional Characteristics of Its Driving Forces. *Econ. Geogr.* **2016**, *36*, 135–142.
25. Liu, Y.B.; Li, R.D.; Song, X.F. Analysis of Coupling Degrees of Urbanization and Ecological Environment in China. *J. Nat. Resour.* **2005**, *20*, 105–112.
26. Li, T.T.; Long, H.L. Study on the spatio-temporal pattern of rural transformation development in Shandong province. *Geogr. Res.* **2014**, *33*, 490–500.

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Article

Micro-Study of the Evolution of Rural Settlement Patterns and Their Spatial Association with Water and Land Resources: A Case Study of Shandan County, China

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Abstract: The balance between population and water and land resources is an important part of regional sustainable development. It is also significant for the ecological civilization in China and can help solve the Three Rural Issues (agriculture, countryside and farmers) in China. The Silk Road Economic Belt and Maritime Silk Road in twenty-first Century Strategy have brought new opportunities for the Hexi Corridor, which is facing challenges in the sustainable development of rural settlements. In this paper, we analyzed the temporal-spatial differentiation of rural settlement patterns in Shandan County of Hexi Corridor and studied the spatial association between rural settlements and water-land resources. Results show that the total area of rural settlement patches (*CA*), the number of rural settlement patches (*NP*), the mean patch area (*MPS*), the maximum patch areas (*MAXP*), the minimum patch areas (*MINP*) and the density of rural settlement patches (*PD*) changed more rapidly from 1998 to 2008 than from 2008 to 2015. In the second period, the indices mentioned before did not change significantly. The kernel density of rural settlements is basically consistent in three periods. Rural settlements mainly distribute along major roads and the hydrographic network and the kernel density of rural settlements decreases in the direction away from these roads and the hydrographic network. In addition, rural settlements in Shandan County are densely distributed in some regions and sparsely distributed in other regions. The dispersion degree of rural settlements increased from 1998 to 2008 and tended to be stable after 2008. These lead to the dispersion, hollowing and chaos of rural settlements in Shandan County. The spatial distribution of rural settlements in Shandan County is closely related to that of cultivated land and the hydrographic network. Our results might provide a theoretical basis for the reasonable utilization of water and land resources in Shandan County. Ultimately, a balance between population and water and land resources and regional sustainable development can be achieved.

Keywords: Micro-study; rural settlements; spatial association; dispersion degree; Shandan County in the Hexi Corridor

1. Introduction

Settlement refers to a place where people concentrate and settle down for living and production purpose. It can also be called residential settlement. According to their characteristics and sizes, settlements can be classified into two categories: urban settlements and rural settlements. Currently, there are about 590 million permanent population living in more than 2 million villages in China, so rural settlements are the main form of settlement for Chinese population [1].

In the world, research on rural settlement geography began in the 19th century. J. G. Kohl, as the originator of rural settlement research, systematically discussed the relationship between settlement location and population concentration in his book *The Relationship between Human Traffic and Terrain* in 1841 [2]. Since then, many researchers have begun to explore the relationship between settlements and environment. For example, Dohme, Matlakowski, Hunziker et al. analyzed house forms in different regions and their adaptability to the geographical environment [2]. Ratzel, the main representative of environmental determinism, explored the dependence of settlement distribution on the natural environment [2]. Lugeon illustrated in detail the relationship between settlement location and environmental factors such as terrain and sunlight [2]. Brunhes comprehensively studied the relationship between rural settlements and the environment in his book *Principles of Human Geography* [3]. Blache, the representative of environmental possibilism, analyzed the relationship between residential buildings and the environment, building materials, house forms [4]. From 1920s to 1960s, there was more and more research on rural settlements. Demangeon in France, Kovalev in the Soviet Union and Doxiadis in Greece et al. qualitatively analyzed the formation, development, type and function of rural settlements [5–7]. After 1960s, metrology concept was introduced in rural settlement research which then entered a qualitative and quantitative stage. *Rural Settlement in an Urban World* (Bunce) [8], *Rural Settlement and Land Use* (Chisholm) [9] and *Determination of Settlement Patterns in Rapidly Growing Rural Areas* (Goodwin) [10] were such examples. Since 2000, research on rural settlements has been focused on their spatial layout and influencing factors [11], their spatial form and type [12–14], the evolution and reconstruction of rural settlement patterns [15–17], land use and landscape ecology [18,19] and the social perspective [20,21].

In China, the research on rural settlements appeared relatively later. Influenced by Western research on this topic, some researchers began to study rural settlements in 1930s. Lin published his paper *Discussion on Settlement Classification* on the *Journal of Geography*, Chen published his paper *Settlement near Zunyi* on the *Journal of Acta Geographica Sinica* and Yan published his paper *Xikang Living Geography* on the *Journal of Acta Geographica Sinica* [22–24]. These researchers preliminarily analyzed the relationship between settlements and geographical environment. From 1950s to 1960s, some researchers extensively studied settlement geography according to the actual situation of village and town planning in China. In 1950, Wu published his paper *How to Do Urban Survey*, in which he classified settlements and proposed to use urban degree to determine whether a settlement had reached the development level of urban areas [25]. In 1959, Zhang and Song published their paper *Basic Experience of Planning of People's Commune Economy in Rural Areas*. They put forward three principles for the layout of residential settlements [26]. First, it should be closely related to the overall planning of commune and be conducive to further development and production. Second, it should adapt to river network. Third, it should consider the influences of various natural conditions, the original residential settlements, major traffic lines and their relationship to residential settlements. From 1970s to 1990s, Ye, Zheng, Chen et al. extensively studied rural settlements in China [2]. Rural settlement geography and urban geography were thus developed rapidly. Jin systematically studied the formation, classification and regional differences between Chinese rural settlements in his book *Rural Settlement Geography* published in 1988 and his book *Chinese Rural Settlement Geography* published in 1989 [27]. Recently, rural areas have entered a new developmental stage as the rapid progression of New Urbanization in China and the proposal and implementation of national policies such as Three Rural Issues, New Countryside, Coordination of Urban and Rural Development, Beautiful Countryside [28]. The spatial density and form of rural settlements in China have changed significantly. A series of research on rural settlements including their form and structure [29–32], their function [33,34], their evolution and driving mechanism and the hollowing and arrangement of rural settlements [35–37] has been conducted. The research areas mainly include the southwest Karst mountain area, the hilly area of the Loess Plateau, the Huang-Huai-Hai plain, the Bohai rim region and the Chang-Zhu-Tan area [30,35,38]. Integrated application of GIS, RS and landscape methods for rural settlement research is increasing and macro-scale research is changing to micro-scale research.

In China, oasis area accounts for 3–5% of the total area of arid region but it can provide resources supporting more than 90% of the population and create more than 95% of industrial and agricultural output value. Shandan County is a typical arid oasis region. Rural settlements are distributed in this area and human activities such as agricultural production and processing also occur in this area. Rural settlement is the main form of spatial agglomeration of rural population in Shandan County. Water and land resources are the most basic constituents of oasis and the existence and development of rural settlements are restricted by these two factors, which eventually determine the scale and carrying capacity of rural settlements [39]. Restricted by agricultural production technology, water and land resource endowment as well as rural population in Shandan County are closely related to the formation, scale, structure and change of rural settlements and the exploitation and utilization of water and land resources will be reflected in the settlements in oasis [40]. With the integrated development of urban and rural areas, the residents' quality of life in Shandan County is greatly improved. The flow of people, resources and information between urban and rural areas is being strengthened. On the one hand, rural labor force is transferred to urban areas and some rural land is converted into urban land (with urbanization rate increasing from 14% in 1998 to 42.44% in 2015). Because of large-scale population transfer, rural areas tend to "Hollowed". On the other hand, the change of rural residents' living standard and lifestyle lead to new requirements of production and life in rural areas. This causes the number of rural settlements to grow, the cultivated area to expand and the density of the hydrographic network to increase. The structure and form of rural land use have changed greatly, so the relationships between population and water and land resources have changed adaptively, which will affect regional sustainable development.

Water and land resources are the most basic constituents of oasis. In fact, oasis can be simply defined as a place with water in desert. The abundance of water resources determines irrigated land area, which further affects the oasis's carrying capacity for social economy. Settlement is a place of oasis population aggregation and it is also the concentrated expression of human economic activities. The spatial layout of oasis settlements is determined by the long-term interaction between settlements and the environment. The spatial association between oasis settlements and water and land resources is an important factor influencing the adaptability of the relations among population, land and water. Shandan County, located in the middle of Hexi Corridor, has special geographical location, where water and land resources are scarce, the economy is relatively weak and the ecological environment is fragile. Shandan Country is a typical arid oasis region and the relationships between population and land resources and between population and water resources are complex and sensitive, which will affect regional sustainable development by different allocation of resource [40]. Therefore, we explored the temporal-spatial differentiation of the rural settlement patterns in Shandan County from 1998 to 2015. Further, we studied the spatial association between rural settlements and water and land resources. Finally, we revealed the general pattern of the temporal-spatial change of rural settlements. The results might provide a theoretical basis for the reasonable utilization of water and land resources in Shandan County, help provide decision-making basis for the government and achieve regional sustainable development. Meanwhile, this study is important for deepening and expanding the theory of research on oasis settlements, guiding the construction of new socialist countryside, scientifically planning and building rural settlements and promoting the integrated development of urban and rural oases.

2. Overview of the Research Area

2.1. Natural Geography

Shandan County is located in the middle of the Hexi Corridor and is the eastern "gate" of Zhangye City in Gansu Province of China. Shandan County is often known as "the wasp-waist of corridor" and "the throat of Ganliang". In fact, the ancient "Silk Road" passes this area. Shandan County is bounded by Yongchang County in the east, Minle County in the west, Ganzhou District in the northwest, the

Huangcheng District of Sunan Yugur Autonomous County in the southeast, the Lenglong mountain range of the Qilian Mountains and Qinghai Province in the south and Longshou Mountain in the north. The other side of Longshou Mountain is Alashan Right Banner in the Inner Mongolia Autonomous Region. Shandan County is a typical oasis. It has a total area of 5402.43 km^2, a north-south length of 136 km and an east-west width of 89 km. It is in 100°41′–100°42′E and 37°56′–39°03′N (Figure 1). This area has an alpine semi-arid climate, with uneven distribution of seasons, strong solar radiation, long sunshine hours, low temperature, large temperature difference between day and night, little but concentrated rainfall, high evaporation, low humidity and short frost-free period. The mean annual temperature is about 6.5 °C, the mean annual precipitation is 199.4 mm, sunshine hour is 2964.7 h, evaporation is 2351.2 mm and the frost-free period is 165 d. Its altitude ranges from 1549 to 4444 m above the sea level. The highest point is in the Lenglong mountain range of Qilian Mountains. The lowest point is in Xitun Shahe of Dongle County. There are the Maying river, Huocheng river, Sigou river and Shandan river in Shandan County. In addition, there are many ditches such as Liushui Kou, Ciyao Kou, Nanshan Kou.

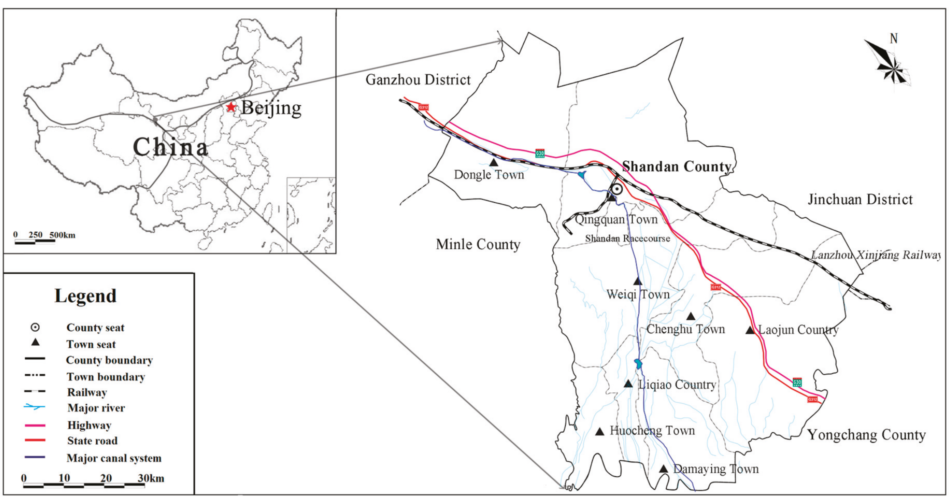

Figure 1. Regional location map of Shandan County.

2.2. Social Economy

Shandan County has jurisdiction over 2 townships (Liqiao and Laojun), 6 towns (Qingquan, Chenhu, Huocheng, Weiqi, Dongle and Damaying), 110 villages, 6 committees and 754 villager groups. It had 167.3 thousand permanent residents in 2015, among which urban population was 71,000. Thus, the urbanization rate was 42.44%. There are 14 minorities living in Shandan County including Hui, Dongxiang, Tibetan, Manchu, Zhuang, Miao, Tu, Tujia, Yugur, Bonan, Mongolian, Yi, Daur and Xibe. These minorities have a population of 747, accounting for 0.39% of the total population in the county. The GDP of Shandan County was 4.3 billion Yuan in 2015 and the ratio of three sectors (primary, secondary and tertiary) was 22.5: 26.5: 51in 2015. Clearly, the primary and secondary industries accounted for small proportions. Considering the total economic output, the per capita disposable income of farmers (10,526.6 Yuan) and the per capita disposable income of urban residents (19,445.1 Yuan), the industrial structure of Shandan County is relatively advanced.

3. Methods and Data Sources

3.1. Methods

3.1.1. The Indices of Rural Settlement Pattern

The indices of rural settlement pattern, such as *CA*, *NP*, *MPS*, *MINP*, *MAXP* and *PD* were used to analyze the evolution and differentiation of rural settlements in Shandan County and reflect their structural composition and spatial characteristics. Among the indices mentioned before, $MPS = CA/NP$ and $PD = NP/S_{county\ area}$.

3.1.2. Dispersion Degree

By using different size grids, the temporal-spatial change of rural settlements can be better revealed. The land use vector data (rural settlement patches) in 1998, 2008 and 2017 were converted into grid data (7055 grids) with a resolution of 1 km × 1 km. Dispersion degree of rural settlements refers to the amount of map patches that rural settlements occupy in each grid. The change in dispersion degree can reflect the temporal-spatial process of dispersion, mergence and disappearance of rural settlements [31].

3.1.3. Kernel Density

According to the nonparametric method for calculating surface density, the kernel density of rural settlements was determined. The higher the kernel density, the higher the distribution density of rural settlements. The formula was:

$$f(x,y) = \frac{1}{nh^2}\sum_{i=1}^{n} k\left(\frac{d_i}{n}\right) \tag{1}$$

where *f(x,y)* is the density estimate at (*x*,*y*), *n* is the number of observations, *h* is bandwidth (Mean Integrated Squared Error (*MISE*) is used in bandwidth estimation), *k* is Kernel function (Gaussian Kernel Function), d_i is the distance between position (*x*,*y*) and the *i*th observation point.

$$h_{MISE} = \left(\frac{4\hat{\sigma}^5}{3n}\right)^{\frac{1}{5}} \approx 1.06\hat{\sigma}n^{-\frac{1}{5}} \tag{2}$$

$$k = \exp\left(-\|x - x'\|\right)^2/2h^2 \tag{3}$$

where $\hat{\sigma}$ is standard deviation and x' is the center of Kernel function [41].

The GIS-based Kernel Density Estimation (KDE) method used in this paper is based on a moving window to calculate and output the point density of each grid cell. The specific methods are: (1) Define a search radius, move the circle and count the number of events that fall within the circle; (2) Determine the size of the output grid according to the density precision requirements; (3) Calculate the density contribution value of each event to each grid in the circle through the kernel function; (4) Assign density value to each grid and its value is the sum of the density contribution value of each event in the grid; (5) Output the density value of each grid. By setting different search radius, a better density distribution effect was achieved in this paper [42].

3.1.4. Spatial Hotspot Detection

Detection of a hotspot (or a coldspot) in spatial data and temporal-spatial data sets is very meaningful. Spatial hotspot detection (*Getis-Ord*G_i^*) was used to determine whether the number of rural settlement patches was significantly large or small (in statistics) in some regions. Then, the hotspots and coldspots were visualized for further study of the differentiation of rural settlement scale. The equation was:

$$G_i^*(d) = \sum_{j=1}^{n} w_{ij}(d)x_j / \sum_{j=1}^{n} x_j \tag{4}$$

where $w_{ij}(d)$ is spatial weight defined according to distance principle and x_i and x_j are variables in *i* and *j* zone, respectively. If $Z(G_i^*)$ is positive and statistically significant, the area will be a hotspot area, i.e., a large number of rural settlement patches accumulate in this area. If $Z(G_i^*)$ is negative and statistically significant, the area will be a cold spot area, i.e., rural settlement patches are sparsely dispersed in this area.

3.1.5. Spatial Association Model

In this paper, we proposed a model based on grids for exploring the spatial association between population and land resources and between population and water resources. ArcGis spatial overlay tool was used to obtain the distribution of spatial association.

$$K = S_{rural\ settlements} / S_{cultivated\ land} \tag{5}$$

$$L = S_{rural\ settlements} / H_{hydrographic\ network} \tag{6}$$

where $S_{rural\ settlements}$ is the area of settlements in each grid, $S_{cultivated\ land}$ is the area of cultivated land in each grid and $H_{hydrographic\ network}$ is the length of the hydrographic network in each grid. A larger *K* value indicates that there is a lack of cultivated land in the grid and the conflict between population and land resources is serious. On the contrary, a smaller *K* value suggests that there is enough arable land in the grid and the conflict between population and land resources is not evident. Relevant research shows that under the strong control and guidance of the hydrographic network in the arid oasis area, the length and density of the hydrographic network are closely related to the water supply [40,43]. The water supply of the hydrographic network determines the size of irrigated land, which then also determines the carrying capacity of the population. Therefore, a larger *L* value indicates that the density of the hydrographic network is low and the water supply is inadequate in the grid but rural settlement size is larger and cannot be carried by water supply of the hydrographic network, the conflict between population and water resources is violent. Otherwise, a smaller *L* value means that the density of the hydrographic network in the grid is high and the water supply is adequate in the grid, rural settlement size is smaller and can be carried by water supply of the hydrographic network, the conflict between population and water resources is not evident.

3.2. Data Sources

The data came from four sources. (1) Basic maps. Topographic map (1:250,000) of Shandan County and vector administrative boundaries (1:250,000) were provided by Gansu Province Bureau of Surveying and Mapping. (2) Land-use vector data. Survey data of land use in Shandan County in 1998 and 2008 were provided by Gansu Province Land and Resources Department. Detailed survey data of land use in Shandan County in 2015 were provided by Shandan County Land Bureau. (3) Statistical data of social economy. Data such as population, GDP, tourism output of Shandan County in 1998–2015 were from statistical yearbook of Zhangye City (Zhangye Municipal Bureau of Statistics), National economic statistics of Shandan County, statistical yearbook of Shandan County (Shandan County Bureau of Statistics) and Shandan County land web (http://sz.shandan.gov.cn/). (4) Specify surveys information. Using participatory survey method and interview method, we interviewed 14 villages and 174 people, mainly collected data about the form, structure, pattern and evolution of rural settlements in Shandan County and local farmers' perception about the factors influencing rural settlement evolution by two field studies in July 2015 and June 2016, respectively (Table 1).

Table 1. Data sources.

Data Types		Scale	Year	Data Sources
Basic maps	Topographic map	1:250,000	2010	Gansu Province Bureau of Surveying and Mapping
	Vector administrative boundaries	1:250,000	2010	Gansu Province Bureau of Surveying and Mapping
Land-use vector data	Survey data of land use	1:10,000	1998	Gansu Province Land and Resources Department
	Survey data of land use	1:10,000	2008	Gansu Province Land and Resources Department
	Detailed survey data of land use	1:10,000	2015	Shandan County Land Bureau
Statistical data of social economy			1998–2015	Yearbook of Zhangye City, National economic statistics of Shandan County, statistical yearbook of Shandan County and Shandan County land web (http://sz.shandan.gov.cn/)
Specify surveys information			2015, 2016	Field research data

4. Results and Discussion

4.1. Temporal Change of Layout of Rural Settlements in Shandan County

4.1.1. Temporal Change of the Indices of Rural Settlement Pattern

ArcGIS10.2 was used to extract the vector data of rural settlement distribution in 1998, 2008 and 2015 from the land-use vector data (Figure 2).The indices of rural settlement pattern such as *CA*, *NP*, *MPS*, *MINP*, *MAXP* and *PD* were chosen for comparative analysis (Table 2).

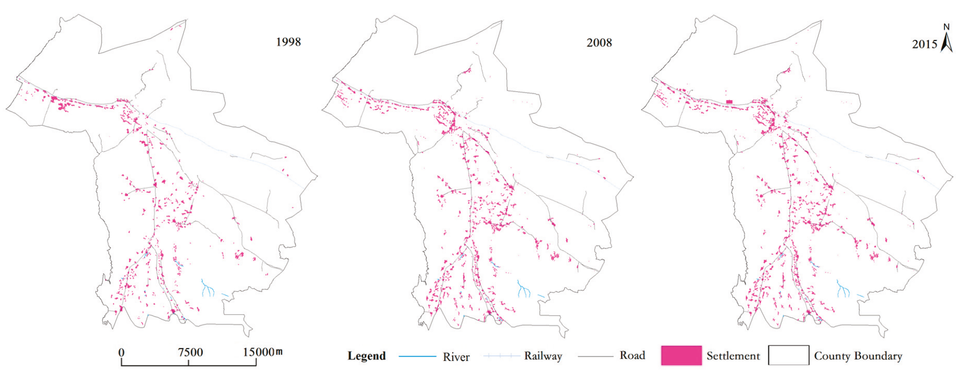

Figure 2. Distribution of rural settlements in Shandan County in 1998, 2008 and 2015.

Table 2. The indices of rural settlement pattern in Shandan County in 1998, 2008 and 2015.

Year	*CA* (hm^2)	The Proportion of Total Patch Area in County Area (%)	*NP*	*MPS* (hm^2)	MAXP (hm^2)	MINP (hm^2)	PD (Patch Number/km^2)
1998	3385.84	0.627	760	4.46	106.97	0.01	0.14
2008	3424.83	0.634	2920	1.17	38.53	0.03	0.54
2015	3740.02	0.692	3143	1.19	119.86	0.01	0.58
$\Delta_{2008–1998}$	38.99	0.001	2160	−3.28	38.53	0.02	0.4
$\Delta_{2015–2008}$	315.2	0.058	223	0.02	81.33	−0.02	0.04

The indices of rural settlement pattern in Shandan County change more rapidly from 1998 to 2008 than from 2008 to 2015 (Table 2 and Figure 2). Rural settlement pattern tends to be stable in recent years. The *CA* increased by 38.99 hm^2 from 1998 to 2008 with an average annual increase of 3.9 hm^2 and increased by 315.2 hm^2 from 2008 to 2015 with an average annual increase of 52.53 hm^2. Thus, the *CA* changed more drastically in the second period. The *CA* accounts for only a small proportion of the county area. The proportion was 0.627% in 1998, 0.634% in 2008 and 0.692% in 2015, indicating a slowly rising trend. The *NP* changed significantly, especially in the first period, increasing by 2160 from 1998 to 2008. The ratio of the *MAXP* to the *MINP* was 10,697 in 1998, 1284.33 in 2008 and 11,986 in 2015. In 2008, the difference between the *MAXP* and the *MINP* reduced, while in 2015 this difference enlarged. The *MPS* in 1998 was large, about 4.46 hm^2. In 2008 and 2015, however, the *MPS* was smaller, only accounting for 1/4 of that in 1998. The *PD* showed an overall increasing trend, especially from 1998 to 2008, increasing by 385.7%. The *PD* in 2008 was close to that in 2015.

The reasons for above changes areas follow. After 2000, the area of rural settlements in Shandan County expands rapidly. The distribution of rural settlements tends to be more dispersed, so the intensive degree of land use decreases. The increase in the *NP* leads to increase in the *PD*. In addition, the newly-formed rural settlement patches are often small and some large rural settlement patches might be broken into smaller ones. Thus, the *MPS* and the ratio of the *MAXP* to the *MINP* show a decreasing trend, indicate that the intensive degree of land use decreases. According to the specify surveys, the development of individual rural settlement is mainly in the form of expansion rather than the optimization of original structure, so the area of rural settlements expands, posing a huge threat to arable land resources.

4.1.2. Temporal Change of the Size of Rural Settlements

According to the areas (or sizes) of rural settlement patches in Shandan County, the rural settlements could be classified into four categories: solo settlements, small settlements, middle settlements and large settlements (Table 3). From 1998 to 2015, the numbers of solo and small settlements increased the most rapidly, by 751 and 1509, respectively. Notably, the increases in the numbers of solo and small settlements from 1998 to 2008 accounted for 91.5% and 93.1%, respectively. In addition, the total area of small settlements increased the most rapidly, by 441.05 hm^2 from 1998 to 2015. The total area of solo settlements increased slightly, by 52.25 hm^2 from 1998 to 2015. The number of middle settlements increased by 129 and their total area increased by 213.93 hm^2 from 1998 to 2015. The number of large settlements decreased by 6 and their total area decreased by 353.04 hm^2.

During the specify surveys, we found the following.

(1) Shandan County entered a rapid developmental stage in 1998–2008, which was promoted by China's rural development strategy and farmers' own needs. During this period, the spatial structure of rural settlements changed greatly. After 2008, the rural development tended to be stable and the spatial structure of rural settlements did not change significantly.

(2) Furthermore, the newly-formed settlements mainly include solo settlements and small settlements that are formed by several solo settlements close to each other. The area of such small settlement is smaller than 1 hm^2. In addition, some large settlements could be divided into smaller ones. These lead to more solo and small settlements. In the past, the settlement area per household in Shandan County exceeded the standard value. Some farmers expanded the area of their settlements by building various buildings for production purpose. This promotes the formation of large settlements. Recently, because of the implementation of strategies such as New Countryside, Beautiful Countryside, New Rural Community, the area of household is restricted by government regulation and the buildings built temporarily for production or living purpose are demolished to optimize the layout of rural settlements and promote intensive land use.

Table 3. Classification of rural settlements in Shandan County.

Classification	Area (hm^2)	1998		2008		2014	
		Number	The Total Area (hm^2)	Number	The Total Area (hm^2)	Number	The Total Area (hm^2)
Solo settlement	≤0.1	16	0.93	705	49.6	767	53.18
Small settlement	>0.1–1	217	112.59	1623	516.15	1726	553.64
Middle settlement	>1–10	448	1618.62	522	1715.34	577	1832.55
Large settlement	≥10	79	1653.7	70	1143.74	73	1300.66

4.1.3. Temporal Change of Dispersion Degree of Rural Settlements

Using 1 km × 1 km grids, we obtained the dispersion degree of rural settlements in 1998, 2008 and 2015 (Table 4 and Figure 3). In general, the dispersion degree of rural settlements increased from 1998 to 2008 and tended to be stable after 2008. The number of grids with rural settlements increased from 538 in 1998 to 727 in 2009 (by 35.13%) and increased by only 3.3% from 2008 to 2015. In 1998, the proportion of grids in which the dispersion degree of rural settlements is lower than 10 was 99.63% and decreased to 87.62% in 2008. Consequently, the proportion of grids in which the dispersion degree was higher than 10 increased by 12.02% from 1998 to 2008. In addition, the number of grids in which the dispersion degree is in the range of 0–5 decreased slightly (by 4.09%) from 1998 to 2008. However, the proportion of such grids decreased significantly, from 95.35% in 1998 to 67.68% in 2008. The number and proportion of grids in which the dispersion degree was higher than 6 increased. Especially, the number and proportion of grids in which the dispersion degree was in the range of 6–10 increased the most significantly, from 23 and 4.28% in 1998 to 145 and 19.94% in 2008. According to the field investigation results, the dispersion degree of rural settlements increased is caused by the formation of solo settlements (≤0.1 hm^2) and small settlements as well as the division of large settlements into smaller ones. Thus, rural settlements tend to be more dispersed.

The reasons for the changes are as follows. Obstructed by the urban-rural dual security system (urban and rural have different social security systems, the urban security system has an impact on the entry of farmers), farmers found it hard to live and work in cities and towns. This has boosted the farmers' demand for housing construction in rural areas, also resulted in a large-scale contiguous expansion and sporadic dispersion of rural settlements in space. Furthermore, driven by outside interests, the income of farmers increased is caused by a large number of invisible unemployed rural laborers turned to urban areas. The first wave of funds brought by farmers have encouraged the redevelopment of rural areas and expanded the number and area of cultivated land and settlement.

Table 4. Grids with rural settlements at different dispersion degree in Shandan County in 1998, 2008 and 2015.

Year	1998		2008		2015	
Range of Dispersion Degree	Grid Number	Proportion (%)	Grid Number	Proportion (%)	Grid Number	Proportion (%)
0–5	513	95.35	492	67.68	496	66.05
6–10	23	4.28	145	19.94	154	20.51
11–20	2	0.37	79	10.87	89	11.85
21–30	0	0.00	9	1.24	10	1.33
31–40	0	0.00	1	0.14	1	0.13
41–46	0	0.00	1	0.14	1	0.13
Total	538	100.00	727	100.00	751	100.00

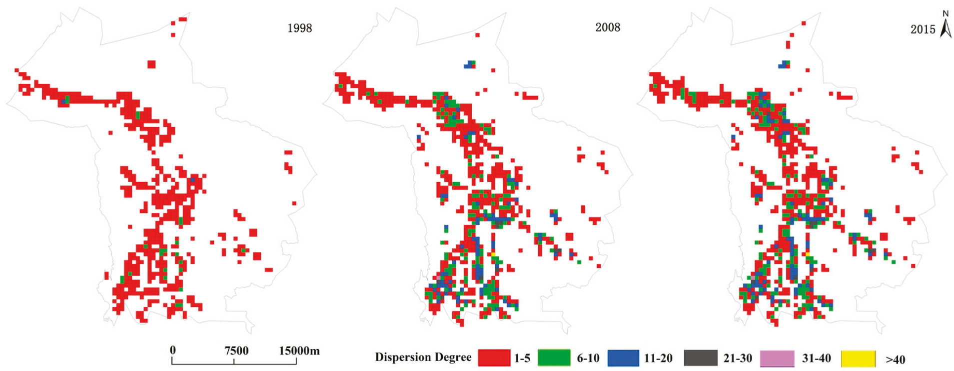

Figure 3. Distribution of grids with rural settlements at different dispersion degree in Shandan County in 1998, 2008 and 2015.

4.2. Spatial Differentiation of Rural Settlements in Shandan County

4.2.1. Spatial Differentiation of the Kernel Density

Feature to Point tool of Arc GIS10.2 was used to obtain the central points of rural settlement patches in 1998, 2008 and 2015. Using Kernel methods and 400-m search radius, the kernel density of rural settlements in 1998, 2008 and 2015 were obtained (Figure 4).

(1) The kernel density of rural settlements in 1998, 2008 and 2015 are basically consistent. Rural settlements concentrate along Lanxin Railway, State Road 312 line, Lianhuo Highway and major canals. Then, the kernel density of rural settlements decreases in the direction away from these main roads and canals.

(2) The position of settlement-intensive regions with kernel density larger than 2patches/km^2 and the concentration degree change. In 1998, the settlement-intensive regions were relatively dispersed and distributed along major roads and canals. They were Wudun Village, Dazhai Village, Xiaozhai Village, Dongwan Village, Weiqi Village and Xiguan Village. In 2008 and 2015, the settlement-intensive regions were more concentrated and distributed around county seat (i.e., Qingquan Town).

(3) The number and area of settlement-intensive regions changed from 1998 to 2015. In 1998, there were eight settlement-intensive regions and the area of each was relatively small. In 2008 and 2015, there were only three settlement-intensive regions and the area of each was relatively large. The areas of settlement-intensive regions in 2015 were especially large.

(4) In 2008 and 2015, the number of regions with kernel density in the range of 0–2 patches/km^2 increased obviously compared with that in 1998and their distribution tended to be more dispersed.

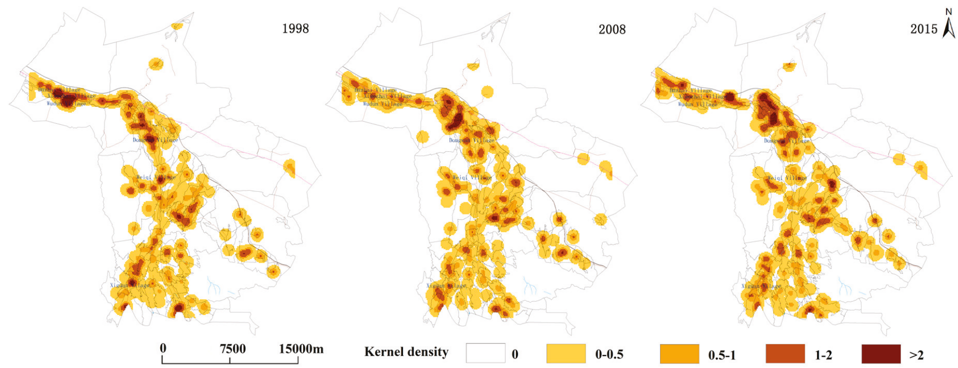

Figure 4. Kernel density of rural settlements in Shandan County in 1998, 2008 and 2015.

4.2.2. Spatial Differentiation of Hotspots and Coldspots

Hotspot detection tools were used to obtain the distribution of hotspots in Shandan County in 1998, 2008 and 2015 (Figure 5). Patch area was taken as the statistical attributes. A hotspot is a zone in which rural settlements are highly concentrated. A coldspot is a zone in which rural settlements are sparsely distributed. The results are as follows.

(1) The spatial differentiation of hotspots and coldspots is evident. The north region of Shandan County is where hotspots concentrated and the south region of Shandan County is where coldspots concentrated.

(2) From 1998 to 2008, the hotspot and coldspot zones expanded, especially hotspot zone. Hotspots distributed closely to county seat and oasis areas along Lanxin Railway, State Road 312 Line, Lianhuo Highway and major canals. The expansion of hotspot zones is because more settlement patches are formed and the construction of infrastructure such as highway makes the dispersed settlement patches more concentrated. The expansion of coldspot zones is due to the implementation of policies such as New Rural Construction, which leads to the decrease in the scale of rural settlement patches.

(3) From 2008 to 2015, the distribution of hotspots did not change significantly, whereas that of coldspots changed greatly. The size of rural settlement patches and cultivated land area expanded, so rural settlement patches tended to be more concentrated. This leads to the smaller area of coldspot zone.

(4) Combining the results of kernel density and hotspot detection, we can see that large-scale rural settlements densely distribute in some regions and small-scale rural settlements sparsely distribute in other regions of Shandan County.

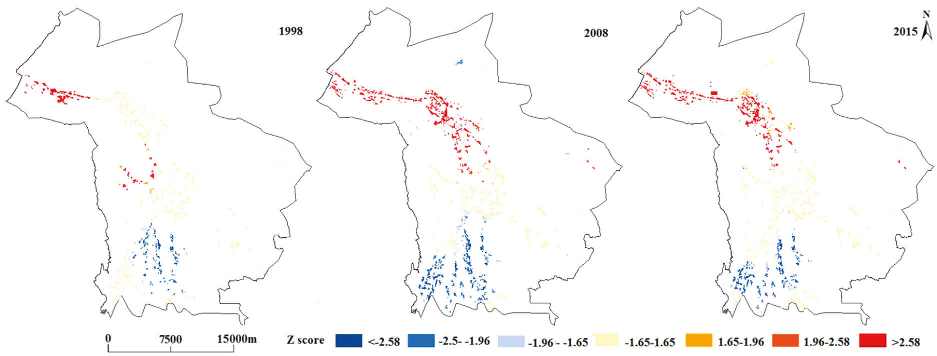

Figure 5. Distribution of hotspots and coldspots in Shandan County in 1998, 2008and 2015. Each point represents the centroid of a rural settlement patch and its color represents the *Z* score. Red zone denotes hotspot zone. The deepness of color represents statistical significance. Blue zone denotes cold spot zone. Yellow zone denotes zone where settlements randomly distributed.

4.2.3. Spatial Differentiation of Dispersion Degree

Rural settlements tended to be more dispersed from 1998 to 2015. In 1998, rural settlements in Shandan County were relatively concentrated and 95.35% of the grids with rural settlements had a dispersion degree below 5.0. In the north region of Liqiao township, the grids with rural settlements had a relatively higher dispersion degree and there were a large number of rural settlements that were densely distributed in this region. In 2008 and 2015, rural settlements tended to be more dispersed and grids in which the dispersion degree was above 6.0 increased by 27.68% and 29.3%, respectively. In some region, there were grids in which the dispersion degree was even above 21, accounting for 1.52% and 1.59% in 2008 and 2015, respectively. From 1998 to 2008, the number of grids in which the dispersion degree was in the range of 6–10 increased in regions around county seat. In Chenhu town, Liqiao township, Huocheng town and Damaying town which were at the south of county seat, there were more grids with dispersion degree in the ranges of 6–10 and 11–20. From 2008 to 2015, the number of grids with dispersion degree in the range of 11–20 increased around county seat but the dispersion degree of rural settlements in other towns did not change significantly.

During the specify surveys, it was found that there is a lack of scientific planning of the layout of rural settlement in Shandan County. The area of land for use expands outward but the efficiency of land use is relatively low. After 1998, population in Shandan County increased. The relationship between population and land resources in rural areas changed. The land within the effective farming radius cannot support the increasing population. In order to increase income, villagers began to cultivate new land, so cultivated land area expanded outward. Consequently, rural settlements expanded outward, leading to the dispersion, hollowing and chaos of rural settlements.

4.3. Spatial Association between Rural Settlements and Water and Land Resources in Shandan County

The rural settlements and their spatial distribution are affected by both natural and anthropogenic factors. Generally, rural settlements in hilly area are affected more by natural factors such as altitude, slope degree and slope direction, whereas rural settlements in plain oasis area are affected more by anthropogenic factors such as transportation, the hydrographic network, cultivated land. These factors will affect the location, structure and pattern of rural settlements. Shandan County is a typical plain oasis area, so its spatial layout should be affected more by cultivated land and the hydrographic network. Since there is almost no natural hydrographic network in Shandan County, the artificial hydrographic network was chosen for study.

4.3.1. Spatial Association between Rural Settlements and Land Resources

K values were calculated for the relationship between rural settlements and land resources in different situations. According to the agricultural land area per capita worldwide (1920 m^2) and construction land area per capita worldwide (83 m^2), the *K* value was calculated to be 0.04below which the conflict between rural settlements and land resources will not exist. According to the lower limits of agricultural land area per capita (533.3 m^2) predetermined by Food and Agriculture Organization and construction land area per capita in rural areas (150 m^2) predetermined by Chinese government for the New Urbanization strategy, the *K* value was calculated to be 0.28 above which there will be a conflict between rural settlements and land resources. If $K < 0.04$, the conflict between rural settlements and land resources does not exist, meaning there are less people and enough and resources. If $0.04 < K < 0.28$, there would be a balance between rural settlements and land resources. If $K > 0.28$, the conflict between rural settlement and land resources exists and is violent, meaning there are a large population but limited land resources. Note that $K = 88$ indicates that there are settlements but no cultivated land in the grid, so the conflict between rural settlement and land resources exists and is violent. $K = 99$ indicates that there is cultivated land but no settlements in the grid, so the conflict between rural settlement and land resources does not exist.

Using coupling relationship model, *K* values were calculated and the number of grids with different *K* values were counted (Table 5). The distribution of grids with different *K* values was also presented (Figure 6).The results are as follows.

(1) Note that the distribution of rural settlements in Shandan County is closely related to that of cultivated land. In 1998, the conflict between rural settlement and land resources was evident. In 2008 and 2015, the conflict between rural settlement and land resources became less evident.

(2) In 1998, the conflict between rural settlement and land resources existed in Dongle town and regions along major roads and canals in the south of county seat. In other towns, the relationship between rural settlement and land resource varied. In 2008 and 2015, there was a balance between rural settlements and land resources in Dongle town and in regions around county seat. In Chenhu town and Weiqi town in the middle of Shandan County, the conflict between rural settlement and land resources almost did not exist. In Damaying town at the south of Shandan County and Huocheng town near the boundary of Shandan County, the conflict between rural settlement and land resources still did not exist. The conflict between rural settlement and land resources in 2008 and 2015 have weakened compared with 1998.

(3) The conflict between rural settlement and land resources in Shandan County was the most violent in 1998 and the proportion of grids with $K > 0.28$ even reached 42.01%. In Dongle town, the conflict between rural settlement and land resources was especially severe. In other towns, the conflict between rural settlement and land resources did not exist in most regions. After 2008, the conflict between rural settlement and land resources became less violent and the total number and proportion of grids with $K > 0.28$ or $K = 88$ decreased. In 2015, the total proportion of grids with $K > 0.28$ or $K = 88$ decreased to 18.89% and these grids distributed in regions around county seat, in Damaying town at the south of Shandan County and in Huocheng town near the boundary of Shandan County.

(4) In 1998, the distribution of rural settlements was consistent with that of cultivated land. After 2000, villagers began to cultivate new land, so there were more than 30% grids with $K = 99$. Note that rural settlements also tend to be more dispersed, which is related to the expansion of cultivated land area.

Table 5. Grids with different *K* values in Shandan County in 1998, 2008 and 2015.

K Value Classification	1998		2008		2015	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
0–0.04	108	20.07	181	15.60	179	15.11
0.04–0.28	204	37.92	346	29.83	349	29.45
>0.28	226	42.01	95	8.19	110	9.28
88	0	0.00	103	8.88	113	9.61
99	0	0.00	433	37.33	434	36.94
Total	538	100.00	1160	100.00	1185	100.00

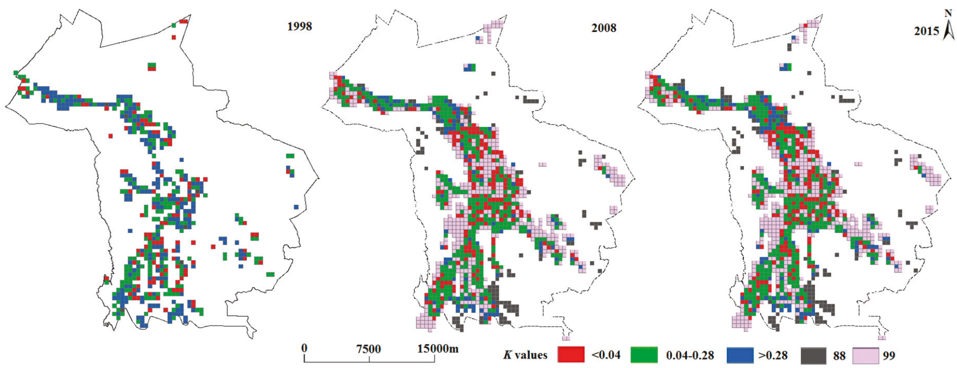

Figure 6. Distribution of grids with different *K* values in Shandan County in 1998, 2008 and 2015.

4.3.2. Spatial Association between Rural Settlements and the Hydrographic Network

Irrigation area in Shandan County is the main area that uses water. Currently, there are four irrigation areas in Shandan County: Huocheng, Laojun, Mayinghe and Sigou. Irrigation is mainly achieved by the hydrographic network, which is also the controlling factor for the spatial layout of cultivated land and rural settlements.

Different *L* values indicate different relationships between rural settlements and water resources. If $L < 0.1$, there is no conflict between rural settlements and water resources, meaning the hydrographic network can support the population. If $0.1 < L < 1$, there is a balance between rural settlements and water resources. If $L > 1$, the conflict between rural settlements and water resources exists, meaning the hydrographic network cannot support the population. Note that $L = 88$ indicates that there are rural settlements but no hydrographic network in the grid, so the conflict between rural settlements and water resources exists. $L = 99$ indicates that there is the hydrographic network but no rural settlement in the grid, so the conflict between rural settlements and water resources does not exist. Using coupling relationship model, *L* values were calculated and the number of grids with different *L* values were counted (Table 6). The distribution of grids with different *L* values was also presented (Figure 7). The results are as follows.

(1) Note that rural settlements distribute along the hydrographic network. The proportion of grids with *L* values in the range of 0–0.5 was 78.81% in 1998, 91.51% in 2008 and 89.75% in 2015, indicating there is almost no conflict or a balance between rural settlements and water resources. The spatial layout of the hydrographic network determines that of rural settlements and cultivated land.

(2) Notably, there is spatial difference in *L* values. In regions around county seat, the conflict between rural settlements and water resources exists. In regions at the northwest of county seat, there is a

balance between rural settlements and water resources. In regions at the south of county seat, the conflict between rural settlements and water resource does not exist.

(3) According to specify surveys, rural settlements, cultivated land and the hydrographic network are mutually dependent on each other. After 2000, the expansion of cultivated land area leads to the expansion of the hydrographic network. The expansion rates of cultivated land and the hydrographic network are higher than that of rural settlements. Thus, there were 43.86% grids with the hydrographic network but without rural settlements in 2008. The amount of water supplied (in fact, it should be water distribution amount) by the artificial hydrographic network determines the irrigation area. The direction of the hydrographic network determines the direction in which irrigation area expands and further affects the size and spatial layout of rural settlements.

Table 6. Grids with different *L* values in Shandan County in 1998, 2008 and 2015.

L Value Classification	1998		2008		2015	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
0–0.1	312	57.99	483	37.30	479	36.65
0.1–0.5	112	20.82	134	10.35	133	10.18
0.5–1	14	2.60	14	1.08	19	1.45
1–10	20	3.72	9	0.69	10	0.77
>10	1	0.19	2	0.15	3	0.23
88	79	14.68	85	6.56	102	7.80
99	0	0	568	43.86	561	42.92
Total	538	100.00	1295	100.00	1307	100.00

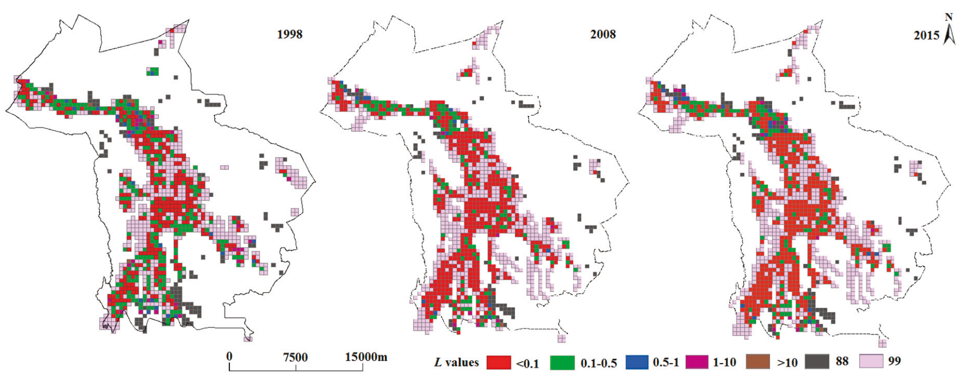

Figure 7. Distribution of grids with different *L* values in Shandan County in 1998, 2008 and 2015.

5. Conclusions

We analyzed the temporal-spatial differentiation of the rural settlement patterns in Shandan County using 1 km × 1 km sq. grids, GIS quantitative analysis, grid analysis, spatial hotspot detection and spatial association model. Further, we studied the spatial association between rural settlements and water and land resources. The conclusions are as follows.

(1) On the time scale, the total area of rural settlements in Shandan County expanded rapidly and the rural settlements tended to be more dispersed from 1998 to 2015. The increase in the number of rural settlement patches led to a higher density and a smaller average area of rural settlement patches. The *CA*, *NP*, *MPS*, *MAXP*, *MINP* and *PD* changed more rapidly from 1998 to 2008 than from 2008 to 2015. In the second period, the indices mentioned before did not change significantly.

The formation of new small settlements and the division of large settlements contributed to the increase in the number of solo and small settlements.

(2) On the spatial scale, the kernel density of rural settlements in 1998, 2008 and 2015 are basically consistent. Rural settlements mainly distribute along major roads and the hydrographic network and then the kernel density of rural settlements decreases in the direction away from these roads and the hydrographic network. In 1998, the settlement-intensive regions were relatively dispersed. The number of such regions was large but the area of each was small. In 2008 and 2015, the settlement-intensive regions were more concentrated. Their number decreased but the area of each increased. In addition, there is spatial difference in the distribution of hotspots and coldspots. In other words, large-scale rural settlements densely distribute in some regions and small-scale rural settlements sparsely distribute in other regions of Shandan County. From 1998 to 2008, the hotspot zone and coldspot zone expanded. From 2008 to 2015, the hotspot zone did not change significantly, whereas the area of coldspot zone decreased significantly.

(3) From 1998 to 2008, the dispersion degree of rural settlements increased. After 2008, the dispersion degree of rural settlements tended to be stable. In 1998, rural settlements in Shandan County were relatively concentrated and there were 95.35% grids in which the dispersion degree of rural settlements was below 5.0. In 2008 and 2015, rural settlements tended to be more dispersed and the proportion of grids in which the dispersion degree was above 6.0 increased to 27.68% and 29.3%, respectively. There were even grids in which the dispersion degree was above 21 and they accounted for 1.52% in 2008 and 1.59% in 2015. These lead to the dispersion, hollowing and disorder of rural settlements in Shandan County.

(4) The spatial distribution of rural settlements in Shandan County is closely related to that of cultivated land and the hydrographic network from 1998 to 2015. It can be expressed in three kinds of spatial relationships: conflict, balance and no conflict. There is a conflict between rural settlement and land resources and the conflict in 2008 and 2015 has weakened compared with 1998. In contrast, there is almost no conflict or a balance between rural settlements and water resources from 1998 to 2015.After 2000, the expansion of cultivated land led to the expansion of the hydrographic network. The expansion rates of cultivated land and the hydrographic network were higher than that of rural settlements. Thus, there were 37.33% grids with cultivated land but without settlements and 43.86% grids with the hydrographic network but without settlements in 2008, this is the main reason for the conflict decreased between rural settlement and land and water resources.

This paper can provide a systematic framework for the theoretical and empirical research on the rural settlements in oasis at a micro scale. Different from the conventional comprehensive evaluation of the temporal-spatial distribution of rural settlements, we choose water and land resources, which are the most basic constituents of oasis, as the controlling factors for the development of rural settlements. We then explored the spatial association between rural settlements and water and land resources. Finally, we revealed the driving force of the spatial-temporal evolution of rural settlement patterns at a micro scale. This study can help guide the rural planning in oasis, promote intensive land utilization and lessen the conflict between rural settlements and water and land resources. Then, sustainable development and rural revitalization in China can be achieved. However, the study has not thoroughly and systematically discussed the essence of the spatial-temporal evolution of rural settlements in different periods and has not pointed out a direction for the spatial reconstruction of rural settlements in the future. Therefore, we will systematically analyze the evolution and driving mechanism of rural settlements under the background of rural economic and social transformation in future study. In addition, we will try to explore the spatial reconstruction of rural settlements in oasis so that a balance between land resources and population in oasis can be achieved.

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References

1. Zhou, G.H.; He, Y.H.; Tang, C.L.; Yu, T.; Xiao, G.Z.; Zhong, T. Dynamic mechanism and present situation of rural settlement evolution in China. *J. Geogr. Sci.* **2013**, *23*, 513–524. [CrossRef]
2. Jin, Q.M. *Rural Settlement Geography*; Science Press: Beijing, China, 1988. (In Chinese)
3. Jean, B. *The Principle of People*; Ren, M.E., Li, X.D., Eds.; Zhongshan Press: Nanjing, China, 1935.
4. Blache, P.V. *Principes de Geographie Huonaine*; Zhen, C.C., Ed.; Commercial Press: Beijing, China, 1930.
5. Demangeon, A. *La Geographie de I'habitat Rurale, Report of the Commission on Types of Rural Settlement*; Montgomery Shire Express, Limited: Newtown, UK, 1928.
6. Demangeon, A. Types de Villages en France. *Ann. Geogr.* **1939**, *48*, 1–21.
7. Doxiadis, C.A. *Ekistics: An Introduction to the Science of Human Settlements*; Oxford University Press: Oxford, UK, 1968.
8. Bunce, M. Rural Settlement in an Urban World. *Real Estate Econ.* **1986**, *14*, 171–172. [CrossRef]
9. Chisholm, M. *Rural Settlement and Land Use*; Transaction Publishers: Piscataway, NJ, USA, 1962.
10. Goodwin, H.L.; Doeksen, G.A.; Oehrtman, R.L. Determination of settlement patterns in rapidly growing rural areas. *Ann. Reg. Sci.* **1984**, *18*, 67–80. [CrossRef] [PubMed]
11. Banski, J.; Wesolowska, M. Transformations in housing construction in rural areas of Poland's Lublin region-influence on the spatial settlement structure and landscape aesthetics. *Landsc. Urban Plan.* **2010**, *94*, 116–126. [CrossRef]
12. Sevenant, M.; Antrop, M. Settlement models, land use and visibility in rural landscapes: Two case studies in Greece. *Landsc. Urban Plan.* **2007**, *80*, 362–374. [CrossRef]
13. Infante-Amate, J.; Villa, I.; Jiménez, F.; Martínez Martín, M.; Martínez López, D.; Cunfer, G.; González de Molina, M. The rise and fall of the cortijo system: Scattered rural settlements and the colonization of land in Spain's Mediterranean mountains since 1581 Original. *J. Hist. Geogr.* **2016**, *54*, 63–75. [CrossRef]
14. Han, Y.W.; Song, Y.K.; Burnette, L.; Lammers, D. Spatiotemporal Analysis of the Formation of Informal Settlements in a Metropolitan Fringe: Seoul (1950–2015). *Sustainability* **2017**, *97*, 1190. [CrossRef]
15. Conrad, C.; Rudloff, M.; Abdullaev, I.; Thiel, M.; Löw, F.; Lamers, J.P.A. Measuring rural settlement expansion in Uzbekistan using remote sensing to support spatial planning Original. *Appl. Geogr.* **2015**, *62*, 29–43. [CrossRef]
16. Porta, J.; Parapar, J.; Doallo, R.; Barbosa, V.; Santé, I.; Crecente, R.; Díaz, C. A population-based iterated greedy algorithm for the delimitation and zoning of rural settlements. *Comput. Environ. Urban Syst.* **2013**, *39*, 12–26. [CrossRef]
17. Mao, Y.; Liu, Y.F.; Wang, H.F.; Kong, X.S. A Spatial-Territorial Reorganization Model of Rural Settlements Based on Graph Theory and Genetic Optimization. *Sustainability* **2017**, *9*, 1370. [CrossRef]
18. Haines, A.L. Managing rural residential development. *Land Use Tracker* **2002**, *1*, 6–10.
19. Pino, A.; Hormazábal, N. Informal settlements: Reinterpreting rural imaginary in urban areas: The case of Valparaiso's ravines. *Habitat Int.* **2016**, *53*, 534–545. [CrossRef]
20. Popović, S.; Djurovic, N.; Murgul, V. Formation, development and issues of Montenegro rural settlements in the case of village Orja Luka in Bjelopavlici. *Procedia Eng.* **2015**, *117*, 832–840. [CrossRef]
21. Paulo, R.M.; Nicolás, S.; Denise, P.B.; Maria, A.M.S. Larval habitats of Anopheles species in a rural settlement on the malaria frontier of southwest Amazon, Brazil Original. *Acta Trop.* **2016**, *164*, 243–258.
22. Lin, C. Settlement classification discussion. *Geography* **1938**, *6*, 17–18. (In Chinese)
23. Yan, Q.S. Living geographic in Xikang. *Acta Geogr. Sin.* **1939**, *6*, 43–58. (In Chinese)
24. Chen, S.P.; Yang, L.P. Settlement near the Zunyi. *Acta Geogr. Sin.* **1943**, *10*, 69–81. (In Chinese)
25. Wu, C.J. *Relationship between Human and Economic Layout (Wu Chuanjun Collection)*; Academic Press: Beijing, China, 2008. (In Chinese)
26. Zhang, T.Z.; Song, J.T.; Su, Y.X.; Wu, Y.R.; Su, S.R.; Hu, R.X. Preliminary experience in the economic planning of the rural people's Commune. *Acta Geogr. Sin.* **1959**, *25*, 107–119. (In Chinese)

27. Jin, Q.M. *Rural Settlement Geography in China*; Science and Technology Press of Jiangsu: Nanjing, China, 1989. (In Chinese)
28. Sun, G.Y.; Wang, C.S.; Xiao, L.; Dong, G. Rural residential land use change and its influencing factors in the rapid-urbanization region: A case study of Longgang District, Shenzhen. *Prog. Geogr.* **2011**, *30*, 352–360. (In Chinese)
29. Zhu, F.K.; Zhang, F.R.; Li, C.; Zhu, T. Functional transition of the rural settlement: Analysis of land-use differentiation in a transect of Beijing, China. *Habitat Int.* **2014**, *41*, 262–271. [CrossRef]
30. Ma, L.B.; Fan, H.; Shi, P.J.; Guo, X.D. Spatial pattern of rural settlements in loess hilly area: A case study of Tianshui City, Gansu Province. *Chin. J. Ecol.* **2015**, *11*, 3158–3165. (In Chinese)
31. Yang, R.; Liu, Y.S.; Long, H.L.; Qiao, L.Y. Spatio-temporal characteristics of rural settlements and land use in the Bohai Rim of China. *J. Geogr. Sci.* **2015**, *25*, 559–572. [CrossRef]
32. Yang, R.; Xu, Q.; Long, H.L. Spatial distribution characteristics and optimized reconstruction analysis of China's rural settlements during the process of rapid urbanization. *J. Rural Stud.* **2016**, *47*, 413–424. [CrossRef]
33. Tian, Y.S.; Kong, X.S.; Liu, Y.L.; Wang, H.R. Restructuring rural settlements based on an analysis of inter-village social connections: A case in Hubei Province, Central China. *Habitat Int.* **2016**, *57*, 121–131. [CrossRef]
34. Wang, C.; Huang, B.; Deng, C.; Wan, J.; Zhang, L.; Fei, Z.H.; Li, H.Y. Rural settlement restructuring based on analysis of the peasant household symbiotic system at village level: A Case Study of Fengsi Village in Chongqing, China. *J. Rural Stud.* **2016**, *47*, 485–495. [CrossRef]
35. Long, H.L.; Zou, J.; Liu, Y.S. Differentiation of rural development driven by industrialization and urbanization in eastern coastal China. *Habitat Int.* **2009**, *33*, 454–462. [CrossRef]
36. Tan, M.H.; Li, X.B. The changing settlements in rural areas under urban pressure in China: Patterns, driving forces and policy implications. *Landsc. Urban Plan.* **2013**, *120*, 170–177. [CrossRef]
37. Liu, Y.S.; Yang, Y.Y.; Li, Y.R.; Li, J. Conversion from rural settlements and arable land under rapid urbanization in Beijing during 1985–2010. *J. Rural Stud.* **2017**, *51*, 141–150. [CrossRef]
38. Li, T.T.; Long, H.L.; Liu, Y.Q.; Tu, S. Multi-scale analysis of rural housing land transition under China's rapid urbanization: The case of Bohai Rim. *Habitat Int.* **2015**, *48*, 227–238. [CrossRef]
39. Ding, W.H.; Meng, B. A study on interaction between oasis water resource and oasis urbanization: Taking example of Northwest Region. *J. Inner Mong. Norm. Univ.* **2005**, *34*, 502–505.
40. Wang, L.C.; Gao, J. Spatial coupling relationship between settlement and land and water resources based on Irrigation Scale—A Case Study of Zhangye City. *J. Nat. Resour.* **2014**, *29*, 1888–1901. (In Chinese)
41. Dehnad, K. Density Estimation for Statistics and Data Analysis. *Technometrics* **1992**, *29*, 296–297. [CrossRef]
42. Cai, X.J.; Wu, Z.F.; Cheng, J. Analysis of road network pattern and landscape fragmentation based on kernel density estimation. *Chin. J. Ecol.* **2012**, *31*, 158–164. (In Chinese)
43. Jiao, Y.M.; Xiao, D.N.; Ma, M.G. Spatial pattern in residential area and influencing factors in oasis landscape. *Acta Ecol. Sin.* **2003**, *23*, 2092–2100. (In Chinese)

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The Creation of an Ecovillage: Handling Identities in a Norwegian Sustainable Valley

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Abstract: This paper presents a qualitative study of Hurdal Ecovillage in Norway. It explores how the actors involved have interacted over time and contributed to shaping the ecovillage. The study demonstrates that the ecovillage as a concept is continuously refined both internally on an individual level and in the village, and in mainstream society. At stake is the question of ecovillage identity and what this should entail. The interviewed ecovillagers report two main motives for deciding to move to the village. One is to become part of the ecovillage community, while the other is grounded in the ecovillage as a means to achieve sustainability rather than as a goal in itself. Hurdal Ecovillage has undergone two distinct development phases. First, the members jointly owned the land, built their own houses, and attempted to be self-sufficient. The ecovillage was largely isolated from the local community. In the second phase, professional actors took over responsibility for developing the village, offering ready-made houses to be owned by individual families. This shift resulted in the ecovillage appearing more like conventional settlements. Today's ecovillagers express a wish to constitute an attractive, sustainable alternative to conventional living, but to do so they have to maintain a distance between themselves and the wider community.

Keywords: ecovillage; sustainability; collective identity; mainstreaming; distance

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1. Introduction

The ecovillage (EV) movement has received considerable attention in the literature. For example, scholars have looked at how EVs, as a particular form of 'intentional community' and lifestyle movement, have emerged and evolved over the years, and at various barriers experienced in the process of establishing and maintaining such initiatives, which have often failed. Forster and Wilhelmus [1] (p. 378) for instance observe that 80 per cent of ecovillage communities have ceased to exist within two years of starting.

Typically, EV initiatives articulate an intention to change society by promoting and practising sustainable living. A substantial part of the academic work on EVs has focused on the shared values underpinning these initiatives, which constitute the essence of such projects for sustainable living. A central and overarching idea observed among EVs which is often articulated within the movement itself is the notion of 'connectedness' between, for example, human beings today and those of the future, or between humans and nature. Looking at how EVs are maintained and changing over time, Sargisson [2] (p. 398) points out that EV members are, on the one hand, often attuned to opening themselves spiritually and socially. On the other hand, to sustain their identity and purpose as a group, they need to maintain a social, ideological and normative distance to the surrounding society ('estrangement') (Ibid.).

Working from a sociotechnical transitions framework, Boyer [3,4] treats the relationship between niche initiatives such as EVs and mainstream society. The study of this relationship is key for understanding how the diffusion of niche practices occurs. Several studies have focused on understanding the process of translation by which niche practices influence or become adopted by mainstream society. Translation "involves changes in a dominant set of interdependent social, physical, or regulatory structures that accommodate the niche" [4] (p. 34).

Smith [5] argues that the success of niches at influencing the mainstream rests on the ability of the niche to form intermediate projects where the sociotechnical contexts between the niche and mainstream society might bridge. The conditions for such intermediacy are "when a niche shares some, but not all, properties of a regime it prefigures" [4] (p. 32). Other studies put forward the importance of the political and social contexts surrounding the lifestyle projects or the niches for them to develop successfully [6,7]. As Seyfang concludes: "Socio-technical transformations cannot be achieved by niches alone" [6] (p. 7632). Hence, the local context matters to the success of these niches, as does the initiator's ability to network with other grassroot movements [8,9].

As an example of niche practices, this paper examines Hurdal Ecovillage in Norway with a particular focus on how the relationship between Hurdal EV and mainstream society was maintained and redefined over a period of 15 years. The objective is to contribute to understanding: (i) the significance of the local context in terms of defining the EV; and (ii) the tensions that may arise as the EV needs to maintain a unique identity and distance from the local context at a point in time where mainstream society is turning towards values of environmental sustainability.

We first explore how and to what extent residents of the EV express political and moral concerns when accounting for their choice and practising their lifestyle. We ask whether residents of Hurdal EV perceive themselves as being associated with a wider EV lifestyle movement, the intention of which is to produce social change. We follow Holland et al.'s [10] (p. 97) definition of a social movement's collective identity as "participants' shared sense of the movement as a collective actor—as a dynamic force for change—that they identify with and are inspired to support in their own actions". Second, we focus on how the collective identity of the ecovillage in question changed over time. We acknowledge the possibility that there are multiple intentions, practices, and (partly shared) identities within the EV. Furthermore, following Sargisson's [2] observation of the need for an EV to distance itself from the surrounding society, we are particularly interested in examining the relationship between the EV, the local community, and mainstream society, as it evolved over time, and which contributed to forming Hurdal EV's identity (cf. the notion of 'alter-versions' treated by Holland et al. [10] (p. 106)). This perspective resonates with classical anthropological work [11] (p. 10) on group identity and belonging. To social groups, maintenance of boundaries (distance to other groups) is an enduring concern.

This study primarily reflects various groups' perceptions of each other and does not seek to trace structural influences which the EV may potentially on mainstream society (which may be changing for different reasons). Thus, we do not provide a full account of the translation process which ultimately leads to diffusion. However, we show how the EV relates to mainstream society and argue that this micro-study of the dynamic relationship between an EV and its surroundings provides some insights into understanding translation processes in general. As we will show, a key feature in this process involves a certain level of tension in terms of ecovillagers' need to handle and balance two contradictory concerns: their wish to influence mainstream society on the one hand, and maintaining their own, unique identity on the other. For these purposes, we examine various types of relationships that have contributed to the creation of Hurdal EV. This includes internal relationships in the EV, and the ecovillagers' relationship with the local population in Hurdal and with mainstream society. We draw on in-depth interviews with residents, representatives of the local population, and with the developer/architect of the EV.

The next section presents a brief review of the literature on EVs and intentional communities. Section 3 accounts for the methods used in this study. In Section 4, we present Hurdal municipality and two key phases in the development of the EV. Section 5 presents the motivation of today's ecovillagers for moving to Hurdal EV, and accounts for various types of relationships that have contributed to the creation of Hurdal EV. In Section 6, we discuss the findings, and Section 7 presents a conclusion.

2. Literature Review

Intentional communities are defined by Kozeny [12] (p. 18) as:

> [. . .] a group of people who have chosen to live together with a common purpose, working cooperatively to create a lifestyle that reflects their shared core values. The people may live together on a piece of rural land, in a suburban home, or in an urban neighbourhood, and they share a single residence or live in a cluster of dwellings.

The current EV movement forms part of what has been described as the fourth wave of 'intentional communities' [13]. Smith [13] draws on Kanter [14], who identified the three earliest periods of intentional or communal development in the United States: the first wave was devoted to communities with a religious theme (continued up to 1845), the second emphasized economic and political issues (lasted up to 1930), and the third focused on psychosocial issues (peaked in the late 1960s). The current movement of intentional communities, including the growing number of EVs, is characterised by eclecticism and is "not as alienated from mainstream culture as were their predecessors; and they appear to be more adept at balancing individual and community needs" [13] (p. 111).

Globally, the increasing concern for climate change and the environment over the past decades has spurred renewed interest in intentional communities as potential models for sustainable living [15]. EVs tend to highlight four 'pillars' on which the movement is based: environment, economy, community, and consciousness [16]. Because EVs vary considerably in terms of which pillars are emphasized, Litfin uses the metaphor of 'the windows of a house' to highlight how different EVs embrace the four pillars to varying extents and in different ways [16] (p. 31). One example is the Findhorn Ecovillage in Scotland, which started as a spiritual community in the 1960s but which—since the 1980s and negotiations surrounding the Rio Summit—came to include environmental sustainability as a central pillar or 'window'. Renewed interest in EVs should thus be understood in the context of increasing concerns about the environment. Kaspar [17] considers the EV movement as an attempt to create an integrated ethic in which both humans and nature are considered to have a value in their own right. Moreover, dissatisfaction with societal trends towards further segmentation of people and nature, development away from community principles, and withdrawal from political participation, appear to motivate the formation of EVs [17,18].

Current EV initiatives may also qualify as 'lifestyle movements' [3] (p. 2). By introducing this concept, Haenfler et al. [19] (p. 2) aim to bridge theories associated with social movements on the one hand, and lifestyles on the other. They seek to place the analytical focus on the "intersections of private action and movement participation, personal change and social change, and personal identity and collective identity". Lifestyle movements (in line with political consumerism and socially conscious consumption) represent ways in which individuals express political and moral concerns outside explicitly political realms such as voting and protesting practices [20] (p. 452). Here, lifestyle choices constitute the protagonists' main strategy to obtain social change, and personal identity work plays a key role [19] (p. 8). Lifestyle movements and scholarly literature pertaining to this subject are closely linked to studies of grassroot movements and niches which, in part, form sources of systemic change or societal transformation (see for instance, [5]).

Through their oft-articulated intention to change society by promoting and practising sustainable living, an important question is whether EV practices are diffused to mainstream society. Summarising works by different scholars [5,6,21,22], Boyer [3] points to three different pathways in which niche projects diffuse their practices to mainstream society:

(a) Replication, meaning that practices (for instance the building of straw bale houses) spread through a network of dedicated activists, but are limited to that networks.

(b) Scaling up beyond a network of activists—for instance diffusion of photovoltaics—and spreading to different groups in mainstream society.
(c) Translation, where practices from the niches diffuse into mainstream society at a higher institutional level; for instance to municipal planning or building practices.

Smith [5] considers specifically the last point on translations between niches and mainstream society, analysing the interactions between them. He shows how niche diffusion requires sufficient common ground between the niche and the practices of mainstream society to impact the latter. Three different types of translation between the niche and the regime are identified: (1) How a societal problem guides the principles of the niche; for instance, how pressing issues of sustainability motivate the establishment of lifestyle movements and their guiding principles; (2) How interactions between the niche and mainstream society modify practices and strategies of the two; for instance, by adapting niche practices to lessons learnt about the mainstream; and (3) How pressing societal problems alter the context of the mainstream, bringing the latter closer to the conditions in the niche. Furthermore, Smith [5] (p. 440) proposes that niches that are too much in line with mainstream society will lead to little change, while radical niches too divergent from the mainstream will become detached and will only diffuse their practices to a limited extent. Hence, he concludes that translation most likely happens in intermediate projects where the sociotechnical contexts between the niche and mainstream society might be bridged. Niches such as lifestyle movements might need to compromise elements of their ideology in order to engage with mainstream actors and facilitate the translation from niche to mainstream [3].

Boyer [4] offers an account of the conditions that underlie diffusion pathways. It draws on in-depth studies with founders of cohousing initiatives in the US. While the cohousing movement articulates a socio-environmental critique and provides an alternative that mitigates some of the adverse effects of mainstream society, it also works in and with institutions in mainstream society [23]. Boyer [4] illustrates the importance of this pragmatic strategy in the translation process towards mainstream society. He also shows how the intermediacy of cohousing initiatives helps the translation process by its pragmatism. For instance, it does not demand that the residents abandon their economic independence or adhere to specific values or belief systems. The factors of success and the failure of grassroot initiatives like the lifestyle movements are investigated in the study by Seyfang [6]. She studies grassroot initiatives as strategic green niches with a potential for diffusion into mainstream society. Through studying community-based sustainable housing initiatives in the US, she points to the challenges of diffusing their ideas and practices beyond the niche. This is due to the fact that grassroot movements might need to invest a lot of effort into maintaining their community and ideas. However, she also points out that the translation processes of niche practices into mainstream society require certain political and social contexts in order to occur: "Socio-technical transformations cannot be achieved by niches alone" [6] (p. 7632). The factors for success and failure of niches are also investigated by Feola and Nunes [9]. They define success according to how niches manage to create social connectivity and empowerment, and contribute to improved environmental performance, also externally. The authors show that many of the members in these initiatives tend to focus on internal factors rather than external ones to secure their own development. The members also tend to pay little attention to material resources, which may be because of their heavy reliance on volunteers (also pointed out by [1,7]). Further, an initial incubation period seems to be an important explanatory factor for the success of these movements, as is a simultaneous interaction process between the niche and mainstream society, as also pointed out by Smith [5]. Feola and Nunes [9] emphasize that the local context matters for the success of the initiatives, and that geographical location and place attachment may also play a role. Urban grassroot initiatives are apparently less successful than their rural counterparts, which they suggest can be explained by a weaker local place attachment [9]. In line with this, but also expanding on the focus of Feola and Nunes [9], Nicolosi and Feola [8] studied a suburban grassroot initiative in the US. The local context played an important role in its success, but so did networking with other grassroot movements, cultivating an environment where they could perform experiments of social and environmental change.

Ergas [7] also studies the dynamic relationship between a grassroot initiative such as an EV and the mainstream society that surrounds it. She conducted a joint analysis of identity formation among ecovillagers on the one hand, and the macro-political structures on the other. The author showed that some of the studied ecovillagers (in the United States) projected a collective identity by attempting to be 'a model of sustainable living' for mainstream society [7] (p. 49). However, the ecovillagers had no unified vision of how to achieve this goal. Ergas [7] (p. 43) also found that the ecovillagers' relationship with the dominant cultural structure is interactive. Here, mainstream society both provided opportunities for and posed constraints on sustainable living (e.g., local housing codes). In response, the ecovillagers sought to push back by modifying the limiting structures [7] (p. 50). This is an important type of relationship that will be examined in the present work.

Moreover, pointing to the importance of the political and social contexts for a successful translation of niche practices into mainstream society, North and Longhurst [24] argue that proximity to larger power structures may lead to more visibility and possibilities to transfer niche practices to other places. They thus challenge Feola and Nunes' [9] conclusion that grassroot initiatives face more challenges in urban settings. North and Longhurst [24] argue that urban areas have a diversity of actors who are able to work on developing grassroot initiatives, and hence, add more robustness to the movement. Sager [25] elaborates these arguments by showing how intentional communities in urban areas may succeed in using activist planning to influence their position vis-à-vis municipalities, and in bringing their ideas to political decision-makers as a result of their proximity to these actors.

The potential mutual influence between conventional, mainstream architecture and traditional ecological architecture has been studied from the perspective of science and technology studies. Ecological architecture (often employed in EVs) aims at low-tech alternatives using local resources, and often demands active involvement from the inhabitants when building the houses [26]. Berker and Larssæther [27] refer to the architecture used in the first phase of the Hurdal project as "experimental building projects within and outside of the ecovillage movement" [27] (p. 103). As we will discuss later, the project consisted of low-tech, self-built houses using local materials, and confirmed the idea of traditional ecological architecture as home-spun and low-tech [26]. The majority of architects in Norway perceived this type of architecture as rather uninteresting and poorly designed [28]. Drawing on the work of Ryghaug [28,29], Sørensen [26] notes that, in the realm of architecture, it is the concept of sustainability associated with traditional ecological architecture that has been mainstreamed. This is in contrast with technologies like electric cars where the materials, practices, and processes are mainstreamed, and not the concept. However, as we will show, Hurdal EV went through different phases with radically different architectural designs; we will discuss how this affected the relationship between the EV and the local population.

3. Methods

We selected Hurdal EV as our case because it is the largest ecovillage in Norway. It also has an interesting historical trajectory, in that some of its characteristics as an ecovillage have changed over the years. As we elaborate below, the ecovillage shifted from a reliance on jointly owned, self-built houses and self-sufficiency to a pragmatic approach with ready-made houses and less emphasis on subsistence. By studying this shift and how interactions between various types of actors contributed to shaping the ecovillage, this case provides insights into how the ideas and concepts associated with an ecovillage are formed through a dynamic relationship with mainstream society. This relationship is important for understanding processes of translation.

Our main empirical material derives from interviews, as presented below. We also reviewed reports and visited previous studies and websites focusing on the Hurdal case. Two sources were particularly useful for understanding the history of the EV ([30,31]), and our account in Section 4.2 relies on a triangulation between information deriving from these sources and material collected during interviews. We also reviewed the general literature, previous studies, and online material. In the scoping phase, we searched scholarly databases for relevant literature using keywords such as 'ecovillage', 'intentional communities', 'sustainable living', 'community', and 'Hurdal'. In the revision phase, we received useful input on additional references from two anonymous reviewers. We participated in the Hurdal Sustainable Valley Festival in 2015. The festival is an annual event organised by Hurdal municipality and attended by national politicians and well-known NGOs. During this event, we observed how the municipality representatives spoke about sustainability as a central element of Hurdal's collective identity, and how they presented the EV as a central part of the municipality's way of achieving sustainability. This event also gave us the opportunity to mingle informally with both participants in the EV and outsiders. To gain insight into the EV movement, we visited Findhorn Ecovillage, regarded as one of the first of its kind and often termed 'the mother of all EVs', in the UK in May 2016. We draw upon observations made by the research team on their frequent visits to Hurdal EV, as well as on reports and information retrieved online about Hurdal EV. The ecovillage also has two Facebook groups, one public and one private.

Hurdal EV has received substantial attention in the popular media. In 2015, the Norwegian Broadcasting Corporation [32] produced a television documentary about Hurdal EV which claimed to document some of the challenges and conflicts experienced in the process of establishing the community. Our study also draws on the findings of this documentary.

3.1. Recruiting Respondents

In total, we conducted 23 in-depth interviews in 2016. Fifteen of these included individuals or families among the current 64 households (150 inhabitants) in the EV. Six interviews were held with people representing Hurdal's local community (see below), and three were with individuals who played a central role in initiating and/or developing the EV: Kristin Seim Buflod (General Manager, Hurdal EV), Simen Torp (Filago) and Rolf Jacobsen (Aktivhus, formerly Gaia Architects). These three interviewees agreed to be identified by name in the present work. Seim Buflod is also one of the 15 ecovillagers interviewed.

With one exception, the ecovillagers were engaged in the current study through self-recruitment. One of the architects involved in developing the EV put us in contact with the communications adviser in Filago. Filago is a Norwegian company that develops and builds EVs. The communication adviser wrote an email to all the EV inhabitants describing the project and inviting them to participate in interviews. Fourteen households responded and were interviewed. In addition, we recruited one couple spontaneously while visiting the EV. All the interviews with the ecovillagers took place in their homes, and lasted approximately one and a half hours.

Respondents not affiliated with Hurdal EV were contacted directly by looking up their names online, calling them, and following up with emails. They included the mayor, the head of planning and building services in the Hurdal municipality, and four municipal employees (working at the primary school and in the commercial services sector). In addition to the 23 formal interviews, we talked to other individuals and groups we met in the Hurdal town centre and at the café in *Fremtidssmia*, the recently opened (2016) cultural centre run by the EV. These informal meetings provided additional insights into the relationships and interactions between EV inhabitants and the local population in Hurdal.

3.2. Interview Topics and Strategy for Analysing the Material

The interviews were semi-structured, which allowed the respondents to bring up issues of concern. We developed a specific interview guide for each of the three types of respondents (Hurdal EV, municipal staff, and people from the local community). Generally, after introducing ourselves and the project, we provided information about how the data would be collected, stored and used, and asked for consent to record the interviews. All participants received information about the project, including their right to withdraw, and how we would manage anonymity.

The interviews with the ecovillagers covered four main topics. First, we asked about their background (age, gender, family background, occupation, where they came from), their consumption practices in general, and their reasons for moving to Hurdal EV. Second, we asked them to elaborate on their experiences of living in the EV (the house, the solar panel and other equipment, social aspects, organisation of daily life, etc.) and whether their habits, consumption patterns and attitudes had changed after moving to the EV. Third, we invited them to reflect on their relationships with fellow inhabitants in the EV and with the local community. Finally, we asked about their views on broader issues such as the role of EVs in mainstream society.

The interviews with the local population centred on their views on the process of establishing the EV and on the relationship between the local administration/population and the EV. In the interviews with the EV developers, we focused on the process and the various individuals, technologies, and relationships involved.

Four researchers conducted the interviews, most of them individually. With three exceptions, the interviews were audio-recorded and transcribed. To help structure the analysis, we produced a coding tree with key issues from the interview guide, and systemised and coded the material accordingly.

4. Hurdal and the *Ecovillage*: The *Place* and the *Project*

4.1. Hurdal

Hurdal municipality is situated in Akershus County, about 80 km from Oslo, and comprises 2910 inhabitants (2016). Hurdal EV is situated approximately four kilometres from the administrative centre. Figure 1 shows where Hurdal and the EV are located.

Figure 1. Map of Hurdal municipality and the ecovillage.

The municipality's stated ambition is "to be a plus society by 2025, which implies that Hurdal will be carbon neutral or better, experience economic growth, and provide improved quality of life to inhabitants and visitors" [33].

4.2. Establishing Hurdal Ecovillage

4.2.1. Phase 1 (1996–2009)

The story of Hurdal EV goes back to 1996 and the establishment of the ecocommunity *Kilden Økosamfunn* [30]. The founders of Kilden wanted to establish an EV in Norway. This group looked at approximately 60 different properties in the region around Oslo to find a suitable plot, and in 2001 came across the property in Hurdal, which was for sale. At the same time, the community was approached by the mayor of Hurdal, who was positive about selling Gjøding farm, owned by Hurdal municipality, to the EV group. Gjøding was situated only an hour's drive from Oslo, had a substantial amount of land for growing crops and attractive plots for building houses, and the municipal plan had already allowed for the building of houses in this area. In total, Gjøding covers 146 acres of land, of which 40 acres is farmed land. The ecocommunity proceeded to establish an EV on this site. The community rented Gjøding from 2002, and members of the EV built temporary housing using materials such as straw and wood, in line with traditional ecological architecture (see Figure 2) Euro pallets were used for the foundations for some of the houses because they were built on agricultural land. The municipality therefore had to grant dispensation from the Planning and Building Act on the condition that the houses would be removed after three years. However, the process of establishing the village took longer than expected (actually 10 years), and permission to keep the houses was extended several times.

An EV cooperative was established in which each member owned a share of the farm and had a say in the decision-making process [30]. The initial inhabitants had to carry the costs of establishing the EV, and subsequent newcomers to the village had to pay a certain amount to join.

In 2001, the cooperative began collaborating with Gaia Architects, an umbrella organisation for architectural firms interested in contributing to sustainable design [34]. The Gaia project, headed by architect Rolf Jacobsen, assisted the cooperative in developing the zoning plan for the area as part of the approval process for building the houses.

Figure 2. Self-built houses in Hurdal EV, Phase 1. (Photo: Simen Torp).

However, the project soon faced challenges in the county administration [31], due to a conflict over the protection of important cultural heritage sites. Spruce trees on the hill that formed part of the site planned for the EV were a central element of the cultural heritage site. However, just weeks after the cooperative's application was rejected by the county administration, a fierce storm hit Hurdal. As a result, all the trees were blown down, and the county subsequently issued approval for the plans. In 2004, the EV bought Gjøding from the municipality, and in 2006 the zoning plan was approved.

The small EV community lacked the necessary economic and legal expertise. For instance, obtaining funding to establish a substantial number of new houses proved a major challenge.

They therefore decided to collaborate with a developer who would carry the financial risk. They also saw a need for a different concept for building the houses. Self-building required a lot from individuals in terms of expertise and time [27]. Hence, the EV project turned towards using ready-made modules and individual ownership of properties and houses.

4.2.2. Phase 2 (2009–Today)

The overall zoning plan for the EV was approved in 2009. The company Aktivhus was established the same year, partly as a result of the experiences gained by Gaia Architects in Hurdal, where they saw a need for standardised houses that could be produced more professionally than those made in the first phase of the EV development. Gaia also saw a potential for promoting eco-friendly houses more generally, and was motivated to offer an alternative to passive houses [27], which were mainly designed to minimise building energy consumption and take broader environmental aspects, such as the life cycle of materials, into account.

Aktivhus provides module-based, eco-friendly houses under a concept referred to as 'Shelter' [35] and became a close partner and important actor in Phase 2 of the EV.

The financial challenge remained. In its search for a developer, the EV tried to establish collaboration with several actors. In 2012, the company Vitrina AS (later Filago) took over financial responsibility for the project. Some of our respondents said they felt very relieved when an investor was willing to take over the debt.

Construction of the Shelter houses started in 2013 (see Figure 3). Aktivhus had to balance the ideals of ecological architecture (e.g., natural materials, natural ventilation, healthy indoor climate and energy-efficient construction) with national regulations and available support schemes. For example, to meet the energy requirements specified in the Regulations on Technical Requirements for Building Works, pursuant to the Planning and Building Act (TEK 10) and zero emission requirements, which would entitle the group to considerable support from Enova, they installed solar panels on the roofs. (Enova is owned by the Ministry of Petroleum and Energy, and was established in 2001 to contribute to reducing greenhouse gas emissions and transitioning to climate-friendly energy consumption and sustainable energy production). Furthermore, in order to better regulate ventilation and indoor climate, some of the houses were equipped with smart technologies. To receive additional support, the project also agreed to install monitoring equipment in some of the buildings to enhance research. This led to the introduction of smart technologies for controlling window screens, lighting, etc. Nonetheless, the architect was determined to use natural rather than balanced ventilation, hence *active* rather than *passive* houses.

Figure 3. The Shelter houses in Hurdal EV. (Photo: Nadia Fransen).

However, the EV faced new challenges when subcontractors went bankrupt and technical equipment failed to function as prescribed. As a result, Aktivhus nearly went bankrupt. As shown below (Section 5.2), there is still considerable frustration among our respondents over the equipment, as well as concerns about the financial viability of the two companies involved. Table A1 in the appendix summarises the two main phases, some of the characteristics of the EV at the two points in time, and how the EV is regarded by the municipality and the local community, though our material on the latter group is limited.

5. Identities and Relationships

This section begins by presenting ecovillagers' expressed motivation for moving to the EV. This will help us answer the question of whether ecovillagers perceive themselves as part of a lifestyle movement. We then examine how ecovillagers relate to each other and to other internal 'actors' such as houses and smart technology, and how they relate to the local community. We discuss the implications of the findings in Section 6.

5.1. Stating Intentions: Why Move to Hurdal Ecovillage?

Our EV respondents varied in terms of when and why they moved to the ecovillage. Some of them had been there almost from the start while others had moved there recently. All expressed a wish to achieve a sustainable lifestyle. Two main types of motivation were mentioned, which we term 'community' and 'example'. Though several respondents reported both types of motivation, most of them emphasized one in particular.

The first category, 'community', denotes respondents who said they were primarily motivated by the opportunity to join a community, both to meet other people with shared values, and to get away from conventional society where they found that their attitudes, views, and practices were at odds with or diverged from what was considered 'normal'. The other category, 'example', denotes respondents who used the word 'example' to convey that their motivation for moving to the EV was to demonstrate to others what sustainable living may imply, and to inspire others to do likewise. As we elaborate below, the first type of motivation is directed inwards, while the second draws attention to the role of the EV and mainstream society.

5.1.1. Seeking a Sense of Community

The importance of social belonging was a theme in many of the respondents' accounts. One male respondent (PH1) told us: 'For sure, the dream is to have an environment that one recognizes and feels at ease with.' A female respondent (PH2) provided more details:

> There are people here who don't think you are strange because you make such choices. Because you buy used clothes or don't buy clothes. There is a complete understanding from people who live here. And it helps feeling that people understand you. I have received strange looks and things like that [outside the EV].

Other community-oriented respondents complained about the barriers to sustainable living in mainstream society:

> We are environmentally conscious and think it may be difficult to have an environmentally friendly lifestyle in our society. In that respect, it's no coincidence that we're here. (PH9)

These quotes signal that the respondents had felt uncomfortable or constrained when living in conventional communities, which is why they wanted to move to the EV. People in this group elaborated on different aspects of the community dimension and on what living here meant to them. Some were preoccupied with giving their children a good upbringing in what they termed the 'protective environment' provided by the EV. Others, as PH2 above, said that they found it valuable to meet people who shared the same views as themselves when it came to consumption patterns and other issues. A passion for growing their own food was another highly motivating factor for moving to the EV.

On the issue of spirituality, six of our respondents specifically mentioned that it was important to them that the EV did not place too much emphasis on spirituality. At the same time, some ecovillagers said they appreciated the possibility to practice spirituality without being judged by others in the EV community.

5.1.2. Setting an Example

Some people said that their main motivation for moving to the EV was to "set an example" and actively seek to be pioneers who showed the way for others. They stressed the importance (six out of seven 'examples') of being part of a lifestyle movement that contributed to social change with respect to food consumption, transport, housing, and how people live together. For that purpose, they reflected on how their own activities match the 'normal' criteria set by mainstream society:

> So we thought, okay, we want to try to live a bit more sustainably, or like push and see how far we can go, but at the same time, like, that it's within the four walls of society and within normal boundaries. The good thing about being part of this project is that it's, like, pretty ... easily accessible in that respect. To the general public, too. (PH14)

Hence, in terms of setting an example, the link to society was important and should be actively maintained, as PH14 further elaborated:

> Then there was, at least one of the most important questions to me, was ... to get an impression of whether this was some sort of isolated unit, a little village on its own that took a step away from society to do something different, or if they actually were part of wider society and tried to take part in creating something. (PH14)

5.2. The Developers: The Architect Aktivhus and Contractor Filago

Respondents expressed mixed feelings about the architect and contractor. On the one hand, they expressed admiration for the houses and the contractors: "Innovation takes time, innovation is frustrating" (PH6). They appreciated the physical structure and quality of the housing. Few of them spoke about aesthetics, but many conveyed satisfaction with living in houses built from materials they considered to have a limited environmental impact. Several emphasized the good indoor quality and the direct access to outdoor air through valves rather than having a closed system of balanced ventilation. One respondent with a background in natural sciences said he highly appreciated the fact that the houses were not concealed "aluminium tins", and referred negatively to passive houses. On the other hand, the respondents expressed dissatisfaction with several technical aspects of the houses (particularly in the early Phase 2), and the way in which their complaints were met by Filago, Aktivhus, and subcontractors. Respondents complained about draughts around uneven window frames, cracks in kitchen countertops and yellowing grout. Several also commented that the materials had been processed and shipped from eastern Europe and processed in Denmark—hence transported over considerable distances, with environmental implications.

A common question was: who would be financially responsible when technical problems occurred. Our respondent from Aktivhus underlined that his company was responsible for ensuring that the houses functioned. However, delays in getting things fixed and the lack of response to emails made many residents question this promise and Filago's financial capacity to do the necessary work. Some respondents also doubted whether Filago "is as idealistic as they claim to be". Others were uncertain of what property (the farm and the cultural centre) Filago actually owns today, or were sceptical about Filago's previous involvement with a Czech company that went bankrupt after supplying building materials to the EV. Finally, there was considerable confusion among residents regarding the distribution of responsibilities between the ecovillagers and the three actors on the supply side: Aktivhus (the architect), Filago (the contractor), and various subcontracting firms. One of the points of confusion was that some individuals were said to be working for both Filago and Aktivhus. From the perspective of our respondent from Aktivhus, the shift from Phase 1 to Phase 2 represented a risk, in the sense that the people moving to the EV might lack commitment to engage in joint activities. For example, one year after Phase 2 began, there was uncertainty as to whether the new generation of ecovillagers would be interested in taking part in running the farm and/or establishing new joint initiatives.

The ecovillagers, on the other hand, argued that they did indeed possess the capacity to initiate activities. Most of the interviewed families belonged to at least one of many groups initiated by the ecovillagers (dancing courses, painting courses, wine club, Friday club for women, yoga courses, outdoor recreation, boating groups), and were by default part of the residents' association (*beboerforening*), to which many contributed on a voluntary basis. Though there were some complaints about some individuals being 'free riders' rather than contributing to the common good, our interviewees were more concerned that Filago should relinquish some of its responsibilities.

> I think many people, us included, expected that Filago and Aktivhus would not decide so much. After all, people have come here to discuss things thoroughly. So it kills our enthusiasm a little. (PH3)

> Because people thought they could just start things here. I can shovel snow in the winter, so someone asked Filago if that was ok, and they said they'd already thought about that, so don't bother. So then that person lost all motivation. (PH3)

Hence, there seems to be a mismatch between expectations regarding decision-making, with some residents calling for more independence while Aktivhus and Filago retain control to ensure the project's viability. One woman put it this way: "People don't want to follow [the developer's] dream, but their own dream" (PH3).

5.3. The Local Community

The value of social involvement with the local community was often highlighted by the ecovillagers. Several expressed the importance of maintaining contact with mainstream society to avoid becoming isolated from it.

> But I do hope there will be more ... how can I put it ... sort of integration. Between us and people in the village. I think it's ... well I think it's important. That we don't become some kind of sect. (PH9)

Moreover, it was the outward reach of the EV that had triggered some of the respondents to move to the EV (Section 5.1). Many ecovillagers regarded the *Fremtidssmia* cultural centre and the open courses (in dancing and painting) that were attended by people from Hurdal as a bridge between them and the local population (PH13). One man said he liked to exchange knowledge and gain traditional botanical knowledge in Hurdal (mapping meadow flora, PH14). However, another man remarked that some events were not so suited to the local population because they were too alternative or "very hippy-oriented".

The respondents representing the Hurdal municipality spoke warmly of the EV's influence on the local community, emphasizing the EV's outreach and contributions to the Hurdal Sustainable Valley Festival and to activities involving the local school, where EV residents have taken part in teaching programmes: "Things move faster with their engagement" (HL2). They also expressed concern that not all EV families sent their children to the local school and stressed that Hurdal should be 'a place in which people can dwell, live and work' referring to the municipal strategy 2010.

Like the municipality employees, ordinary residents in Hurdal also acknowledged what they considered to be positive contributions of the EV. They pointed to the attention Hurdal had received nationally as a result of the EV, making Hurdal more visible:

> How clever they've been in receiving all kinds of people, and that has opened, I mean, it's put Hurdal clearly on the map right from the start, so there have been people from all over the world, and they've been here and worked for free. (HL4)

However, local satisfaction with the EV for it putting Hurdal on the map did not erase former, local markers of identity. The notion of *Huddøling* (meaning a native of Hurdal) came up in interviews with local residents. They emphasized that in order to be a *Huddøling*, one had to be born there, and hence, it would be hard for anyone moving to the village to acquire this label. Despite 30 or even 50 years of living in Hurdal, an Oslo-born resident may still experience being excluded from certain social networks: "You are and remain an immigrant, in a way" (HL1).

The local respondents gave vivid accounts of the transition from Phase 1 to Phase 2, and of their perceptions of the radical change that occurred in the kind of people that came to live in the EV over the years.

> But all the first houses they built down on the farm courtyard, they were those straw houses covered with concrete on the outside, and that's eco ... eco ... well, the beginning, in a way. And then ... then we saw it for years ... that those who were living there, it was all foot-shaped shoes and lilac scarves and thinking how living in the countryside was all lovely and cosy, everything had to be cultivated and ... they nearly froze to death in the winter. (HL3)

Other comments about the first phase of the development of the EV included questions about the ecovillagers' financial capability: "You can't make a living from eating apples and carrots" (HL3); and about their lack of hygiene and tidiness: "The children were dirty and had problems at school" (HL1). However, local inhabitants also acknowledged the increase in economic activity that the EV had brought to the area and regarded this as a shift in relations towards greater 'reciprocity' (HL4).

Some local inhabitants also reported how some ecovillagers caused feelings of inferiority within the local community: "They're posher than us" (HL1). Strengthening this impression of a hierarchy, local residents highlighted that the EV residents now had proper jobs and were living in "nice houses worth three million kroner upwards, more than other houses in Hurdal".

6. Discussion

6.1. Positioning Hurdal EV in the Global Ecovillage Community

The concept of Hurdal EV, despite its young age, changed radically as the initiative moved from infancy (Phase 1) to early adulthood (Phase 2). Our empirical material was collected during Phase 2, but secondary sources [31] and accounts of the shift indicate that the first project largely resembled the four-pillar concept observed in other EVs across the globe [16]. In the current phase (Phase 2), the shared values of the actors involved appear to be less settled and less comprehensive, and most of the newcomers display a diversity of perspectives on and motives for joining the EV. However, both the developer and most of the ecovillagers tend to place a strong emphasis on environment (pillar) and community (pillar) as joint values in Hurdal EV. In doing so, they create and reproduce some key connections while living in the EV, both to the environment and to each other as a community.

As for the third pillar often associated with EVs, namely, economy, this aspect has less explicit connotations in Hurdal EV today than what has been observed elsewhere, where "the purpose of the economy is to promote human wellbeing within the limits of finite ecosystems" [16] (p. 78). Primary production (e.g., of food) constitutes an important economic element, as does sustainable consumption. However, in Hurdal EV, food production was not (at the time of data collection) a joint enterprise, but rather, was maintained either by the developer (Filago owns the farm) or by some individuals. In 2016 a preliminary community-supported agricultural scheme (CSA) was introduced to test whether this model would be suitable for organising the production of vegetables on the farm. With 30 members in 2016, the farm management and the CSA members embraced the model, and in

2017 all vegetables were grown by the CSA, which today consists of 116 members, mainly ecovillagers (personal communication, General Manager, Hurdal Ecovillage, 21 September 2017). Moreover, the system of individual ownership of houses has meant that the collective economy component of sustainable living in Hurdal EV is far less articulated than in many other EVs.

Regarding the fourth pillar of EVs, spirituality or consciousness [16], the present Hurdal EV declares itself publicly as a secular community. Although several interviewees explained that they were regularly involved in spiritual activities such as yoga and meditation, they all refuted suggestions by external individuals (such as the researchers) that spirituality was a central, shared dimension of their community. In official documents [36], Norway is characterised as a pluralist society (*det livssynsåpne samfunnet*) where many religions and practices coexist. Religious activities in Norway are considered to belong to the private sphere, and are less organised than before [37]. By regarding spiritual activities as private matters, Hurdal EV has adopted a stance on spirituality similar to that of mainstream society. In conclusion, Aktivhus, Filago, and the ecovillagers in Hurdal EV all strongly articulate the dimensions of environment and community, which become their markers of distance to the mainstream society, while the other two pillars (economy and consciousness) constitute more individualised spheres of practices, and represent less prominent parts of the community.

Moving from Phase 1 to Phase 2 implied adopting a more pragmatic approach to the values and principles guiding the EV. As Boyer [3,4] and Smith [5] point out, intermediate niche projects that lie between radical movements withdrawn from mainstream society and ones that are too much in line with it, are those with the highest chance of success. The pragmatic approach guiding the second phase of the development of Hurdal EV might be a successful recipe for translating EV practices to mainstream society (cf. [4]).

6.2. Translating Niche Practices to Mainstream Society: Pragmatism as the Way Forward

The presented material provides an account of how a Norwegian EV was created and recreated. We started off with the premise that there might be multiple discourses, practices, and identities within the EV, and that the ecovillagers' collective identity might also be influenced by the perceptions and activities of outsiders, such as the local population in the Hurdal Valley, who provide 'alternate versions' [10] of what the EV is. After scrutinising the various types of relationships involved in this process, we are now in a position to discuss how social boundaries and identities played out in the process of creating the EV. Because Hurdal EV has gone through two radically different phases, its story is particularly revealing in terms of illustrating how the concept of an EV may change. The case of Hurdal EV demonstrates the relational nature of the ecovillage as a project and locus for identity construction, heavily informed through interaction with the outside world. The outside world has notably changed during this period.

The most striking shift in relations has been the way in which the local population perceives the EV, shifting from hostility to admiration. In the first phase, the relationship was highly distanced, and perceptions of 'dirty children' evoke associations with impurity and social danger [38]. By contrast, today's local population expresses admiration for and sympathy with the EV, and in some cases, even a sense of inferiority vis-à-vis the ecovillagers. The most decisive moment in this transformation was when the project abandoned the experimental architecture resembling traditional ecological architecture and replaced it with ready-made housing. This shift in the choice of 'cultural artefacts' [10], or material representations of the EV, significantly changed local perceptions of the EV, and also how ecovillagers perceived themselves. This illustrates how modifications to niche practices may influence perceptions of the EV in mainstream society, and thereby, potentially increase the likelihood of EV practices translating and diffusing into mainstream society (cf. the second type of translation of practices between niches and mainstream society outlined by [4,5]). In this process of 'moving closer together', the EV nonetheless needs to maintain a certain level of distance from mainstream society in order to sustain its identity. In this connection, we found some variation in opinion amongst the ecovillagers in terms of how they wished to relate to the outside world.

All ecovillagers shared the basic value of environmental sustainability and wished to become socially engaged in a larger group of like-minded people. However, when we probed further into their motivation for moving to the EV, two main types of rationale appeared in people's arguments and reflections: community orientation, and setting an example. These two categories are not always mutually exclusive, and to some they may constitute conflicting concerns. Interestingly, in both cases, mainstream society serves as the reference point, albeit in different ways. The community-oriented rationale implied moving to Hurdal EV in order to *get away* from the criticism in their former neighbourhoods. For example, they wanted to be able to keep chickens or grow carrots without being judged by others. By moving to the EV, community-oriented individuals created distance between themselves and mainstream society. They became typical inhabitants among equals rather than outcasts.

The other type of rationale implied a wish to set an example for sustainable living. This goal fits explicitly with perceptions of EVs as a lifestyle movement that actively seeks to promote social change [19] (p. 2). Individuals who emphasized this rationale cherish *continuity* with their former external relationships and networks, and seek to *influence* mainstream society. They underlined that the EV was not a sect, that the houses were very comfortable to live in, and that they were fortunate to be close to Oslo so that people could visit. Hence, their external networks, including the local population in Hurdal, are important witnesses to their self-creation: progressive, responsible people who have managed to merge their sustainability ideals with comfortable living. To distance themselves (and the EV) from being judged as too alternative, they spoke critically about practices associated with the EV in Phase 1, such as straw-bale houses, sects, and spiritual practices. Protagonists of the 'example' rationale expressed the need to display a collective identity that was normal enough for mainstream society to be willing to adopt their lifestyle. At the same time, as pioneers or early adopters in a sustainability market, they are likely to enjoy social esteem from their wider social networks [39]. Hence, the pragmatism inherent in the strategy of setting an example for sustainable living moved Hurdal EV towards being an intermediate project, i.e., what Boyer [4] identifies as a success factor for translating practices between niches and the mainstream. The two main types of motivation are guided by perceptions of the environmental problems inherent in mainstream society, and in both cases, these represent the core principles for establishing the EV [5].

Seemingly positioned at the steering wheel in the endeavour to create an EV according to their vision, we find Aktivhus (the architect) and Filago (the contractor). They expressed a clear intention to influence mainstream society and to be part of a lifestyle movement resembling our group of 'examples'. The translation of sustainability practices from this niche to mainstream society is an expressed goal, and Hurdal EV is perceived as the start of a larger project in Norway. The enduring contact with the municipality in order to transform Hurdal into 'Sustainable Valley' in the long term confirms this ambition, and also confirms the arguments of Feola and Nunes [9] and Seyfang [6] on the importance of the local context. The interactions between the municipality and Hurdal EV have facilitated its development, both through the efforts made by the municipality to plan for the village, and through their mutual interest in promoting Hurdal as a Sustainable Valley.

However, the developers face a challenge in handling the internal diversity in aspirations. The most articulated tension between the developers and the ecovillagers was the issue of the farm in terms of who should own it and be responsible for operating it. While the developers seemed hesitant about surrendering control to the ecovillagers, the latter group called for more responsibility. Finally, the developers worry that the ongoing provision of ready-made houses in the open market will attract people to the EV who are not committed to sustainability. Hence, while wanting to be part of a lifestyle movement, the developers also expressed concern that the distance between the EV and mainstream society may dissolve. The risk involved in this balancing act was that of losing one's EV identity. From this perspective, Hurdal EV has moved closer to mainstream society in terms of demonstrating how to live a sustainable life in a comfortable way. This corresponds with what has been termed the *fourth wave of intentional communities*, in which members increasingly attempt to become integrated with mainstream society rather than escape and become alienated from mainstream culture [7]. At the same time, the wider community has changed, becoming more attuned to the values and practices that constitute important principles for Hurdal EV. In Norway, sustainability is increasingly accepted as an important policy dimension, and concerns for climate change seem to be generating a growing number of initiatives for developing novel, more eco-friendly solutions [40]. This clearly illustrates how a pressing societal problem, sustainability, has altered the context by moving mainstream society closer to the niche, and hence, facilitating the translation of practices between them [5].

As mentioned above, Sørensen [26] suggests that the mainstreaming process in ecological architecture is more conceptual than innovative and practical, and that this field is still dominated by small-scale, locally-controlled activities using an experimental approach. However, the presented material on how Hurdal EV developed from the first to the second phase demonstrates that this mainstreaming process was not only conceptual, but also practical and technological. The EV adopted some norms held by mainstream society, and the interactions between the EV and mainstream society modified niche practices. Figure 4 below illustrates the translation process by which Hurdal EV and mainstream society have approached each other.

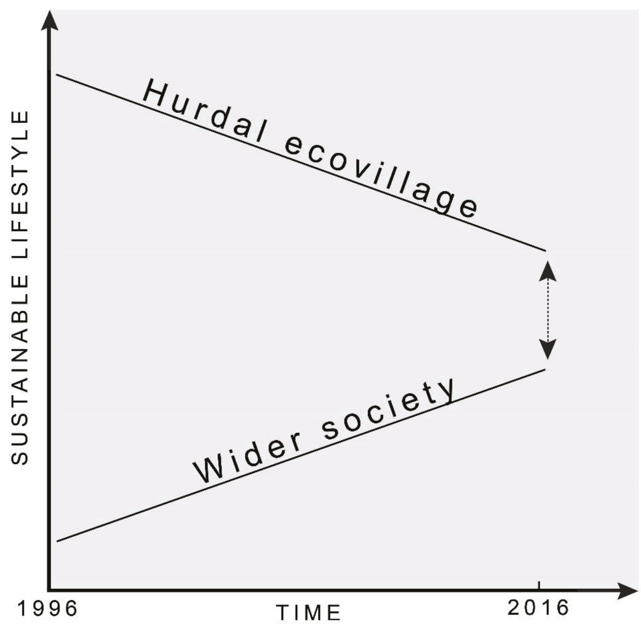

Figure 4. The relationship between Hurdal EV and mainstream society.

In the early days of the movement, there was a large discrepancy between the ecovillagers' values and lifestyle and those of mainstream society. As Smith [5] and Boyer [3,4] argue, the ability to translate practices from this niche to the mainstream might have been restricted because the lifestyle of the EV might have appeared too radical for mainstream society. Today, this gap has narrowed. Mainstream society has not necessarily become more sustainable. Although sustainable practices (such as driving electric vehicles) are increasingly being adopted, so too are unsustainable ones (such as air travel). But several sustainable practices, such as eating less meat, are now considered less radical than before. The EV concept has been modified to constitute a pragmatic and attractive sustainable alternative to mainstream society because it is not beyond reach, but rather, draws on a mix of values in terms of sustainability, comfort, and aesthetics that are widely shared. Some distance remains between the ecovillagers and mainstream society (illustrated by the gap in the figure in year 2016 (the year of data collection). Both internal and external forces are currently seeking to close that gap, but at the same time, it is crucial to ecovillagers to maintain a distance and an identity if the EV is to survive as an alternative to conventional living and also be able to push towards more sustainable lifestyles in mainstream society [4,5].

7. Concluding Remarks

In this paper we have examined how the actors involved in Hurdal EV have interacted over time and contributed to shaping the ecovillage. The study shows how the ecovillagers have sought to maintain a distance between themselves as a group and the wider community while balancing the various values and practical implications of living in accordance with such values. It demonstrates how the ecovillage as a concept is changing, both internally within the ecovillage community and vis-à-vis mainstream society. The different phases of developing Hurdal EV illustrate the importance of adopting an intermediate project [4,5] for translating practices from a niche—such as the EV project—to mainstream society. Adopting a pragmatic approach towards developing the EV, as was done in the second phase of Hurdal EV, is at least one element for success in this translation process.

The journey towards this more pragmatic strategy for developing Hurdal EV also involved modifying the pillars on which it was built. Only two of the four pillars of EVs [16] are clearly embraced by the Hurdal ecovillagers in the second phase of the development: community and eco-friendly living. The economy and consciousness pillars tend to be played down and kept more private. Most of the ecovillagers come to the EV to enjoy community life and share their interest in leading an eco-friendly lifestyle. Some of them openly emphasize a wish to contribute to a lifestyle movement where their practices and ideas lead to social change. Others have a more inward orientation. When living in their previous neighbourhoods, the ecovillagers we met had sometimes experienced disapproval of their lifestyle, but in the EV they did not encounter such social sanctions. Despite their somewhat different emphases, however, they are all participants in a lifestyle movement, promoting private action towards social change, and cultivating a meaningful identity [19].

The adoption of a more pragmatic strategy in the second phase of the project has narrowed the gap between the EV and mainstream society. In the beginning, the EV inhabitants were largely isolated from the local community and were looked upon as odd. However, by mainstreaming the EV concept and practices through revising ecological architecture and streamlining a top-down process for promoting, constructing and selling houses, and recruiting new ecovillagers, Hurdal EV earned more esteem and acceptance for their values and practices from mainstream society. Moreover, the increasing general acknowledgement of environmental problems contributed to normalising the EV. In this process, the ecovillage as a concept was modified by different stakeholders and outsiders who contributed to the negotiations about what the EV should be.

This study clearly confirms the argument put forward by Smith [5] and Boyer [3,4] that the success of translation hinges on intermediate, bridging projects. Correspondingly, we find that Hurdal EV's pragmatic choices and adjustments to move closer to mainstream society facilitated a bridging between the EV as a niche and mainstream society. It also illustrates the perceived risks associated with the EV should it move too close to mainstream practices, as losing its identity would also mean losing its ability to promote an alternative to mainstream lifestyles. Where this line should be drawn is contextually dependent and therefore dynamic, and involves work that is both inwardly and outwardly directed. What would too mainstream a practice entail for its ability to foster social change?

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Appendix A

Table A1. The two phases of Hurdal EV.

	First Phase (1996–2009)	Second Phase (2009–2017)
Physical buildings	Self-construction, traditional ecological architecture.	Ready-made units, modern ecological architecture including advanced technology.
Community markers	Every member had a say in joint decisions.	Individual homes: individual decisions Farm: owned by Filago, lack of clarity regarding decision-making in the future. Shared social activities, some also open to people outside the EV.
Environmental values	Clearly expressed	Clearly expressed
Spirituality	?	Not a shared value
Position of municipality vis-à-vis the EV	Took initiative to collaborate.	Highly engaged in collaboration.
Position of local population vis-à-vis the EV	Distanced	Admiration

References

1. Forster, P.; Wilhelmus, M. The role of individuals in community change within the Findhorn intentional community. *Contemp. Justice Rev.* **2005**, *8*, 367–379. [CrossRef]
2. Sargisson, L. Strange Places: Estrangement, Utopianism, and Intentional Communities. *Utop. Stud.* **2007**, *18*, 393–424.
3. Boyer, R.H.W. Grassroots innovation for urban sustainability: Comparing the diffusion pathways of three ecovillage projects. *Environ. Plan. A* **2015**, *47*, 320–337. [CrossRef]
4. Boyer, R.H.W. Intermediacy and the diffusion of grassroots innovations: The case of cohousing in the United States. *Environ. Innov. Soc. Transit.* **2018**, *26*, 32–43. [CrossRef]
5. Smith, A. Translating sustainabilities between green niches and socio-technical regimes. *Technol. Anal. Strateg. Manag.* **2007**, *19*, 427–450. [CrossRef]
6. Seyfang, G. Community action for sustainable housing: Building a low-carbon future. *Energy Policy* **2010**, *38*, 7624–7633. [CrossRef]
7. Ergas, C. A Model of Sustainable Living: Collective Identity in an Urban Ecovillage. *Organ. Environ.* **2010**, *23*, 32–54. [CrossRef]
8. Nicolosi, E.; Feola, G. Transition in place: Dynamics, possibilities, and constraints. *Geoforum* **2016**, *76*, 153–163. [CrossRef]
9. Feola, G.; Nunes, R. Success and failure of grassroots innovations for addressing climate change: The case of the Transition Movement. *Glob. Environ. Chang.* **2014**, *24*, 232–250. [CrossRef]
10. Holland, D.; Fox, G.; Daro, V. Social movements and collective identity. *Anthropol. Q.* **2008**, *81*, 95–126. [CrossRef]

11. Barth, F. Introduction. In *Ethnic Groups and Boundaries*; Barth, F., Ed.; Waveland Press Inc.: Long Grove, IL, USA, 1969; pp. 9–38.
12. Kozeny, G. Intentional communities: Lifestyles based on ideals. In *Fellowship for Intentional Communities, Communities Directory: A Guide to Cooperative Living*, 2nd ed.; Kozeny, G., Sandhill, L., Eds.; Fellowship for Intentional Community: Rutledge, MO, USA, 1995; pp. 18–24.
13. Smith, W.L. Intentional communities 1990–2000: A portrait. *Mich. Sociol. Rev.* **2002**, *16*, 107–131.
14. Kanter, R.M. *Commitment and Community*; Harvard University Press: Cambridge, MA, USA, 1972.
15. Litfin, K. From me to we to thee: Ecovillages and the transition to integral community. *Soc. Sci. Dir.* **2013**, *2*, 64–78. [CrossRef]
16. Litfin, K. *Ecovillages: Lessons for Sustainable Community*; Polity Press: Cambridge, UK, 2014.
17. Kaspar, D.S. Redefining Community in the Ecovillage. *Hum. Ecol. Rev.* **2008**, *15*, 12–24.
18. Kirby, A. Redefining social and environmental relations at the ecovillage at Ithaca: A case study. *J. Environ. Psychol.* **2003**, *23*, 323–332. [CrossRef]
19. Haenfler, R.; Johnson, B.; Jones, E. Lifestyle Movements: Exploring the Intersection of Lifestyle and Social Movements. *Soc. Mov. Stud.* **2012**, *11*, 1–20. [CrossRef]
20. Dobernig, K.; Stagl, S. Growing a lifestyle movement? Exploring identity-work and lifestyle politics in urban food cultivation. *Int. J. Consum. Stud.* **2015**, *39*, 452–458. [CrossRef]
21. Seyfang, G.; Haxeltine, A. Growing grassroots innovations: Exploring the role of community-based initiatives in governing sustainable energy transitions. *Environ. Plan. C Gov. Policy* **2012**, *30*, 381–400. [CrossRef]
22. Ornetzeder, M. Old technology and social innovations. Inside the Austrian success story on solar water heaters. *Technol. Anal. Strateg. Manag.* **2001**, *13*, 105–115. [CrossRef]
23. Sargisson, L. Second-wave cohousing: A modern Utopia? *Utop. Stud.* **2012**, *23*, 28–56. [CrossRef]
24. North, P.; Longhurst, N. Grassroots localisation? The scalar potential of and limits of the 'transition' approach to climate change and resource constraint. *Urban Stud.* **2013**, *50*, 1423–1438. [CrossRef]
25. Sager, T. Planning by intentional communities: An understudied form of activist planning. *Plan. Theory* **2017**, *17*, 1473095217723381. [CrossRef]
26. Sørensen, K.H. From 'alternative' to 'advanced': Mainstreaming of sustainable technologies. *Sci. Technol. Stud.* **2015**, *28*, 10–27.
27. Berker, T.; Larssæther, S. Two exemplar green developments in Norway. Tales of qualculation and non-qualculation. In *Actor Networks of Planning. Exploring the Influence of Actor Network Theory*; Rydin, Y., Tate, L., Eds.; Routledge: Abington-on-Thames, UK, 2016; pp. 95–110.
28. Ryghaug, M. Miljøarkitektur: Fra grav til vugge? In *Mellom Klima og Komfort. Utfordringer for en Bærekraftig Energiutvikling*; Aune, M., Sørensen, K.H., Eds.; Tapir Akademiske Forlag: Trondheim, Norway, 2007; pp. 217–232.
29. Ryghaug, M. Towards a Sustainable Aesthetics: Architects Constructing Energy Efficient Buildings. Ph.D. Thesis, Norwegian University of Science and Technology, Trondheim, Norway, 2003.
30. Halvorsen, R. Kilden Økosamfunn. *Samfunnsliv*, 20 June 2003; p. 1.
31. Miller, F.; Torp, S. 10 økolandsbyer på 10 år i Norge. Report Supported by the Norwegian Ministry of Climate and Environment, Oslo, Norge, 2003. Available online: http://okosamfunn.no/wp-content/uploads/10-okolandsbyer-paa-10-aar-i-Norge.pdf (accessed on 17 September 2017).
32. NRK. Økolandsbyen. (A Documentary on Hurdal Ecovillage in Four Parts). Norwegian Public Broadcasting Corporation, 2015. Available online: https://tv.nrk.no/serie/oekolandsbyen (accessed on 20 September 2017).
33. Bærekraftsdalen. Available online: http://www.sustainablevalley.no/ (accessed on 9 September 2018).
34. Gaia Arkitekter. Available online: http://www.gaiaarkitekter.no/ (accessed on 6 February 2017).
35. Om Aktivhus. Available online: https://www.aktiv-hus.no/page-om/ (accessed on 22 February 2017).
36. NOU. Det Livssynsåpne Samfunn—En Helhetlig Tros- og Livssynspolitikk. NOU 2013:1, 2013. Available online: https://www.regjeringen.no/no/dokumenter/nou-203-1/id711212/ (accessed on 13 September 2017).
37. Taule, L. Norge—Et sekulært samfunn? *Samfunnsspeilet* **2014**, *1*, 9–16.
38. Douglas, M. *In the Active Voice*; Routledge & Kegan Paul Ltd.: London, UK; New York, NY, USA, 1982.

39. Pantzar, M. Domestication of Everyday Life Technology: Dynamic Views on the Social Histories of Artifacts. *Des. Issues* **1997**, *13*, 52–65. [CrossRef]
40. Wang, L.; Westskog, H.; Selvig, E.; Mygland, R.; Amundsen, H. *Kortreist Kvalitet. Hva Betyr Omstilling Til et Lavutslippssamfunn for Kommunesektoren?* KS FoU-Prosjekt nr. 154025; Norwegian Association of Local and Regional Authorities (Kommunenes Sentralforbund): Oslo, Norway, 2016.

sustainability

MDPI

Review

Smart Villages: Comprehensive Review of Initiatives and Practices

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Abstract: Over recent decades, people's (rural and urban) communities are facing numerous social and economic changes and challenges. Some of those challenges have been increasingly addressed through the lenses of technological developments and digitalization. In this paper, we have made a review of already existing practices while focusing on the existing implementations of the Smart Village concept and the importance of digital transformation for rural areas. We give special attention to EU policies that we are using as an already existing framework for understanding our own forthcoming examples. We have shown the parallels between the findings and insights from different regions and made an evaluation of presented practices. Our main argument stems from our own previous experiences and experiences of other research approaches, and is grounded on the argument that rural areas are not uniform, and that smart rural development has to be applied in combination with place-based approach. We present the cases of Slovenian pilot practices and support our argument by proposing the FabVillage concept.

Keywords: Smart Villages; smart development; sustainability; digitalization; ICT

1. Introduction

One of the most important and accurate questions that contemporary societies have to address is how to make people's communities and their settlements more sustainable. An ever growing number of aspects of most societies and their economies are inextricably linked to changes brought forward by technological developments that are transforming people's everyday routines, perceptions of the environment, access to the electricity, food, health, education and many other. To properly address those changes in 2015, the 2030 Agenda for Sustainable Development (the so-called #Envision2030) was adopted by the General Assembly of the United Nations, and it included seventeen Sustainable Development Goals (SDGs) [1]. As will be detailed later on, the agenda took a holistic approach to sustainable development for everyone and in every segment of life, including education, employment, inequality, accessibility of settlements, etc.

One part of the answer towards achieving higher levels of sustainability and SDGs is to find the right ways on how to deal with economic disparities, climate changes, accessibility to modern technologies and other necessary infrastructure. Considering the (dis)advantages of some already existing practical approaches, one of the most promising ways is to make them smart(er). Disregarding the somehow vogue meaning of the "smartness" in general [2,3] that will be explained later on, it is important to note that the concept for urban smart communities is already very well established—e.g., Smart Cities, but less so for rural communities as the concept Smart Village has only recently gained momentum; for example, in the EU, the Smart Village Initiative was launched by the European Parliament in 2017, and the EU Action for Smart Villages document was published by the European Commission together with the European Parliament. Moreover, 'Smart Villages' was initiated as a subtheme within the European Network for Rural Development (ERND) work on 'Smart and competitive rural areas' between September 2017 and July 2018 [4].

The main objective of this paper is to review and discuss already existing initiatives and projects on rural development and especially in Smart Villages in Europe and beyond. In order to understand the influences of smart development and how communities embraced it, it is necessary to make a review of the practices, policies and initiatives. Only then we can use and apply the concept into new environments more successfully.

What Is a Smart Village?

The so-called smart development of infrastructure is hardly strictly divided into two polarized sets of frameworks, rural and urban. As is vividly described by Srivatsa [5] in the case of Indian smart development, it is necessary to consider both spaces simultaneously, their mutual interconnections and take into account that significant changes in one will affect the other and another way around. Therefore, the paper considers both contexts and combines the findings from the two.

What exactly do we mean by talking about smart development, Smart Cities or Smart Villages? Is there any clear definition of a smart community?

Firstly, no, there is not one clear and definite definition of neither one [6]. As communities are not a "thing", inanimate and unchangeable, and are thus always dependent of the environment and changes in socio-cultural structures, there cannot be a one-size-fits-all proposed definitions. Every proposed definition is dependent upon different circumstances, societal problematics and reflects difficulties encountered by each individual community. For example, discussing the smart growth plans in Wisconsin, USA, Edwards and Haines define six smart growth goals that were most widely incorporated into smart growth plans in the Wisconsin case. In their contribution, they emphasize (i) creating new housing choices and opportunities; (ii) making communities more accessible by foot; (iii) enforcing the sense of place in communities; (iv) preserving different environmental zones; (v) connecting new and the existent developmental aims; and (vi) more varieties in terms of transportation [3]. On the other hand, the European Union is moving towards the application of the "smart" growth on the wings of a "knowledge based economy" [7] (pp. 56–58).

Secondly, even though the implications of technologies are often used in discourses on smart communities, the technological and digital components of the transformation are not the only ones, not necessarily the most important in specific cases. Annamária Orbán is making a report on smart and self-sustaining rural villages in Hungary on the example of Túristvándi, a small village that began its journey towards the label 'Smart Village' in the field of agriculture and with the decision to become self-sufficient in food production [8] (pp. 678–680). On the basis of smart/successful agricultural decisions, the education level of the village inhabitants has increased, the population has grown, and health services improved. As is claimed by Jucevičius et al. [2], a more detailed and comprehensive analysis of initiatives and practices of smart social system brings to the fore the important finding that, while looking at the smart system, it is not always the case that they are grounded on the information and communication technologies (ICT). In the proposed model, instead, they are focusing more on the relationships with the environment. However, even though the digital dimension does not pervade all the models of the Smart Cities/Villages and its main features, it is indeed important to all of them [9] (p. 149).

Thirdly, and stemming from the above claims, the smart dimension of the development might not always be addressed under the label "smart" but could also be intertwined with other dimensions, as in the case of SDGs where the smart dimension is addressed in most of them addressing other specific aspects: sustainability, well-being, (inclusive and equitable quality) education, empowerment of women and girls, management of water resources, accessibility of sustainable energy, sustainable economic growth and decent work, building resilient infrastructures, fostering innovation, reducing inequalities, making human settlements more inclusive and sustainable, taking actions to combat climate change, protecting ecosystems, etc. [1].

Slipperiness of trying to precisely define the smart development per se allows us to propose only vague, very broad definitions of smart communities. This is so because the classifications are always case dependent and based on given, specific conditions (e.g., locality, geographical conditions, (social and natural) resources) and influenced by the most visible challenges that communities face [10] (p. 177).

A Smart City is an urban living environment, built or upgraded/renovated [9] to enable the best possible coordination for otherwise fragmented urban sub-systems, and to facilitate everyday lives of inhabitants, making cities more liveable and sustainable [11]. A very broad definition proposed by Cohen states that "smart cities use information and communication technologies (ICT) to be more intelligent and efficient in the use of resources, resulting in the cost and energy savings, improved service delivery and quality of life, and reduced environmental footprint—all supporting innovation and the low-carbon economy" [10] (p. 178). The most representative features of the Smart City are shared ICT structures, time optimization, open government, energy efficient technologies, reduced emissions, and orientation towards green environment [6,12,13].

If the transition to smart infrastructure is important for urban living environments, this transition is even more necessary and complex in the case of more sparsely inhabited areas. To identify challenges and their potential solutions in this cases, it is necessary to use local and regional knowledge and implement it. More precisely, in the context of European Union, the concept Smart Villages refers to "rural areas and communities which build on their existing strengths and assets as well as on developing new opportunities. In Smart Villages, traditional and new networks and services are enhanced by means of digital, telecommunication technologies, innovations and the better use of knowledge for the benefit of inhabitants and business" [14]. To sum up, to apply the Smart Village concept, it is necessary to use bottom-up integrated approaches, build effective public-private-community partnerships, develop supportive policy frameworks and enable access to financing mechanisms [15]. The crucial point in the process is to put the communities themselves behind the steering wheel and not impose developmental paradigms that would not be compatible with community's desires and cultural environments.

A Smart Village enables its inhabitants to make use of the contemporary technological and social achievements, while its infrastructures are still being developed in line with Sustainable Development Goals, offers an opportunity to efficiently deal with future of energy security and issues of local and circular economies. However, as it will be shown later on in the case of Indian Smart Cities and Smart Villages, to treat Smart Villages as an autonomous and independent entities poses a threat to only partial understanding of the framework. Instead, the interspatial dimension is of great importance. Therefore, this paper, although focusing primarily on the smart rural development and Smart Villages' initiatives, constantly draws the parallels with Smart Cities, towns and national developmental policies. Within the smart development discourse, at the forefront of this paper will be the consideration of the perspectives of the digital transformation of the rural environments.

2. Worldwide Initiatives on Smart Villages

Seen in the worldwide context, there are several initiatives promoting or using the concept of the Smart Villages.

Smart Village initiative: new thinking for off-grid communities worldwide [16] and IEEE Smart Village: Empowering off-grid communities [17] are both worldwide active and striving to meet the SDG 2030, especially goal 7, Affordable and Clean Energy. The first one promotes access to sustainable energy as a main catalyst for the development of good education and healthcare systems, access to clean water, sanitation, economic growth, enhanced security, gender equality, etc. The most important vision of the Initiative is to apply more holistic and integrated approaches to enable the access to the energy in the rural contexts, while connecting/involving governments, developmental and private sector in the process. The component most emphasized is how to connect renewable sources of energy with ICT [15]. The activities of the Initiative are taking place in six large regions, namely East Africa, West Africa, South Asia, South-East Asia, South America, and Central America, Caribbean, Mexico—the so-called developing world with limited possibilities to access (educational, electrical, economic and other) infrastructure. To find the most suitable solutions, there is a wide range of professionals working on the field and otherwise: villagers, NGOs, development organizations, entrepreneurs, policy makers, engineers, and experts from the field of humanities [18]. Their search for solutions is encompassing and, based on long-term research, analyzing local and regional circumstances, identifying cross-cutting issues and proposing suitable solutions. More than 30 workshops have been organized where more than thousand stakeholders from 70 countries have presented their views and evidence [16] (p. 140). By now, the majority of their activities was funded by Cambridge Malaysian Education and Development Trust and Malaysian Commonwealth Studies Centre.

Similarly, the IEEE Smart Village initiative is aiming to promote off-grid communities through education and the creation of sustainable businesses in the energy sector. The initiative was originally established as a Community Solutions Initiative (2009) and took over the current name in 2014. The activities are spread worldwide, by now serving more than 50,000 people, living in 34 villages, mostly located in African continent (e.g., Benin, Cameroon, Kenya, Malawi, Namibia, Nigeria, South Sudan, Zambia), but also in Haiti and India [19]. Its main financing mechanism is fundraising. Besides the development of energy-smart villages mentioned before, the main products of the initiative's efforts are a SunBlazer II—a mobile solar-based power base station and Learning beyond the Light Bulb—a nine-month program of remote study that enables the exchange of practices of all communities in order to create the mutual benefit, and equips the students with knowledge on different development models and other skills and knowledge needed for the fieldwork.

One of the most propulsive worldwide programs is the CIGAR research program on Climate Change, Agriculture and Food Security (CCAFS) that started in 2011 [20,21]. The program is funded by the CIGAR fund and different donors (e.g., Australia, Irish Aid, Netherlands, New Zealand, Switzerland, Thailand, UK Aid, US Aid, the EU, and the International Fund for Agricultural Development). Within its framework, the concept of Climate Smart Villages is being developed and put into practice in different parts of the world, whereas the ones with the most climate-related difficulties are chosen (West and East Africa, Latin America, South and Southeast Asia). This is an ever evolving program where different stakeholders (researchers, politicians, framers, local residents) are collaborating in order to find the most productivity enhancing and smart solutions considering the local conditions. Their solutions are based on smart technologies and services, designed in collaboration with local people, and aim at lessening the climate footprint from the perspective of the developing agricultural activities, while not reducing their benefits for the given community. The program is claimed to be very successful, as there is more than 30 existing climate-Smart Villages all over the globe. More importantly, the villages are on a good track to being sustainable in the long term as the program aims to train the local people and not providing locals with the external teachers on the long-term basis. Within this objective, an important role is also played by women. One of the other practical outputs of the program is, for example, the CCAFS Climate Analogues Tool for making rain and climate predictions, developed to help smaller farmers make decisions based on accurate information [22].

Perhaps one of the most extensive and most recent attempts of smart transformation development is India. Firstly, urbanization of India is increasing rapidly as never before. According to the predictions of the United Nations, by 2050, almost 814 million of Indian people will live in towns and cities, which is twice as many as today [10]. Secondly, in 2015, the Government of India, Ministry of Urban Development launched a nationwide program Smart city mission [23]. The aim of the Mission is the comprehensive development of (physical, institutional, social, economic) infrastructure, and thus improvement of the quality of life and to attract people and investments. The governmental mission covers 100 cities, selected in the "City Challenge" process, but also recognizes that there is no single definition of the Smart City that would encompass important factors for all the different cases and therefore aims to set the examples that could be replicated in various regions and cities within the country. Thirdly, a Smart City initiative was supplemented by the Indian Smart Villages Initiative [24] aimed at harnessing the benefits of ICT for the people living in the rural sites. Despite the urbanization processes, in India, around 67% of population still lives in the rural areas, but rural-urban migrations are posing big problems in India [5] (p. 4). For example, according to the estimates of Indian Ministry of Statistics and Programme Implementation, in years 2009/2010 more than 60% of the male rural-urban migrations was due to employment related reasons. Agriculture only has a minor part in the Indian economy (e.g., around 17%), compared to the services sector that is flourishing (almost 54%) [25]. As it has been stated by Srivatsa, to somehow maintain the "equilibrium" between the urban and rural areas, the smart development of both has to be parallel and simultaneous. In this way, the large migration from rural to urban areas can be limited or even stagnate [5] (p. 4). It is anticipated that carefully designed Smart Villages will provide a basic framework for local people to enhance their participation on a local level and to improve their economic, social and living conditions and thus make their community stronger and more flexible for the challenges of the outside world [5] (p. 8). Within the "Digital India" plans, Indian government envisages that, by the year 2019, 250,000 Indian villages will have access to the internet and telecommunications networks [26]. Therefore, there is a need to design and develop villages that have established good endo- and exogenous connections, e.g., they have good connections to the outside world, but, at the same time they maintain their independence in providing employment and services. To summarize, in the Indian case, two approaches are used as being complementary, Smart Villages serving as engines to Smart Cities' economic growth, by producing services and goods for rural but also for wider (inter)national markets. Unfortunately, there is no synthesis on how many Smart Villages has already been developed/ established in India, there are only some fragmented lists and websites dedicated to specific villages, which makes it difficult to keep up with the numbers.

A closer look at the initiatives working at the worldwide level presented above enables us to make some very broad conclusions. Looking at the main objectives and activities taking place within their frameworks, but also regarding some other reports [27,28] and models, the energy sector lies at the core of dealing with sustainable and smart community development. Even though the focus on sustainable energy supply is not explicitly in the forefront of the global developmental initiatives, it is implicitly involved within other objectives, such as lessening the climate footprint of agricultural practices. As it will become more evident in the next sub-chapter, a closer look at the European practices reveals also that focus areas of global initiatives have different social and economic conditions and therefore propose different solutions adapted to needs of the communities. Whereas global initiatives are primarily focusing on the areas with the lack of basic infrastructure (electricity, water supply, internet access, etc.), the European initiatives are working in the areas with basic infrastructure already provided and are therefore addressing different challenges of smart and sustainable development through products and services with social, economic, and environmental benefits.

3. EU Policies, Initiatives and Examples

In line with the described global initiatives and tendencies towards smarter and more sustainable communities, the European Union has also taken a holistic and integrative approach towards those objectives.

The first step specifically connected to Smart Villages was made in 2016 when the Cork Declaration 2.0 has been proposed (Cork, Ireland), under the name A Better Life in Rural Areas [29]. The declaration has very openly addressed some concerns about the state of the rural areas, specifically rural exodus and youth drain and thus paved the way for further orientations of future policies, including Smart Villages agenda. Through the ten points of addressing problematics of rural spaces, one of the main conclusions was that investment in rural areas is necessary, especially in the sense of encouraging of their identification processes, acknowledging their potentials for (economic) growth and ensuring that they will become attractive places for people of all ages to live in and work at. Particular attention has also been paid to overcome the digital divide between rural and urban spaces and developing the potential of digitalization in rural areas.

In the following year, 2017, the European Commission launched EU Action for Smart Villages [14] with the purpose to initiate some reflections on the villages of the future. Besides some funds and policies that have already existed before (e.g., Common Agricultural Policy, Rural development policy, EU Cohesion Policy), some new ones have been proposed: European Innovation Partnership for Agriculture (EIP-AGRI) that is directed towards development in the field of forestry and food production and The European Network for Rural Development (ENRD). In order to promote Smart Villages, the plan proposed 16 actions suggesting organization of some workshops/seminars/conferences, thematic groups, new platforms (e.g., Smart specialization platform agri-food), setting up new offices (like Broadband Competence Offices), and very importantly, also suggesting some projects on SMARTA (Smart Rural Transport 'Areas') and Smart Eco-Social Villages. The latter was specifically focusing on connectivity and digital solutions, but, more broadly, it was aimed at exploring some basic features of Smart Eco-Social Villages and identifying best examples that could be used in rural communities by decision makers in order to build future strategies.

Very recently, in April 2018, another declaration was accepted: Bled Declaration (Bled, Slovenia). The Declaration acknowledges "that the rural digital economy, if developed in an innovative, integrated and inclusive way, has the potential to improve the life-quality of rural citizens and, thereby, contribute to tackling the current depopulation of- and the migration from—rural areas" [30]. The Declaration proposed some actions to reach better conditions for developing farming enterprises and a new service sector; the two are addressing the rural Youth Drain, and will be providing the opportunity for the youth to return back home after finishing their studies and pursue white-collar jobs to further their specialization in their local area. By creating synergies between some technological achievements (precision farming, digital platforms—e-learning, e-health, e-administration etc., shared economy, circular economy, bio based economy, rural tourism, social innovation), the Declaration called for some Smart Villages to become a role model for further developments already in the following year, 2019. The Smart Village Network has also been established in 2018. It connects villages and associations across Europe enabling them the exchange of information and experiences and therefore making their voices lauder and stronger. Currently Slovenian member is Ptuj, small town in the north-eastern part of Slovenia and University of Ljubljana which is part of the network support [31].

Furthermore, another document that has an important impact on the development of European rural areas is Rural Development policy 2014–2020 [32] that devotes separate attention to specific European regions, contributing funds to their own rural development programs tailored to their regional needs. The policy was designed to meet contemporary challenges in the sphere of environment, economy and in the society, and is worth 100 billion euros. Every program designed within the policy addresses a minimum of four EU priorities for rural areas, oriented towards either fostering, enhancing, promoting innovative and knowledgeable ways towards social agriculture, forestry, food production, agricultural ecosystems and resource efficiency, or development of rural areas into the front [32]. Within this European policy and national programs, the LEADER approach is also being implemented. The LEADER method was already launched in 1991 [33] and was recently extended with more encompassing Community-Led Local Development (CLLD) [34]. The main characteristic of the approach is its focus on the local communities and acceleration of the solutions that are based on the bottom-up local initiatives. Cooperation on different levels is also being encouraged, connecting private and public sectors within the region (in the form of Local Action Groups—LAG), within the country but also between different EU countries. In the programming period 2014–2020, there is altogether already 2600 Local Action Groups (LAG) that are implementing the LEADER approach, which makes it a successful practice. Solutions that are based in the local environments and use local/regional resources are in line with designing the so-called smart developmental solutions and therefore the LEADER approach is an important factor in recognizing such practices.

The European Spatial Planning Observation Network (ESPON) 2020 Cooperation Programme is another program adopted by European Union, aiming at reinforcing the effects of European Cohesion policy. The ESPON strategy is inextricably connected to the European rural areas. For example, in the policy brief, Shrinking rural regions in Europe [35], it is recognized that rural areas in the EU are shrinking or facing depopulation (p. 4) and the policy urges seeing such processes in the broader light and recognize also the possibilities not only the dangers of such processes. ESPON 2020 has been preceded by ESPON 2013 and ESPON 2006, all of them supporting EU vision on territorial cohesion and steady development of all regions but each setting their own specific priorities [36].

Regarding EU measures, it is important to note, that, considering the rural development, abovementioned recent policies and measures were preceded by some important strategies—such as a LEADER approach and the actions taken to better understand also the mutual connection between rural and urban places in Europe [37] that have been addressed in line with the European cohesion actions. The latter has specifically addressed the relationships between the rural and urban regions, their intensive and interdependent relations, and extensive changes they have been going through in the last decades. Within this framework, the need for mutual co-development has been noted and some corresponding actions taken: Study Programme on European spatial planning, ESPON strategy, the project RURBAN (in 2010).

Within all the above-mentioned EU policies and other measures, there have been numerous (re)actions connected to the creation of smart communities, and we are presenting only some of them. One such initiative that serves as an example and offers a deeper insight on how to apply the concept of smart development to a specific regional context has already been mentioned—the case of Hungarian Túristvándi. Their already mentioned smart developmental strategy has had several phases, starting in 2001 when the village participated in the Social Land program and started investing to make local food production self-sufficient [8]. Later (between 2012 and 2014), the Túristvándi and whole Észak-Alföld region were included in the INTERREG project named SMART EUROPE (Smart strategies to create innovation-based jobs in regions of Europe) that was funded by ERDF (January 2012–December 2014) and was worth more than 1.8 million € [38]. Amongst others, the case of Túristvándi was listed as an example of the good practice 'Job-creating practice cooperation between triple helix actors: self-supporting village of Túristvándi' starting in 2006 [39]. As a result of all the efforts, the villagers were able to restore their ancient water mill—the main tourist attraction—and therefore establish some new tourist capacities and attract big numbers of tourists (more than 40,000) [8] (p. 680). The North Great Plain (Észak-Alföld) region is typically characterized by rapid aging of the population, high unemployment rate and traditional agricultural activities [40] from which stems the need to develop more accurate and smarter ways of dealing with regional problematics. In the case of the aforementioned Túristvándi, the development of the touristic potential and local and self-sufficient agriculture is a reasonable and smart move for the future.

Furthermore, there is the Italian "Smart Basilicata" project [12,41], funded by the Cohesion Fund of the Basilicata Regional authority. The Basilicata region has been struggling with the decline in GDP and one of the highest unemployment rates in Southern Italy. In 2015, a great part of the regional enterprises was working in the field of agriculture (32%, which is more than is the national average). A great majority of region (92%) is either farmland or forests [42]. Besides everything mentioned, Basilicata is also one of the two most sparsely populated regions, with 56.6 people/km^2 [43], which is also the consequence of mountainous and hilly territory. The main aims of the project were to make the region more sustainable and resilient, which was done building on local and regional knowledge. The Smart Basilicata project identified the main difficulties, searching for possible practical solutions and ways to put them into practice. This was done through five pillars of Basilicata as a smart region: natural resources, energy, mobility, culture and tourism, smart participation [12] (p. 1028). The duration of the project was 54 months (2012–2015) and has made some visible contributions to enhancing regional smart development. One of the most accessible is the development of an innovative tool to enhance active engagement of citizens in decision-making and encourage public participation through the use of ICT technologies that was developed by using a SUN4Matera approach [44].

Another example offering an insight into how to implement the Smart village concept is German project Digital Villages (*Digitale Dörfer*), taking place between 2015 and 2019. The project was funded by Ministry of Internal Affairs and Sports Rhineland-Palatinate with a total budget of around 4.5 million euros [45,46]. The majority of the people in Germany live in rural areas (63.3%) [47], therefore applying the smart strategy for the rural development is in line with the country's general development goals. The region is the sixth richest German region and its economy is largely based on the chemical and pharmaceutical sector, vehicle construction, mechanical engineering and the food sector. The region is also very well connected and its broadband coverage is even above the country's average [48]. At the forefront of the program is the digital transformation of the three chosen communities: Eisenberg, Gollheim and Beztdorf-Gabhardshain (altogether this is 33 municipalities). The main objectives of the project are to encourage innovation, collaboration (residents-local authorities-local industry), and cross-sectoral, sustainable and affordable solutions. Through using the living-lab-approach, target domains were chosen and, according to this, several solutions have been proposed: local online marketplace, local news portal and digital platform. BestellBar is an online market place that includes more than thirty local vendors and 700 residents registered in only three months of its existence. Similar success was shared by an online local news portal where up to 400 users were recorded per week [46]. The course of the project is deemed successful and some of the cues for similar projects are worth noting: it is good to have local contact persons; it is necessary to gain trust of the villagers; recognizing people's needs is the starting point; permanent involvement is crucial; prototypes are important [47].

Another very extensive initiative on smart digital transformation is connected to one of the Arctic areas, Lapland, and has been carried out within the framework of the ERD funds since 2014. Under the Arctic Smartness Project, the project of the Regional Council of Lapland, there are five distinctive clusters operating in different but interconnected domains: Arctic Industry and Circular Economy, Arctic Development Environments, Arctic Design, Arctic Safety and Arctic Smart Rural Community Cluster (Rural Cluster)—especially the latter being part of our more detailed discussion [49,50]. Within the Arctic Smartness the economic and business opportunities of the region are being improved, therefore enhancing Lapland's economic competitiveness. One of the main areas addressed through the Rural Cluster is connected to the sustainability of renewable energy and natural resources, and local food production. Local authorities, entrepreneurs, developers, researchers, education and some other institutions are connected in the network and coordinated by the cluster to enable the smart and sustainable development of the area. Lapland being the most northern EU region, sparsely populated (with 1.8 inhabitants/km^2) and mostly covered with forested areas (98%), embraced the possibilities of EU funding (especially the ERD and EARD funds) and started intensively developing (inter)national and (inter)regional partnerships, attracting new organizations and entrepreneurs. The Rural Cluster has also been awarded a Silver Label in the cluster analysis. By now, this has developed to be a network consisting of approximately 100 entrepreneurs and around 200 other institutions (such as municipalities, financiers, politicians, advisors, etc.). Especially good practice is the REKO food circle, an electronic sales channel used by local food producers for selling food directly to the users; by now, 100 producers have been included [50]. While the most profitable economic sectors are mining, (nature based) tourism, and the metal and forest industry, the Food Program of the Rural Cluster strives to increase the regional food self-sufficiency.

4. Discussion: (Smart) Villages in Practice

It has already been noted that the implementation of smart concepts into regional, both rural and urban contexts has to be adapted to socio-cultural and environmental circumstances. Thus, in the cities, different issues need to be tackled than in rural areas, where the main challenge is to bridge the distances among relatively small number of people. In the context of digital transformation that is at the forefront of our interest, this means that also digitalization requires adapted concepts, business models and solutions that have to strive to generally improve the well-being of the rural population.

In the context of this paper, we are concentrating on Slovenia as a part of the Alpine space region, thus also sharing its problematics. In this regional view, a need for strategic approach towards some major challenges has been noted: Towards 1. Economic globalization; 2. Demographic trends; 3. Climate change; 4. The energy challenge; 5. Alpine region as a transit region. As a solution to the above listed problematics, the project Smart Digital Transformation of Villages in the Alpine Space (SmartVillages) has been proposed and also approved for funding (Interreg Alpine Space funding) in 2018. The partnership consists of 13 partners from six countries included in the Alpine space region (Italy, Austria, Germany, France, Switzerland, Slovenia), thus covering a great majority of the regional territory.

Main challenges that the SmartVillages project is addressing are in line and complementary to sustainable development goals, EU Action for Smart Villages, EU Rural Development Policy, and proposed objectives of the Bled Declaration. More precisely, it addresses the causes for (youth) brain drain in the region: deprivation of jobs, provision of services, favorable climate for entrepreneurship and social innovation [1]. The project aims to bring together stakeholders from different sectors and to improve the quality of life in villages and small cities through sustainable solutions facilitated by ICT.

It is necessary to learn and draw on good practices from other countries, but meanwhile it is also necessary to consider local and regional frameworks within which the implementation of the Smart Village concept will take place. As it has already been noted by others [51], what is also of vital importance is the quality of rural life. The perceptions of the important building blocks are—once again—locally/regionally conditioned. Therefore, similar to the concept of the "smart" development, the quality of life or well-being of the people are also very slippery and hard to precisely define. In line with the abovementioned challenges of the Alpine space region, it is necessary to recognize and address the main reasons for the youth brain drain. Moreover, not only to identify the indicators for the quality of life in the chosen area, but also to evaluate their accessibility is essential in understanding the real-life situations [51].

In the Slovenian context, besides the aforementioned steps, the successful implementation of the concept is dependent upon the integration of the already existing good practices and initiatives that are adapted to local circumstances and are in line with the Smart Village concept. Below, we will show how a successful integration of a Fab City [52,53] concept developed in and for the context of urban places can be adapted for the use in the rural contexts if based on the grass roots initiatives and an already existing infrastructure.

Fab Cities are cities striving to self-sufficiency in terms of producing what is consumed (also through the mechanisms of FabLab production and know-how solutions) and using locally sourced materials (also obtained with the mechanisms of recycling and digital production [53] (p. 465). Fabrication laboratories or FabLabs [54,55] are creative-learning spaces, usually established by the bottom-up principle that aims to encourage innovation and creativity in approaching different subjects. They also aim to reach people of all ages. Regarding this, one of the most important, already existing infrastructures is a national FabLab Network Slovenia [55]. Namely, to undertake the project that focuses on digital transformation and digital services in particular, it is essential to have or to build up an innovation infrastructure. The Network already connects more than 80 partners from different sectors, amongst them more than 20 fabrication laboratories (FabLabs), e.g., the Network aims to bring modern digital technologies closer to rural communities and enable them to develop 21st century skills and competences. The FabLab network serves as a prototyping and experimentation environment of Digital Innovation Hub Slovenia (DIHS), part of the pan-European network and one of the planned EU actions to promote Smart Villages. More specifically, in Slovenia, there are a number of Fablabs existing in rural places, most of them established on the basis of the grass-roots initiatives. As it was already noted by some authors [54], Fablabs operating in rural areas are creative and innovative places, open to different stakeholders and thus enabling new opportunities for local people, especially the young, and local businesses, especially start-ups, providing them with the space and the infrastructure to gain high quality skills or realize their own business ideas. Fablabs located in the smaller, rural places are enabling local/regional potential on the basis of local intellectual, natural, infrastructural and social resources and thus providing long-term and sustainable development

Secondly, the Alpine space region has a high touristic potential and a great variety of natural and cultural heritage resources. Sparsely populated areas and diverse geographical terrain make conditions to develop touristic infrastructure challenging. In line with preservation of natural heritage, limited tourist facilities and guidelines of Bled Declaration, the development of eco-, health-, recreational-tourism is part of the rural tourism strategy. In Slovenia, the concept of distributed hotels is already very well established [56] and experiences will be used to implement and develop it further it in new localities. Distributed hotels are part of green tourism and circular economy, aiming at including local inhabitants into the process of development. In such an initiative, the local services and resources are used to accelerate local economy. By providing accommodation dispersed in different locations, the concept requires cooperation of the whole community to be sustainable. Tourism development brings new job possibilities, new infrastructure as well as more lively social connections to the region. At the same time, a sustainable approach to tourism development will help with preserving, presenting and celebrating local and regional cultural characteristics and heritage, increasing their universal value and potentials. Such development policies are in line with the objectives of the European Year of Cultural Heritage.

By combining both described initiatives, we are aiming to promote the so-called FabVillages that strive to promote the principles of circular economy, locally sourced materials, development of local (natural, cultural, social) resources and economy are thus a good example of how to apply smart development in rural communities to make them more sustainable and resilient.

5. Conclusions

Over recent years, the challenges arising from the social and economic, but also wider changes of people's communities—rural and urban—have been increasingly addressed through the lenses of technological developments and digitalization. In this paper, we have focused on the applications of the Smart Village concept and the importance of digital transformation for rural areas, always drawing parallels between the findings and insights from different regions. We aim to use these new insights in developing the framework of the international project Smart digital transformation of villages in the Alpine Space.

One of the aims of our paper was also to make a qualitative evaluation of the projects and initiatives presented. Considering the initiatives active worldwide, we have made a comparison of the territories they cover and areas of actions they are focusing to and concluded that the most important issue to address when making the development strategies for the so-called un-developed countries is the access to the sources of energy. Furthermore, in order to make the concept of "smart development" more accessible and useful for our case of Smart Villages, we have made an evaluation of the projects and programs based on criteria that define "smartness" in the broader sense within the framework of EU policies. For deeper understanding of smart development in specific European regions, it is important to make an in-depth analysis of different possible approaches. Below, we are presenting a short analysis of the chosen examples according to the EU pillars/drivers of Smart Villages: (i) Responding to depopulation and demographic change; (ii) Finding local solutions; (iii) Exploring linkages with small towns and cities; (iv) Accelerating the role of rural areas in low-carbon circular economy; and (v) Promoting digital transformation [57]. All presented European cases have/are receiving funds from European Commission, although some of them are carried out within the single project/funding option, whereas others are actually an agglomeration of different projects directed toward achieving specific objective—such as, for example, the Arctic Smartness project, comprised of the clusters and financed by various funding schemes/mechanisms.

According to an ESPON Policy brief on shrinking rural regions in Europe [35], EU territory is experiencing depopulation of rural areas. The demographic challenges were especially addressed in the cases of Hungary and Italy, as the regions under consideration are characterized by agricultural activities and high rates of unemployment. Smart development solutions were therefore mainly addressing the ways to create opportunities for local employment and alleviate the living conditions. On the other hand, the role of transition to circular economy has been accelerated in the case of Lapland where the main issue to address was to stop the outflow of the money especially in connection to the energy and food self-sufficiency. In the case of German Smart Villages, the digital transformation was at the forefront. The region is one of the richest in the country and does not suffer from the depopulation of the area. To invest in digital connectivity within the villages and also within the broader regional community was therefore also to improve opportunities for local/regional and circular economy and to enhance the sustainable development of the area. All of the project cases/initiatives show how important it is to look for strategies and solutions based on local or regional knowledge, even more so when striving for a sustainable future.

To conclude our evaluation, it is also important to note that there are some considerable differences when dealing with rural areas in Europe and elsewhere, as it is necessary to consider local and regional specifics. We have shown this in the case of some global initiatives and their specific developmental efforts and activities. The main difference is that, in Europe, the basic infrastructure is already established, whereas, in some other "un-developed" regions, the infrastructure is yet to be established.

The strategy of our forthcoming project Smart Villages will be founded on the insights offered by the listed projects above and initiatives and on our own experiences. Smart Villages is creating an effective partnership between actors important for the Alpine space region. The main argument, funded on the basis of our own already existing experiences and experiences of other approaches, is that rural areas are not uniform, and that smart development has to be applied in combination with a place-based approach. In our context, the approach has to be in line with cultural and geographical specifics of an Alpine space area, as well as with more specific local characteristics. In line with this, one of the main outputs of the Smart Villages project will be a digital exchange platform intended for the exchange of practices. Another important output will be embodied in the form of a Smart Villages Toolbox, based on insights from our pilot, local-based activities. As such, it will have a great impact on further development and implementations of the concept into reality-based environments and will contribute to better framework conditions for (digital) innovation in societal and technical parts.

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References

1. Envision2030: 17 Goals to Transform the World for Persons with Disabilities. Available online: https://www.un.org/development/desa/disabilities/envision2030.html (accessed on 7 May 2018).
2. Jucevičius, R.; Patašiene, I.; Patašius, M. Digital dimension of smart city: Critical analysis. *Procedia Soc. Behav. Sci.* **2014**, *156*, 146–150. [CrossRef]
3. Edwards, M.M.; Haines, A. Evaluating smart growth: Implications for small communities. *J. Plan. Educ. Res.* **2007**, *27*, 49–64. [CrossRef]

4. European Network for Rural Development, Smart Villages. Available online: https://enrd.ec.europa.eu/smart-and-competitive-rural-areas/smart-villages_en (accessed on 4 May 2018).
5. Srivatsa, P. Rural Urban Migration: Disturbing the Equilibrium between Smart Cities and Smart Villages. *FIIB Bus. Rev.* **2015**, *3*, 3–10. [CrossRef]
6. Gascó-Hernandez, M. Building a Smart City: Lessons from Barcelona. *Commun. ACM* **2018**, *61*, 50–58. [CrossRef]
7. Naldi, L.; Nilsson, P.; Westlund, H.; Wixe, S. What is smart rural development? *J. Rural Stud.* **2015**, *40*, 90–101. [CrossRef]
8. Orbàn, A. Building Smart Communities in the Hungarian Social Economy. *Community Dev. J.* **2017**, *52*, 668–684. [CrossRef]
9. Glasmeier, A.; Christopherson, S. Thinking about Smart Cities. *Camb. J. Reg. Econ. Soc.* **2015**, *8*, 3–12. [CrossRef]
10. Hayat, P. Smart Cities: A Global Perspective. *India Q.* **2016**, *72*, 177–191. [CrossRef]
11. EU Smarti Cities Information System, About the Smarti Cities Information System. Available online: https://smartcities-infosystem.eu/content/about-smart-cities-information-system-scis (accessed on 9 May 2018).
12. Saliva, M.; Cornacchia, C.; Di Renzo, G.C.; Braccio, G.; Annuziato, M.; Colangelo, A.; Orifici, L.; Lapenna, V. Promoting Smartness among Local Areas in Southern Italian Region: The Smart Basilicata Project. *Indoor Built Environ.* **2016**, *25*, 1024–1038. [CrossRef]
13. Programa EkoSmart. Available online: http://ekosmart.net/sl/o-projektu/ (accessed on 3 May 2018).
14. EU Action for SMART VILLAGES. Available online: https://ec.europa.eu/agriculture/sites/agriculture/files/rural-development-2014-2020/looking-ahead/rur-dev-small-villages_en.pdf (accessed on 3 May 2018).
15. Van Gevelt, T.; Canales Holzeis, C.; Fennell, S.; Heap, B.; Holmes, J.; Hurley Depret, M.; Jones, B.; Safdar, M.T. Achieving Universal Energy Access and Rural Development through Smart Villages. *Energy Sustain. Dev.* **2018**, *43*, 139–142. [CrossRef]
16. Smart Villages, New Thinking for Off-Grid Communities Worldwide. Available online: http://e4sv.org/about-us/what-are-smart-villages/ (accessed on 3 May 2018).
17. IEEE Smart Village. Available online: http://ieee-smart-village.org/ (accessed on 3 May 2018).
18. Holmes, J. *The Smart Villages Initiative: Findings 2014–2017*; The Smart Villages Initiative: Cambridge, UK, 2017; Available online: File:///C:/Users/veronikaz/Documents/Smart%20Village/Sustainabilitiy%20(gradivo%20za%20%C4%8Dlanek)/Dodatno%20gradivo/The-Smart-Villages-Initiative-Findings-2014-2017_web.pdf (accessed on 3 July 2018).
19. IEEE. Frequently Asked Questions: About IEEE Smart Village. Available online: http://ieee-smart-village.org/wp-content/uploads/2015/09/IEEE_Smart_Village_FAQs_16SEPT15-2.pdf (accessed on 5 July 2018).
20. Aggarwal, P.; Zougmorè, R.; Kinynagi, J. *Climate_Smart Villages: A Community Approach to Sustainable Agricultural Development*; CIGAR Research Program on Climate Change, Agriculture and Food Security (CCAFS): Copenhagen, Denmark; Available online: https://cgspace.cgiar.org/bitstream/handle/10568/33322/CCAFSClimate-SmartVillages2013.pdf?sequence=9&isAllowed=y (accessed on 12 June 2018).
21. Climate-Smart Villages. Available online: https://ccafs.cgiar.org/climate-smart-villages#.Wyarc6czbIU (accessed on 12 June 2018).
22. CIGAR CCAFS, Climate Analogues. Available online: https://ccafs.cgiar.org/tool-climate-analogue-tool#.Wz24g9Iza72 (accessed on 5 July 2018).
23. Smart City Mission Transformation, Mission Statement & Guidelines. Available online: http://164.100.161.224/upload/uploadfiles/files/SmartCityGuidelines(1).pdf (accessed on 8 May 2018).
24. Smart Villages, Providing Global Means to Local Needs. Available online: http://smartvillages.org/Default.aspx (accessed on 9 May 2018).
25. Statistic Times, Sector-Wise Contribution of GDP of India. Available online: http://statisticstimes.com/economy/sectorwise-gdp-contribution-of-india.php (accessed on 5 July 2018).
26. Digital India—Making Villages 'Smart', Amit Sharma. Available online: https://telecom.economictimes.indiatimes.com/tele-talk/digital-india-making-villages-smart/719 (accessed on 3 May 2018).
27. Poggi, F.; Firmino, A.; Amado, M. SMART RURAL: A Model for Planning Net-Zero Energy Balance at Municipal Level. *Energy Procedia* **2017**, *122*, 56–61. [CrossRef]

28. Poggi, F.; Firmino, A.; Amado, M. Moving Forward on Sustainable Energy Transitions: The Smart Rural Model. *Eur. J. Sustain. Dev.* **2015**, *4*, 43–50. [CrossRef]
29. Cork 2.0 Declaration 2016, a Better Life in Rural Areas. Available online: https://ec.europa.eu/agriculture/sites/agriculture/files/events/2016/rural-development/cork-declaration-2-0_en.pdf (accessed on 3 May 2018).
30. Smart Villages, Bled Declaration. Available online: http://pametne-vasi.info/wp-content/uploads/2018/04/Bled-declaration-for-a-Smarter-Future-of-the-Rural-Areas-in-EU.pdf (accessed on 3 May 2018).
31. Newsletter, The Smart Village Network was launched on 4 April 2018. Available online: https://docs.wixstatic.com/ugd/8fb60d_557112a28208440eb3a804591d760886.pdf (accessed on 20 July 2018).
32. EU Commission, Agriculture and Rural Development. Available online: https://ec.europa.eu/agriculture/rural-development-2014-2020_en (accessed on 9 May 2018).
33. The Leader Approach: A Basic Guide. Office for Official Publications of the European Communities, Luxembourg. 2006. Available online: https://ec.europa.eu/agriculture/sites/agriculture/files/publi/fact/leader/2006_en.pdf (accessed on 17 June 2018).
34. LEADER/CLLD. Available online: https://enrd.ec.europa.eu/leader-clld_en (accessed on 17 June 2018).
35. Policy Brief: Shrinking Rural Regions in Europe. Available online: https://www.espon.eu/rural-shrinking (accessed on 12 June 2018).
36. ESPON. Available online: https://www.espon.eu/programme/espon/espon-2020-cooperation-programme (accessed on 17 June 2018).
37. Bridging the Rural-Urban Divide: Rural-Urban Partnerships in the EU. Available online: http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573898/EPRS_BRI(2016)573898_EN.pdf (accessed on 18 June 2018).
38. SMART EUROPE. Available online: http://www.interreg4c.eu/projects/project-details/index-project=130-smart-strategies-to-create-innovation-based-jobs-in-regions-of-europe&.html (accessed on 3 July 2018).
39. I. General Characteristic of the Practice. Available online: https://www.smart-europe.eu/sites/default/files/Job-creation_Turistvandi.pdf (accessed on 3 July 2018).
40. EU Commission: Growth: Internal Market, Industry, Entrepreneurship and SMEs: North Great Plain. Available online: https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/north-great-plain (accessed on 4 July 2018).
41. Progetto SMART Basilicata. Available online: http://smartbasilicata.tern.it/ (accessed on 9 May 2018).
42. EU Commission: Growth: Internal Market, Industry, Entrepreneurship and SMEs: Basilicata. Available online: https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/basilicata (accessed on 3 July 2018).
43. UrbiStat: Region of Basilicata. Available online: https://ugeo.urbistat.com/AdminStat/en/it/demografia/dati-sintesi/basilicata/17/2 (accessed on 3 July 2018).
44. Pietrapertosa, F.; Chiarini, R.; Clerici Maestosi, P.; Cosmi, C.; Saliva, M. SMARTera Approach: A New Approach for Smart Participation through Social Urban Network. 2015. Available online: File:///C:/Users/veronikaz/Downloads/poster_SUN4Matera_Bolzano2015_FINALE%20(4).pdf (accessed on 3 July 2018).
45. Digitale Dörfer. Available online: https://www.digitale-doerfer.de/ (accessed on 10 May 2018).
46. Digital Villages Germany. Available online: https://enrd.ec.europa.eu/sites/enrd/files/tg_smart-villages_case-study_de.pdf (accessed on 10 May 2018).
47. Hess, S. Digital Villages Platform. Available online: https://enrd.ec.europa.eu/sites/enrd/files/tg1_smart-villages_digital-villages-platform_hess.pdf (accessed on 21 June 2018).
48. EU Commission: Growth: Internal Market, Industry, Entrepreneurship and SMEs: Rhineland Palatinate. Available online: https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/rhineland-palatinate (accessed on 3 July 2018).
49. Arctic Smart Rural Community Cluster: Cluster Report. 2015. Available online: http://luotsi.lappi.fi/c/document_library/get_file?folderId=1664044&name=DLFE-29555.pdf (accessed on 22 June 2018).
50. Arctic Smartness Excellent News: Success Stories of the Lapland's Smart Specialisation. Available online: https://arcticsmartness.eu/wp-content/uploads/2018/03/AS-tabloid_english_web.pdf (accessed on 4 July 2018).
51. Bocinell, F.; Pagnotta, G.; Riccioli, F.; Casini, L. The determinants of quality of life in rural areas from a geographic perspective: The case of Tuscany. *Rev. Urban Reg. Dev. Stud.* **2015**, *27*, 104–117. [CrossRef]
52. What is a Fab City? Available online: http://fab.city/ (accessed on 22 June 2018).

53. Diez, T. Personal Fabrication: Fab Labs as Platforms for Citizen-Based Innovation, from Microcontrollers to Cities. *Nexus Netw. J.* **2012**, *14*, 457–468. [CrossRef]
54. Stojmenova Duh, E.; Kos, A. Fablabs as drivers for open innovation and co-creation to foster rural development. In Proceedings of the 2016 International Conference on Identification, Information and Knowledge in the Internet of things (IIKI), Beijing, China, 20–21 October 2016.
55. FabLab Network Slovenia. Available online: http://fablab.si/en/ (accessed on 22 June 2018).
56. Distributed Hotel Konjice. Available online: https://distributedhotel.si/ (accessed on 10 May 2018).
57. Smart Villages: Revitalising Rural Services. *EU Rural Rev*. 2018. Available online: https://enrd.ec.europa.eu/sites/enrd/files/enrd_publications/publi-enrd-rr-26-2018-en.pdf (accessed on 4 July 2018).

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