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Sustainable Interdisciplinarity

Human-Nature Relations

Edited by

Giuseppe T. Cirella and Alessio Russo

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Cover image courtesy of Giuseppe T. Cirella.

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Editorial

Special Issue Sustainable Interdisciplinarity: Human–Nature Relations

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Abstract: Sustainable interdisciplinarity focuses on human–nature relations and a multitude of contemporary overlapping research between society and the environment. A variety of disciplines have played a large part in better understanding sustainable development since its high-profile emergence approximately a quarter century ago. At present, the forefront of sustainability research is an array of methods, techniques, and growing knowledge-base that considers past, present, and future pathways. Specific multi-disciplinary concentrations within the scope of societal changes, urban landscape transformations, international environmental comparative studies as well as key theories and dynamics relating to sustainable performance are explored. Specializations in complex sustainability issues address international governance arrangements, rules, and organizations—both public and private—within the scope of four themes: sustainability, human geography, environment, and interdisciplinary societal studies. This book contains eleven thoroughly refereed contributions concerning pressing issues that interlink sustainable interdisciplinarity with the presented themes in respect of the human–nature interface.

Keywords: sustainability; human geography; environment; interdisciplinary societal studies

1. Introduction

This Special Issue is comprised of eleven thoroughly refereed contributions that shed light on a wide array of research activities within four themes: sustainability, human geography, environment, and interdisciplinary societal studies. The themes exemplify sustainable interdisciplinarity and the human–nature relational interface. Over the past few decades, a number of societal-challenging changes have arisen, in particular the environmental movement, variations in dialogue regarding sustainable development, social adherence with technological innovation, and socio-political shifts of tolerable norms. These issues have sparked much attention, research, and scientific output [1,2]. Socially scientific-based applications regarding the questions of what human beings require and how compatible or, better yet, functional these requirements are with regard to the environment and co-habitancy with fellow species is the level of interdisciplinarity modern society weighs in on when dealing with this interface [3–7]. Elkington's [8,9] triple bottom line (TBL) concept, where environmental, social, and economic standpoints form the three pillars of sustainability, needs to consider the array of scientific complexities and questions that query combinative efforts of interlinking quantitative and qualitative data. Successfully connecting the two will better interlink sustainability-oriented practice and harmonize societies via TBL reporting [10]. In sustainability terms, developing and comparing a state-of-the-art rationale of societal changes from and between different areas merges a variety of key disciplines including geography, urban development, environmental management, sociology, ethics, and philosophy.

In reference to the development of sustainable societies, there is a critical scope in terms of human interconnectedness with the world-around-us and the noise society bares. Noise, in this sense, is the busyness that societies, especially contemporary, levy on an individual [3]. If one were to assess this levy, it could be labelled, respectively, as weight [11,12]. In a sense, it would be an individual's level of effectiveness or aptitude to participation within society versus one's unproductiveness or imaginative state of thinking "outside of the box". Societies, especially contemporary ones, face diverse challenges that need to acknowledge functional, versus dysfunctional, action. This acknowledgement, evident from reviewing the chronology of art and usage of modern-day social media, relates to a growing worldwide concern of ideas and concepts that people from all scopes of life are probing. This concern correlates the human necessity of need and want at the individual level, and its coexistence and framing via day-to-day living. The level of harmonization societies exert is somewhat of a balancing act in which large scoped challenges such as rising inequality, loss of biodiversity, and armed conflict are at the core of bandage-like fixes that have been relatively inept. The need to rearrange human–nature relations is fundamental to trying to comprehend the noise in which functionality, between human beings and nature, defines societal sustainability. A sustainable society should relate not only to lifestyle, but to an aggregate thought pattern of decisions; touching upon the concept of what human beings need (i.e., for survival) versus want, and whether it is from a top down or bottom up (or another type of) viewpoint. Over the last few decades, similar forms of fragmentation have indicated exactly this via a cause and effect approach (e.g., increased individual indulgence and mass materialism versus the family institution and renovative or repair-like knowhow). This (dis)order, or some might say fragmentation, is a crossroad or transitional point in which forthcoming generations will live and work at a standard consequential to present-day actions.

2. Synopsis of the Contributions

The primary thesis of this Special Issue is to provide a set of innovative contributions regarding linkages between human beings and nature. Sustainable interdisciplinarity is broken down in terms of up-to-date interrelating research between society and our natural surroundings. Of the eleven contributions, nine focus on country-specific studies (i.e., China (two), Cambodia, Poland, Singapore, South Korea (three), and the Czech Republic), while one is written as an essay and another is a concept paper. The collection of contributions provide methodologies and innovative approaches that are useful for both scholars and professionals alike. The contributions were thoroughly refereed and accepted via single-blind review in adherence with MDPI's review guidelines. A synopsis of the Special Issue consists of the following contributions: Xie et al. [13] conceptualized the use of Ostrom's [14] social–ecological systems framework in the context of nature reserves in China by presenting a novel approach (i.e., the hybrid psycho-economic model) and interlinking collective forest management via a dynamic analysis of three case studies. Kim et al. [15] examined the notion of sustainable transformative economy based on community-based ecotourism in a remote area of eastern Cambodia. This contribution examined ecotourism development from the perspective of participation and economic impact. Most households acknowledged ecotourism had a positive impact on community TBL output, however, depleted natural resources and impact on local culture were some problems. As a low-impact alternative to standard commercial tourism, community-based ecotourism can become a transformative form of economics for local communities.

Bieliński et al. [16] investigated bike-sharing systems in Poland as a widely recognized eco-friendly mode of transportation that is able to assist in alleviating air pollution and traffic congestion. The identification of factors that correlated with the performance of bike-sharing systems were positively linked with urban population, tourism, number of bike stations per capita, congestion, bicycle pathway length, and higher temperature while precipitation was negatively linked. In another urban related study, Hu et al. [17] examined stakeholder collaboration on policymaking for sustainable water management in Singapore's hotel sector. This research applied policymaking, in terms of tourism value, through a dynamic network, where stakeholders come to a consensus on sustainability to

investigate stakeholder collaboration within the city's policy domain. Prominent political and industry players were seen to have favorable network positions.

Next, three South Korean studies looked at urban planning and cityscape issues within the context of climatic variability and community development. First, Lee and Oh [18] developed an urban thermal environment management and planning system using mathematical climate simulation modeling to examine urban heat island and thermal environmental effects throughout Seoul. They analyzed meteorological models and applied geographic information system analysis methods to assess urban spatial change scenarios for future urban development. Second, Lee et al. [19] classified urban climate zones (also within Seoul) via spatial statistical analyses to help urban planners delineate clearer boundaries relative to a set of (pre-determined) spatial variables. The scope of the research—effectively—can be extended and applied to other cities to establish urban heat island counter measures within similar weather-related conditions. Third, An and Lee [20] considered nature in a city in the restorative project areas of Cheonggye Stream and Suseongdong Valley. The study explored the historical and cultural background of sustainable planning in the context between "city with nature" and "nature with culture".

Rybova [21] examined the sociodemographic characteristics of waste management and explored the notion of recyclability in the Czech Republic. This research focused on individual characteristics connected to ongoing demographic change as well as municipal level inputs before considering the spatial effects and regional specificity of that nation's recycling program. Zhang and Sun [22] undertook research that looked at attitudes toward genetically modified (GM) food safety among Chinese Internet users. The results indicated that 35.1% of respondents found GM food to be risky while 20.4% did not. Moreover, a higher percentage of younger respondents specified GM food as safe versus persons with higher levels of income and education who stated that it was risky. This contribution explores new insights into understanding the ideological influences on science development and sustainability.

Andreucci et al. [23] wrote an essay on designing urban green blue infrastructure for mental health and elderly wellbeing and presented a number of ways that exposure to and affiliation with nature have shown to support mental health as well as piece together key performance indicators (i.e., metrics) to monitor and adapt open spaces within the context of urban environments. Solutions are discussed and subsequent comparative critical analysis elucidated upon. Finally, Celadyn [24] framed a concept paper on interior architectural design for adaptive reuse by utilizing environmental sustainability principles. The design concept was based on the reintroduction of reclaimed or salvaged building material acquired from demolished or refurbished construction sites for interior structural reuse. Circular design methods and techniques were drawn up and the implementation of a resource efficiency strategy was used. The fulfilment of resource efficiency in conjunction with waste management effectiveness was also explored.

3. Conclusions

In conclusion, these contributions clearly exhibit an important focus on sustainable interdisciplinarity with specific human–nature relational overlaps between society and the environment. This Special Issue addresses a broad range of topics at the forefront of sustainability research. From a human geographical perspective, there is a growing knowledge base exemplar to many of the concerns sustainable societies must consider; this book interlinks this interdisciplinarity to the human–nature interface and overarching theme of sustainable development. Key work within related fields utilize integrated assessment, decision-aiding techniques, and emerging models that, for the most part, stray toward a rethinking. The notion of economizing society is by in large not accomplished by using current economic hypotheses (i.e., the economization of something will need to avoid waste and reduce outflow) [25,26]. Rees [27] argues that modernity and human beings are unsustainable, stating that unsustainability is an inevitable emerging property of the systemic interaction between contemporary technological society and the ecosphere. It is clear that contemporary societies struggle in this regard and continue to maintain the premise of anti-sustainable action where mass-affluence does not formulate

advantageous human–nature relations but more often than not, the opposite. On the other hand, technology, like the extended hand of human ingenuity, should be distributed so that a greater number of people can acquire fuller, unrestricted access. The current parameters in which the international community integrates scientific information into decision-making is key to determining how innovation is justly circulated and efficiently developed. This relationship corresponds with significant concepts in "greener" societies and formulates designs that are based on governance innovativeness and equitable resource opportunities for all [28]. Earth encompasses fundamental rules for survival; this inscribes the premise for basic necessities as central and, if compliant, the harmonization and equilibrial change of society itself.

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Article

Application of Ostrom's Social-Ecological Systems Framework in Nature Reserves: Hybrid Psycho-Economic Model of Collective Forest Management

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Abstract: Nature reserves (NRs) are complex social-ecological systems (SESs). In China, many collective forests (CFs), owned by villagers, are bound within NRs. This paper aimed at carrying out a dynamic analysis of three case studies of CF management based on Ostrom's SES conceptual framework. The hybrid psycho-economic model is designed within this context and tested. Results indicate that CF management is determined jointly by the interaction of all levels of governance based on subsystem characteristics (i.e., resource system, resource units, and actor system) specific to the local social, economic, and political settings. Use of the hybrid psycho-economic model compares one classified harmonious NR scenario with two conflictual ones. The model indicated the scenario with the harmonious NR as having less CF value at the resource level, less dependence on villagers for CF resources, stronger environmental awareness, lower levels of involvement from new actors, overarching governance control (i.e., by the NR administration), greater levels of self-organization (i.e., within villages), and augmented economic compensation and regulation from outside influences. The conflict-oriented NRs mostly revealed opposite sets of interaction. Different public policies, including the ecosystem service payment, are recommended for improving management of CFs in NRs.

Keywords: collective forest; nature reserve; SES framework; community forest; Fujian Province; China

1. Introduction

Nature reserves (NRs) dominate protected areas in China. These are endowed, unique, and irreplaceable environments that exhibit an abundance of biodiversity, shelter endangered wildlife, promote public awareness of nature conservation, and have provided grounds for scientific research for more than five decades [1,2]. From 2014, China established 2729 NRs, covering approximately 15% of its terrestrial lands [3]. Currently, 80.7% of wild flora (i.e., vegetation) in China can be found within at least one NR [1,4,5]. The management system of these reserves, once focalized by top-down and command-and-control policy, has triggered a number of conflicts between local villagers and NR administration [6,7]. Prior to the 1990s, almost all NRs were managed in isolation, failing to incorporate local people or their interests [8,9]. This has created a negative attitude toward conservation among villagers and backlash from some engaged in the destruction of natural resources at the NR level [10,11]. Village desire for economic growth has further agitated the conflict in an effort to resolve widespread poverty [12,13]. Overlapping administrative management and executive control (i.e., instated via multiple government directives) has exacerbated these challenges, especially when multiple

objectives have been simultaneously developed without prioritization [2]. As such, community-based co-management (CBCM) projects introduced in the mid-1990s (i.e., to conserve biodiversity, sustain the use of natural resources, and promote socioeconomic development of NRs and their surrounding villages) became the norm [8,14,15]. As more CBCM projects became implemented, a larger number of local organizations, established under local governments (i.e., administrative departments), have alleviated tensions between villages and NRs [8,15]. Since then, differing results have been observed throughout the country. It can be said that CBCM has worked well in some pilot NRs but not in others [16]. Widespread criticism suggests that, in practice, CBCM tends to gloss over the institutional complexities posed by the management of common-pool resources [17].

Complexities of NR management have gotten worse alongside fast-changing social, economic, and political environments enmeshed within the NR superstructure. The emergence of new users and formation of polycentric governance systems has increased the challenge of translating local knowledge within varying conservation-based scenarios. For example, in Romania, social network analysis applied to management actors as well as to the relationships among these actors revealed a low percentage of participation by locals and a marginal position to conservation organization in Natura 2000 protected areas [18,19]. However, since the late 1990s, conflicts centered around habitat loss in some NRs in South China show an increasing need for attention. The village—NR conflict arose in forests owned by villagers and, so-called, collective forests (CFs), which were designated as one part of an NR [20]. To date, there are government mandates in China that provide compensation to CF owners if losses are incurred, but reports, among varying NRs [2], note the amounts fail to match the loss [20,21]. The objective of this paper was to determine a general theoretic framework for use of Ostrom's social-ecological systems (SESs) within NRs. Moreover, to ensure a better understanding of different problems and solutions, we rely on case-based research. With the absence of a consolidated analytical framework, the objective spans to better understand the obstacle of properly conducting a comparative assessment on the performance of NRs, in general. One of the more useful frameworks for conservation biology is that of Ostrom's [22] SES analysis, which consists of the trifecta arrangement of bio-geo-physical units [23]. SES offers a balanced and nuanced approach to protected area management as well as a holistic framework for comparing and contrasting conservation successes and failures [24]. Its diagnostic nature can help identify case-specific variables, making cross-comparative research more accurate across cases [25].

To do so, this paper employs Ostrom's [22] SES framework to dynamically diagnose three cases of NR management in Fujian Province located in South China. Special attention is given to CF management where CFs account for a dominant portion of the NR. Three key contributions to current research are applied. First, the SES framework in relation to the NR and relevant villages incorporate both ecological and social-based scenarios. Second, interdisciplinary findings enable further national and transnational Sino-comparative research. Third, issues and concerns related to CF management in China's NRs are highlighted. The importance of this research stresses the gap in research that specifically investigates the management issues of CFs in NRs [16,26] in South China. To further the development of Ostrom's [22] SES framework, additional third-tier variables have been added to compensate for the social, economic, and political settings. This crucial higher tier analysis is the core aspect of how we utilize the framework. A breakdown of the paper is structured as follows: Section 2 gives a backdrop of CFs and NRs in China, Section 3 contains the methodology, Section 4 illustrates the results, Section 5 elucidates a discussion on the application and theoretical framing using Ostrom's [22] SES framework, and Section 6 provides the conclusion.

2. Collective Forests and Nature Reserves in China

In China, forests are categorized as CFs and state forests in terms of forestland ownership [27]. Villagers collectively own about 60% of the forestland while the rest is under state control [28]. Collective ownership of forestland was established in the 1950s and managed until the beginning of the 1980s [11]. The expanse of CFs inhabits large rural populations compared to state-owned

forest areas. Spatially, the majority of CFs are located in southern China [2]. Correspondingly, in the mid-1950s, the NR system was established, with specific designation for hunting as well as logging bans in South China [29]. Since the 1980s, inspired by concepts of environmental protection from the United Nations Conference on the Human Environment [30], China's environmental policy has gradually been changing from a view of conquering nature to that of sustainable development-based thinking (i.e., the harmonious co-existence between human beings and nature itself) [31]. In 1993, China became a signatory party of the United Nations Convention of Biological Diversity; one year later, the first regulation on NRs, viz., Nature Reserves Regulations of the People's Republic of China, was enacted [32]. From the late 1990s to the beginning of the 21st century, both the number and total area of NRs in China increased rapidly [2]. As such, a newly established NR concept was put in place, i.e., large enough to ensure an integral ecosystem be protected, which typically meant larger than 10,000 ha. Dating back to China's 1985 directive "Management Measures for Nature Reserves of Forests and Wildlife", CFs were required to be incorporated into the newly established NRs. This action was primarily installed to avoid and reduce interference with local people [33] for a better co-managed co-existence. A nationwide inventory by the SFA [5] in 2013 for the first time revealed that 1385 NRs were made-up of CFs, accounting for 65.15% of NRs run by a centralized forestry administration. At the time, the area of CFs in the NRs amounted to 9.52 million ha, accounting for 7.76% of the total area of NRs. The inventory also disclosed that 9.49 million people lived in NRs, with 1.85 million living in national NRs and 7.66 million in provincial and county-level reserves.

In the early 1980s, the involvement of CFs in NRs was seen as a logical step, accepted by most villagers without much disapproval. Villagers were honored to contribute to state affairs. Both NR managers and village committees within reserve boundaries believed NRs were established and managed for public, ecological, and environmental benefits, and superior to just village-run entities. The villages were faithful followers of institutional arrangements set by the NRs. The communities and NRs operated as two economically independent and spatially isolated actors with inherently different interests with no apparent conflicts. However, from the 1980s, China has had several rounds of CF tenure reform [11,34], with its latest round being held in 2003. The reforms targeted security, right of usage, stability and benefits, and constraint for villages to transfer and lengthen management rights of CFs from village committees to individual households (i.e., with contracted terms from 30 to 70 years) [7]. The reforms have further inspired villagers to ask for other potential rights, impelling them with an endowment of more forest and higher revenue from forest usage. Forestland rights have become a key challenge confronting the whole process [21]. Management of CFs in NRs soon sprawled into the wider administrative challenge of not only the NR departments but all tiers of government. At present, the integration of CFs into NRs has not been fully incorporated and the vast majority of villages still lay claim to the importance of accurately marking out CF territory for compensation and territorial integrity.

3. Methodology

3.1. Conceptual Framework: Social-Ecological System Analysis of Nature Reserves

Without sufficient claim to CF territory, financial compensation, funded by the Ecological Forest Program and respectively hosted by the central and provincial governments, offsets economic loss of villages. Most villagers complain that the financial compensation standard is too low to cover their losses, with some villagers having been refused compensation all together (e.g., Liaoning Province) [1,27]. A number of conflicting viewpoints continue to center around the lack of attention CFs are given (i.e., with the most recent reform process), which negatively impacts the NR system. Irrespective, villagers living in the greater Beijing area and Zhejiang Province have reported satisfaction from the compensation fund [26]. As a result of these pronouncements, newly established NRs need to institute prior agreements with villages to build trust and incorporate rival views. To date, the relationship between NRs and village life is split by two standpoints. First, ongoing mass-scaled NR

migration of rural surplus labor reduces village populations nationwide, thus alleviating stress and dependency on forest resources [35,36]. Second, in areas with newly developed tourism, infrastructure has grown to compensate for large spaces needed for guided tours and hiking, leading to illegal visitor access within NRs. These standpoints have not yet been resolved but illustrate a gap this paper (i.e., to some degree) confronts.

The NR system is a complex SES [24] designated to accurately describe specific ecological and cultural assets as well as provide essential ecosystem services that complement the core role in biodiversity conservation (Figure 1) [24,37,38]. Ostrom's [22] SES framework provides an integrative and multidisciplinary approach to understanding complex interaction within differing systems, scaled around natural resource governance [39,40]. The structure of the framework holds accurate to our objective and is adapted from McGinnis and Ostrom's [41] work and experimentation.

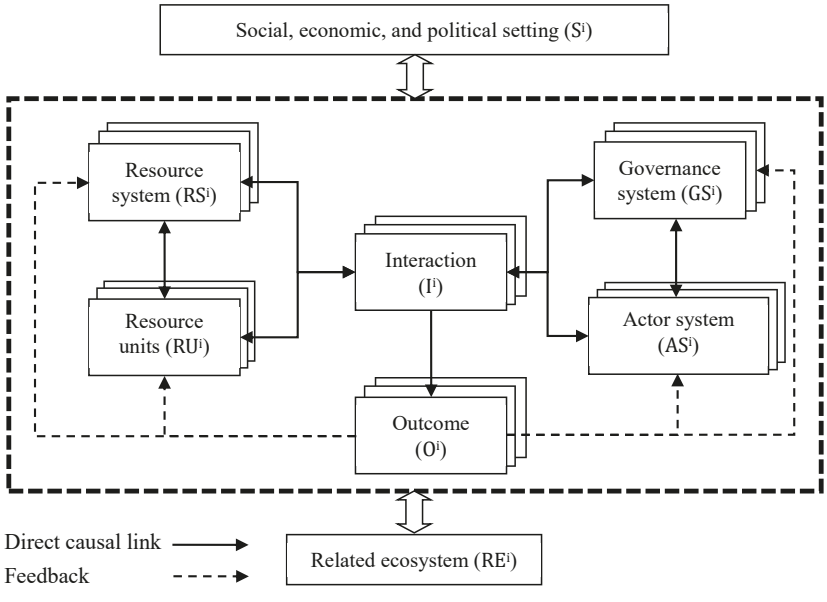

Figure 1. Core framework subsystems for analyzing SES of NRs, adapted from McGinnis and Ostrom [41]; 'i' = variable notation.

The study is broken down in terms of determining what outcome (O^i) will be generated when CF management is implemented, where 'i' refers to the variable notation. The outcome is classified into social performance, ecological performance, and externalities from other SES research [22]. We employ the relationship between NRs and relevant communities as a direct measure of the outcome. The relationship is categorized into two scenarios, i.e., harmonious and conflictual [42]. In the harmonious scenario, the NR and community positively coexist, complement, and benefit one another. On the contrary, in the conflictual scenario, the NR and community complain, accuse, and disagree as counterparts. The resource system (RS^i) is a specified territory containing forest, wildlife, and other natural resources. The resource units (RU^i), considered to be part of or beyond the resource system [41], consist of trees, fruits, seeds, medicinal herbs, mushrooms, bush meat, and other products found within the reserve. The resource system refers to unmovable and undivided stock while resource units refer strictly to flow extracted from stock [43]. In China, regulations on NRs prohibit all resource units from being extracted in core and buffer zones and limits them to experimental zones. As such, prudent use of resources encourages local participation in conservation, which NR administrators welcome, even though multiple functions of the resource system can cause

NR management concerns. The actor system (AS^i) defines actors affecting or affected by the resource system [44]. Villagers, inhabiting within and surrounding the NR, are traditionally and directly primary users sustaining their livelihood through resource extraction. Villagers are also major consumers of the resource units within NRs, while other types of consumers, such as tourists, increase their significant usage as reserves become more developed and accessible. Alongside tourists, tourism employees originating from outside of the reserve (i.e., conditional to tourism infrastructure), NGO staff, and academic researchers diversify user patterns. The governance system (GS^i) incorporates characteristics of the local government, NR administration, village committees, relevant NGOs, regulatory measures from NR management, and local norms for natural resource use and extraction. Subsystems look into the processes through which decisions on SES management are made, implemented, reformed, and reinforced [44]. The process centers on actors who are guided by governance procedures that prohibit, permit, or require participation—at various hierarchical levels—to collectively act and, correspondingly, produce an outcome [40].

The social, economic, and political setting (S^i) describes how the NR SES is affected or may affect the broader socio-economic, political, and ecological context in which they are embedded [44]. The attributes of this subsystem are comprehensive and complex to interpret. As a result, it is vital to clarify the setting (i.e., of the SES) due to unclear boundaries and, potential, externalities [44]. NRs located within a county, as well as those which span over more than one, follow a five-level top-down administrative hierarchical system in China. As such, most variables need to be defined at the county level within the relevant context [44]. The subsystem of the related ecosystem (RE^i), while less used in the existing literature, is also a challenge to identify. As a result, the conceptual framing observes the outcome as jointly determined by actors extracting resource units from the resource system, provisioning the maintenance of the resource system (i.e., in accordance with the regulations and procedures determined by the overarching governance), in the context of the related ecosystem and social, economic, and political setting. The extraction of resource units and the maintenance of the resource systems are major characteristics of the subsystem of interaction (I^i).

In our scope to develop causable relationship between CF management and village net economic benefit, in relation to conservation [45,46], the SES framework falls short. It does, however, offer a close connection with collective action theory [47–49], common-pool resource theory [50–52], and game theory [53–55]. A recent study combined the SES framework with the NR—community conflict theory, revealing determinants of the conflicts in the Taibai Mountain National Reserve, China [56]. As a framework, SES provided the setting for contextual and process variables [40,57]. The conceptual idea is to elaborate the core framework subsystems and use them to analyze the SES of NRs by way of four parameters: Level of development, economic growth, conservation willingness, and relationship between NRs and village life. We can apply these parameters to measure (or interpret) the role of the SES in our study. In examining this matter, we developed a hybrid psycho-economic model built on the psychological orientation and eco-friendliness to economics (Figure 2). The hybrid psycho-economic model is founded on the basis of Liu et al.'s [42] relational categorization of harmonious versus conflictual scenarios. It is presented with reference to the three NR case studies investigated.

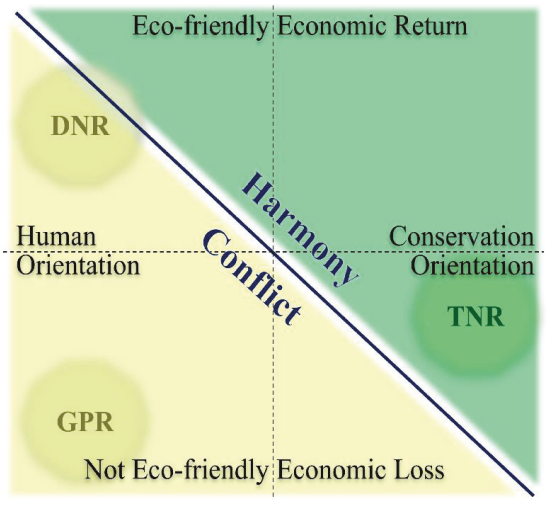

Figure 2. Hybrid psycho-economic model; TNR = Changting Tingjiangyuan National Nature Reserve; DNR = Dehua Daiyunshan National Nature Reserve; GPR = Fu'an Guaxisuoluo Provincial Nature Reserve.

3.2. Study Area

For the study, Fujian Province was selected due to the number of CFs located within its NRs. Fujian is located in South China and is top ranked nationwide in terms of forest coverage (i.e., 63%) in which 89% are CFs [33]. As a pilot province in CF best practices, Fujian participated in the 2003 CF reforms. At present, the province has 89 NRs, among which 15 are national nature reserves (NNRs), 21 provincial nature reserves (PNRs), 9 municipal level NRs, and 44 county-level NRs [58]. Three reserves were selected for the study: (1) Changting Tingjiangyuan National Nature Reserve (TNR) (i.e., a less developed reserve) facing minor economic loss, strong willingness to conserve nature, and strong levels of harmony; (2) Dehua Daiyunshan National Nature Reserve (DNR) (i.e., a medium developed reserve) fostering positive economic return, strong willingness to develop, and low levels of conflict; and (3) Fu'an Guaxisuoluo Provincial Nature Reserve (GPR) (i.e., a highly developed reserve) coping with large economic loss, very strong willingness to develop, and very high levels of conflict (Figure 3). The NRs were chosen from a workshop held in Fujian with NR management experts and officials as well as provincial administers in the first week of July 2018. Criteria for case selection relied on data representation and availability in conjunction with the hybrid psycho-economic model inference (i.e., each NR having a different harmony–conflict status).

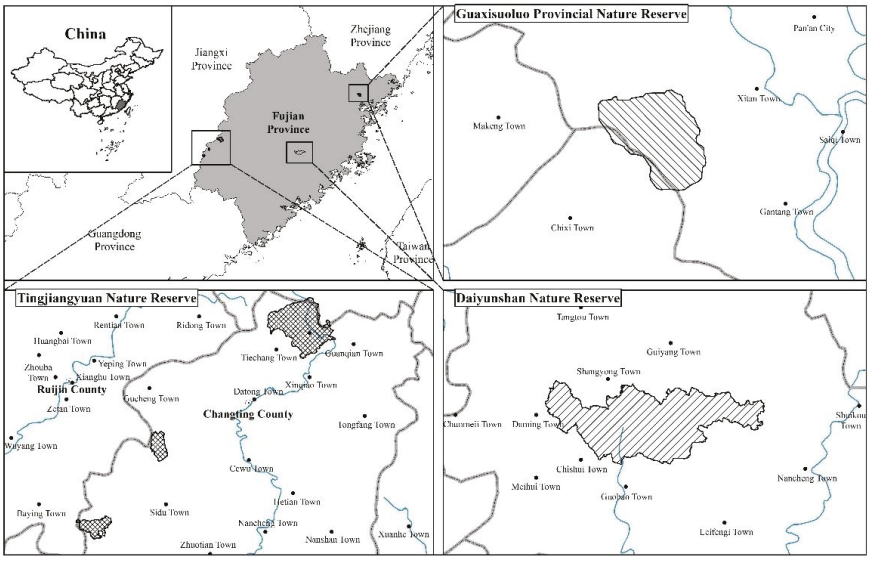

Figure 3. Geographic location of the three NR case studies in Fujian Province, China.

The social and economic characteristics of the counties and cities situated within the three case studies are heterogeneous in nature (Supplementary Table S1). Of the three, Changting County has the highest forest coverage, which is 2% higher than in Dehua County and 12% higher than Fu'an City. The average ratio of forestland versus rural inhabitants is smallest in Fu'an City and largest in Changting County. The gross domestic product (GDP) of Fu'an City ranks highest, dwarfing the other two counties twice over; however, the average gross domestic product (AGDP) of Dehua County tops Fu'an C by 5% and Changting County by 40%. The rural population with the highest net income per capita is found in Fu'an City while the lowest is in Changting; the income gap should also be noted as overwhelming. The rural population in the NRs has a much lower net income on average. It should be noted, in its favor, Changting County has unusually strict environmental policy in which curbing water and soil erosion as well as biodiversity conservation are emphasized.

3.3. Variable Selection

Based on the SES theoretic framework [22,41,57,59] and associated empirical studies (e.g., Williams and Tai [40] and Delgado-Serrano and Ramos [44]), we defined 19 second-tier variables from six broad first-tier ones, and then further delineated 22 third-tier variables from the second-tier ones. The related ecosystem (RE^i) from the first-tier variables was not incorporated due to the difficulty of diagnosing them in relation to the three NR case studies. The relevant secondary- and tertiary-level (i.e., profounder) variables were dependent on particular questions investigated, type of SES, and analyzed spatial and temporal scales [22]. One key inquiry to designing the study was to determine the outcome (O^x) of the SES central to the NRs' handling of their CF area. The collective forest in the nature reserve ($CFNR^i$) is one sector of the NRs' resource system and is of primary concern. Among the nine second-tier variables identified by Ostrom [22], this study utilized only one variable for resource size ($CFRS^3$) to indicate the heterogeneity of the CF in different NRs. $CFRS^3$ was decomposed into two third-tier variables: Ratio of CF in NR to the area of NR ($CFRS^{3a}$) and ratio of CF plantation in NR to the area of NR ($CFRS^{3b}$). Moreover, we selected two second-tier variables, including resource value ($CFRU^4$) and number of units ($CFRU^5$), from the first-tier variable CF resource units ($CFRU^i$). The number of units was further decomposed into two third-tier variables: Number of timber forestland ($CFRU^{5a}$) and number of bamboo forestland ($CFRU^{5b}$).

From the first-tier variable actor system (AS^i), we selected four second-tier variables: Relevant actors (AS^1), socioeconomic attributes of users (AS^2), leadership (AS^5), and importance of resources (AS^8), followed by seven third-tier variables: Economic attributes of villagers (AS^{2a}), social attributes of villagers (AS^{2b}), dependence on bamboo (AS^{8a}), dependence on other nature-based products (NBPs) (AS^{8b}), and dependence on CF for tourism (AS^{8c}). From the first-tier variable governance system (GS^i), we selected six second-tier variables: Government organization (GS^1), NGOs (GS^2), network structure (GS^3), property rights system (GS^4), operational rules (GS^5), and collective-choice rules (GS^6), as well as six second-tier variables: NR administration (GS^{1a}), village committee (GS^{1b}), social network (GS^{3a}), market network (GS^{3b}), rules for participatory conservation (GS^{5a}), and rules for participatory alternative livelihood (GS^{5b}). As recognition of the significant difference of the social and economic disparity in the selected study areas, we chose two second-tier variables from the first-tier social, economic, and political setting (S^i). The second-tier variable of economic development (S^1) was formulated into two third-tier variables: AGDP (S^{1a}) and industrial structure (S^{1b}). The other second-tier variable government resources policies (S^2) were broken down into three third-tier variables: Government regulatory and policy framework (S^{4a}), environmental policy (S^{4b}), and compliance of environmental regulatory and policy framework (S^{4c}). Among 10 second-tier variables that stemmed from the first-tier variable interaction (I^i), we selected information sharing (I^2), conflict resolution (I^4), investment activities (I^5), self-organizing activities (I^7), and networking activities (I^8).

3.4. Data Collection

A qualitative approach was used for data collection followed by a qualitative content analysis to code and analyze themes and patterns. Field data collection was carried out through a formal field survey from August to September 2018 (see Supplementary Table S2 and Supplementary Data S1 for sample questionnaires). A preliminary pilot survey was conducted beforehand in July 2018 to refine the survey plan. A series of semi-structured and structured interviews with key informants, including leaders and other cadres of village committees, elders, and prominent people in a clan as well as other parties (i.e., villagers hired by the NRs, ordinary villagers, officers of the NRs, officers in the county-level forestry department, staff members of relevant NGOs, tourism operators, and other stakeholders) was undertaken. Four focus group sessions were held: Three at the NR level and one at the provincial forestry administrative level. Focus group sessions were held in a participatory manner in which participants were encouraged to articulate historical evolution of subsystems within the NR SES (i.e., governance processes, resource dynamics, and use and institutional reform of CFs). Independent observations were used to oversee interaction between villages and NRs as well as evaluative data pertaining to the CF management outcome. Collection also included informal publications about NR management, implementation of CBCM, CF tenure reform, and local educative development for recommendations and policy improvement.

Qualitative content analysis was used to code data and analyze the subject patterns. A quantitative method was employed to support the use of the qualitative analysis. In analyzing the variable of the size of the CF resource ($CFRS^{3a}$), we made a comparative analysis of the ratio of CF in the NR, in that it was identified as being extremely high if the ratio was larger than 80%, and high if the ratio ranged between 60% and 80%. To assess the CF resource value ($CFRU^4$), we synthesized responses from villagers and NRs to get a primary result. We further collected information about forest types, forest stock, forest quality, and unit market price, and used them to testify the results on the CF resource value. The identified actors (AS^i) were based on the interviews, second-hand data collected from relevant yearbooks, and our own independent field observations. To evaluate leadership (AS^5) and its association with CF management outcomes, we analyzed three outcomes: (1) Major events held by the leader of the village committees, (2) trust of villagers in their leader, and (3) attitude of NRs to the leader. Strong leadership was inferred by the head of a village for leading collective action and balancing village development with nature conservation as well as villager livelihood. Further explanation of this variable is elaborated upon within the literature [41,51,57] and the results. Note, some sampling bias

should be considered, since the three NR case studies investigate all three different types of CBCM and compared them across cases [38]. The assessment also allowed for the examination of SES framework variables by cross-scale and cross-level interactions occurring over time. That, in and of itself, makes it difficult to isolate specific variables as well as their causal relationship in determining outcomes [40].

4. Results

CF management is a core part of NR SES management; it is an ongoing interactional process in which outcomes are determined jointly by the interactions at all levels of governance (i.e., they are based upon characteristics of the resource system, resource units, and actors) in the context of the specified social, economic, and political settings. A breakdown of the three NR SESs indicate that subsystems vary and differ from one another. The analyzed results for the NR SESs are itemized using the core framework subsystems in tabular format.

4.1. Community Forest Resource System and Resource Units

All three NR case studies had a higher ratio of CF embedded within their NR area ($CFRS^{3a}$). Features of each CF differed as seen in Table 1. In TNR, the CF accounted for 72.1%, with a size of 7488.1 ha in comparison to all land and 76.5% of total forestland. A small portion of CF (i.e., 221 ha) exists as plantation, with the remainder in a state of natural regeneration. The plantation consists of 8 ha of bamboo and 213 ha of timber forest. Bamboo is ranked as the top source of cash (i.e., income) for villagers. In DNR, the CF accounted for 86.6%, with a size of 11,661.5 ha of all land, with 89.9% total forestland. A total of 1137 ha is plantation and the remainder CFs are under the state of natural regeneration. The CF plantation consists of 47.7 ha of bamboo, 1088.48 ha of timber forest, and 0.82 ha of shrubs. In GPR, all forests (i.e., amount to 1289.83 ha) are collectively owned, of which 91.5% (i.e., 1179.8 ha) are planted by villagers for individual investment. The forest plantation consists of 152.6 ha of bamboo, 917.1 ha of timber forest, and 110.1 ha of shrubs. The timber forests have matured and are of high economic value ($CFRU^4$). Villagers continue traditional practices by producing non-timber products, such as medical herbs, tea, mushrooms, and honey, for cash and subsistence. Resource dependence varied across TNR, DNR, and GPR (AS^8). In TNR, local villagers had a low dependence on CF resources in the NR with a relatively low cash income. In DNR, local villagers had a high dependence on indirect use of the CF for tourism and cash income (AS^{8c}), which meant less reliance on bamboo and other NBPs for cash income and subsistence (A^{8a}, AS^{8b}). In GPR, local villagers had a strong dependence on the direct use of timber ($CFRU^4$) and bamboo (AS^{8a}).

Table 1. Comparison of resource system (RS^i) and resource units (RU^i) in TNR, DNR, and GPR.

Notation	Variable	Working Definition	TNR	DNR	GPR
$CFRS^i$	Community forest resource system				
$CFRS^3$	Size				
$CFRS^{3a}$	Ratio CF in NR:NR	Ratio of CF in NR to NR area	High	Extremely high	Extremely high
$CFRS^{3b}$	Ratio CF plantation:CF in NR	Area of collective forest plantation in the NR	Low	Somewhat low	High
$CFRU^i$	Community forest resource units				
$CFRU^4$	Resource value	Economic value of the collective forest resource	Low	High	High
$CFRU^5$	Number of units				
$CFRU^{5a}$	Number of timber forest	Total number of collective timber forest resource	Low	High	High
$CFRU^{5b}$	Number of bamboo forest	Total number of collective bamboo forest resource	Low	Medium	High

4.2. Actor System

Among the three NR SESs, actors varied significantly while dependence on CF resources was mixed (Table 2). TNR spans across 5 townships and 15 administrative villages affiliated to Changting County (i.e., 12 administrative villages that are partially located within the NR, totaling 36,812 villagers,

and 3 villages fully located within the NR, totaling 4420 villagers). Most villagers lived along the buffer and experimental zones, with less than 10% living within the core. Most villagers have a similar source of income, such as off-farm work, crop cultivation, and bamboo harvesting. A high number of direct users of the CF (A^{1a}) usually generate potentially high forest dependence and stress, which echoes the village dependence on bamboo (A^{8a}). DNR spans across 6 townships and 22 administrative villages affiliated with Dehua County. There are 20 administrative villages that share a border crossing with the NR, with 31,774 villagers, and 2 villages located solely within the NR, with 2200 villagers. Most villagers live off farming, crop cultivation, and bamboo harvesting. Rapid development of tourism is also prevalent; as such, tourists (A^{1b}), as indirect users, have increased rapidly in recent years, which has led to a high dependence on expanding the CF tourism market (A^{8C}). GPR spans over two townships and seven administrative villages. None of the administrative villages are completely located within the PNR; however, 10 natural villages (i.e., one tier lower than an administrative village) are inside it. The total population is 5796, of which 4236 villagers live in the PNR and 1561 near it. All five villages have common features of a lesser developed economy.

Table 2. Comparative results from the actor system (AS^i) in TNR, DNR, and GPR.

Notation	Variable	Working Definition	TNR	DNR	GPR
AS^1	Relevant actors				
AS^{1a}	Direct users of natural resources	Number of direct users of the CF per m^2	Medium	Low	High
AS^{1b}	Other actors	Number of tourists in the NR	Slow growth	Rapid growth	Slow growth
AS^2	Socioeconomic attributes of users				
AS^{2a}	Economic attributes	Economic condition of villagers	Mostly poor	Few wealthy, mostly middle class	Mostly poor
AS^{2b}	Social attributes	Ratio of adults failed to afford marriage	Low	Low	High
AS^5	Leadership patterns	Ability of village head committee to lead collective action	Strong	Strong	Weak
AS^8	Resource importance				
AS^{8a}	Dependence on bamboo	Villager dependence on bamboo for livelihood	High	Low	High
AS^{8b}	Dependence on other NBPs	Villager dependence on other NBPs for livelihood	Mostly medium	Mostly low	Mostly medium
AS^{8c}	Dependence on CF for tourism	Villager dependence on CF for tourism	Low	High	Low

4.3. Governance System

Both TNR and DNR administrations are stronger and more independent than GPR (GS^{1a}). In line with the leadership of the village head (A^5), the capacity of village committees in TNR and DNR is higher than that of GPR. TNR's administration began as an affiliate to Changting's forestry administration. Three years after its promotion, CNR's administration became an independent organization of the Changting County government (i.e., in 2017), one tier higher than the county forestry administration and township government. DNR's administration was established, along with being designated an NNR, in 1985 and is affiliated with the Dehua County government (i.e., with minimal executive authority). Along with an NNR upgrade in 2015, DNR administrators are direct subordinates to the county government, one tier higher than the county forestry administration and township government. The GPR administration was initially established as a division affiliated to the Fu'an Forestry Administration Bureau in 1996. Soon after, in 1999, it was upgraded to a PNR in which the division has remained the same ever since. The PNR administration is one tier lower than the executive setting of township governments. Finally, non-governmental organizations (NGOs), as a whole, play a positive role in the management of CFs throughout much of the NR; for example, there

are multiple NGOs that promote CF management within TNR and some that reduce conflicts in DNR. In GPR, however, their absence may be reflective of severe conflict and lack of mediation (Table 3).

Table 3. Comparison of the governance system (GS^i) in TNR, DNR, and GPR.

Notation	Variable	Working Definition	TNR	DNR	GPR
GS^1	Government organization				
GS^{1a}	NR administration	Tier for authority of the NR administration	National	National	Provincial
GS^{1b}	Village committee	Capacity of the village committee	Strong	Strong	Weak
GS^2	NGOs	Presence of NGOs	Present - Multiple	Present -Some types	Absent
GS^3	Network structure				
GS^{3a}	Social networks	Vertical and horizontal partners in co-management	Strong	Strong	Weak
GS^{3b}	Market networks	Vertical and horizontal partners in commence	Weak	Strong	Strong
GS^4	Property rights system	Restriction on villager rights to CF use	Partially	Partially	Largely
GS^5	Operational rule				
GS^{5a}	Rules for participatory conservation	Rule for village participation in conservation	Strong	Medium	Weak
GS^{5b}	Rules for participatory alternative livelihood	Rule for village participation in determining alternative livelihoods	Strong	Medium	Weak
GS^6	Collective-choice rules	Rules defined by actors according to local environmental, economic, and political condition	Strong	Medium	Weak

In terms of network structure, a robust social network in TNR and DNR contributes to nature conservation (GS^{3a}) while strong market networks in DNR and GPR provide incentives to exploit nature resources (GS^{3b}). In TNR, operational rules encourage and guarantee villages the ability to participate in nature conservation and encourage alternative sources of income (GS^{5a}, GS^{5b}); however, in GPR, such operational rules are hardly observed. Collective-choice rules in TNR are also strong through effective decision-making mechanisms at the NR SES level.

4.4. Social, Economic, and Political Setting

This study analyzed variables of social, economic, and political settings (S^i), which supplies an understanding on how SESs operate and influence exogenous factors (Table 4). Executively, Fu'an City is at the same setting as Changting County and Dehua County. Fu'an City's population is larger than the other two and fosters advanced secondary and tertiary industries. In terms of the AGDP, Changting County is much less developed than Dehua County and Fu'an City (S^{1a}). Dehua County, on the other hand, is undeveloped agriculturally, instead focusing on tourism development, which encourages villagers in the NRs to explore CF tourism (S^{1b}).

Table 4. Comparison of the social, economic, and political setting (S^i) in TNR, DNR, and GPR.

Notation	Variable	Working Definition	TNR	DNR	GPR
S^1	Economic development				
S^{1a}	AGDP	GDP value per capita in 2018	Low	Medium	Medium
S^{1b}	Industrial structure	Importance of the tourism industry	Medium	Extremely high	Medium
S^4	Government resource policy				
S^{4a}	Government regulatory and policy framework	Governmental regulatory and policy framework for natural resource management	Strong and effective	Strong and medium	Weak and medium
S^{4b}	Environmental policy	Level of implementation and policy direction	Extremely strong	Strong	Weak
S^{4c}	Compliance of environmental regulatory and policy framework	Compliance of inhabitants to governmental regulation, policy, and management	Strong	Medium	Weak

Resource-based policy at the county and higher levels has significant impacts on properly managing CFs throughout the NRs. Development policy boosts village motivation to expand the tourism industry in DNR (S^{4a}). The stringent policies in environmental protection in TNR (S^{4b}) enable inhabitants and other actors to follow governmental regulatory and policy for NR management (S^{4c}) when CF-based activities are implemented (AS^{1b}). An observed issue that requires attention is overly enthusiastic tourism development, which can create conflict with NR management in Dehua County.

4.5. Interaction

While subsystems, such as the resource system, resource units, actor system, and governance system, provide the backbone for the NR SES' interactions (I^i), including: Information sharing, deliberation process, conflict resolution, investment activities, self-organizing activities, and networking activities, the determined outcome is condition-specific. The results illustrate findings from the six interactions, linking relevant variables in the three NR case studies (Table 5).

Table 5. Comparison of interaction (I^i) in TNR, DNR, and GPR.

Notation	Variable	Working Definition	TNR	DNR	GPR
I^2	Information sharing	Sourcing to keep communication between NRs and villages	Strong	Strong	Weak
I^3	Deliberation process	Deliberation for alternative livelihoods	Present	Present	Absent
I^4	Conflict resolution	Workshop or dialogue to address conflict and reach amenable conclusions	Present	Present	Absent
I^5	Investment activities	Building of human and resource capacity in SES	Strong	Medium	Weak
I^7	Self-organizing activities	Collective action activities in governing SES	Strong	Medium	Weak
I^8	Networking activities	Liaison between horizontal and vertical partners to collective action	Strong	Medium	Weak

Information sharing. In TNR and DNR, information sharing (I^2) was active through well-operated village committees (GS^{1b}) under strong leadership (AS^5). The presence of NGOs (GS^2) also facilitated information sharing through environmental awareness, education, and outreach for villagers. Both Changting County and Dehua County had sound government regulatory and policy action for the management of natural resource (S^{4b}) and effective environmental policy (S^{4c}), which benefitted the NR and villages. However, GPR's weak leadership, i.e., the head of the village committee (AS^5, GS^{1b}), absence of NGO support (GS^2), and ineffective regulatory and policy implementation (S^{4a}, S^{4b}) jointly resulted in limited information sharing among actors (AS^{1a}, AS^{1b}).

Deliberation process. Due to weak leadership and self-governance in the associated villages (AS^5, GS^{1b}), the lower tier executive setting for GPR (GS^{1a}), undeveloped social networks (GS^{3b}), and operational rules that failed to convince villagers (GS^{5a}, GS^{5b}) strained the effectiveness of the

deliberation process in GPR SES. As such, operational rules (GS^{5a}, GS^{5b}) did not align with the development of the villages and villager livelihood (i.e., CF management could not be modified through the deliberation process (I^3)). Conversely, the presence of valid deliberation in CNR and DNR contributed to the prevention and alleviation of CF management conflict (I^4) and successfully integrated a number of alternative livelihood options for villagers by reducing the dependence on natural resources (A^{8a}, A^{8b}).

Conflict resolution. Conflict in DNR and GPR has been more intensive than in TNR for more than two decades. It was found that the ratio of CF in DNR and GPR was higher than in TNR ($CFRS^{3a}$). As such, correlative findings of CF plantations, for instance, in GPR at 78%, were a major cause of the conflict under CF management ($CFRS^{3b}$). The high economic value of CF resources for DNR ($CFRU^4$) are dependent on the rapidly increasing tourism industry (AS^{1b}), supported by the local county government (S^{1b}). In TNR, a set of tools (GS^{5a}, GS^{5b}), consisting of dialogue, workshops, and mediation, organized by the co-management committee, play an active role in resolving its conflicts. Moreover, conflict resolution (I^4) gained support from regulatory laws and policies at the county level (S^{4a}, S^{4b}, S^{4c}). The conflicts in DNR seem to be more complex, in that appeals from villagers to develop tourism have been prioritized. In GPR, the conflicts were even more complex due to the low compliance of villagers in obeying governing rules, absence of valid tools to alleviate high pressure conflicts, and strong appeal to harvesting timber from the CF plantation (i.e., the issue that has predominantly overshadowed much of the discord).

Investment activities. Investment activities (I^5), including building human capacity and improving resource quality, were strong in TNR and DNR but weak in GPR, as NNRs (GS^{1a}), i.e., TNR and DNR, received free training and entrepreneurial opportunities organized by the central government. Financial investment also covered improving the condition of natural resources and their value ($CFRU^4$). Historical and on-going project development that combats against water and soil erosion (S^{4b}) contributes to enhancing leadership TNR-wide (AS^5). The village heads in DNR stressed strong leadership as fundamental to tourism promotion (S^{4a}, AS^5). The Fu'an City government mostly funded GPR with a limited budget and financial support package from the provincial-level government.

Self-organizing activities. The primary self-organization (I^7), viz., the village committee, existed in all villages in all three NR case studies. The village committees played different roles in CF management in each of the NRs, including diverse leadership by committee heads (AS^5) and collective action as actors (GS^6). In GPR, the weak role of the village committee in CF management determined much of the property rights system (GS^4), conflict intensity, and environmental regulatory and policy framing (S^{4a}, S^{4b}, S^{4c}). The co-management committee in DNR played a less positive role in CF management even though it possessed the same strong self-organizing capacity as TNR. It can be presumed, since the villagers in DNR had higher intentions to make use of the CFs for tourism, and not strictly for conservation, a discrepancy in self-organization has been established.

Networking activities. Within both TNR and DNR, multi-tier and multi-scale networks with the NR administrative bodies (GS^{1a}), village committees (GS^{1b}), and relevant executive departments at the county and higher levels as well as NGOs (GS^2) were built, creating a strong networking environment. The presence of several NGOs expanded network capacity by interlinking and leveraging resources to strengthen CF management in the respective NR. In comparison, weak leadership in GPR resulted in a weak structured network and a poor level of support (i.e., resulting in ineffective management of the CF (AS^5)). However, it is worth noting that TNR had a unique social network, consisting of Hakka people from abroad, offering an immigrant support system that the CF management could utilize (GS^{3a}).

4.6. Outcome

In terms of outcome (O^i), TNR had strong CF management developed via strong leadership of village committees, effective prevention, and conflict resolution mechanisms. Its strong self-organization and collective action, appropriate dependence on CF resources without negative impact on the NR,

horizontal–vertical social network, and sound social, economic, and political setting made for a harmonious scenario. In DNR, CF management experienced low-to-medium levels of conflict caused by disparity between the booming tourism industry and CF management regulations in the reserve. In GPR, CF management faces severe conflict centered on CF plantations located within the NR and recent strife with overdevelopment.

5. Discussion

Application of Ostrom's [22] SES framework supplied a precise diagnostical experiment of three case studies of CF management in NRs [41,57,59]. The implementation of the framework identified vital processes and contextual variables as well as their interactions associated with CF management outcomes. Derived from the existing literature, this study explored several three-tier contextual variables and first-tier variables of social, economic, and political settings in which the adaptive process complimented the SES framework. As such, this work can assist in developing the framework by building a classification of variables related to CF management and NR best practices. The application of Ostrom's [22] diagnostic framework reveals that management of CFs in NRs is a process of self-organization, networking, conflict resolution, and capacity-building within specific conditions jointly determined by social, economic, and political factors.

Notedly, McGinnis and Ostrom [41] contended that the SES framework is theory neutral even though early studies of the framework relate to the common pool resource theory and public governance theory [41]. Multiple-tier variables channel the analysis by presenting, instead of explaining, different CF management outcomes formed in each of the three NR cases. The hybrid psycho-economic model enables us to set up a causable relationship between the CF management outcome and process and contextual variables. In the hybrid model, psychological orientation and economic impact differentiate village attitudes to NRs, which have a determinate impact on CF management. The psychological orientation and economic impact of the villagers are formed in the dynamic process of the relevant SES. For example, villagers in TNR are conservation orientated due to long-term environmental campaigns supported by central and provincial governments. Confronted with economic loss by inadequate compensation to the CF within TNR, villagers continue to have a semi-negative attitude within the NR. To this sense, the psychological perspective is overdrawn by physical shortage. This is a new finding compared to existing research that links SES and NR–community conflict theory [56]. Human orientation and psychological perspective, however, require additional observation to overhaul the prevailing development economics dominating much of rural China. In comparison, villagers from DNR and GPR have the same human orientation and belief system (i.e., psychological perspective), but suffer much more in terms of economic hardship. Hence, it can be said that CF management is more of a problem in these conflict areas rather than in TNR. The differences in economics for each of the three NR case studies form the interactive process between each of the SES subsystems. The seven interactions in TNR are in good operation with sound performance, which is rooted in the effectiveness of the governance at the actor level—especially in terms of resource utilization. Compared to TNR, villagers both in DNR and GPR are restricted in terms of resource utility, which creates severe economic loss.

The act of NR reservations is not solely to foster sustainability [40]. NRs are complex and dynamic systems with much uncertainty. All subsystems are in the process of evolution, which jointly determines the operation of the whole SES. Each subsystem interacts with the other, affecting the outcome as a collective unit. Policymakers need to deepen their understanding of the complexity of socially and ecologically oriented NR systems to enhance sustainability. CF management problems are rooted in the connectivity of CFs within NRs. As such, more appropriate economic compensation is needed to offset economic loss caused by CFs, especially for the NRs with abundant CF plantations. The poverty of villagers in NRs should attain more attention from NR authorities and the government in general. For example, villagers in GPR are easily affected by market demand and prone to exploitative forces. As such, alternative income needs to be created with active participation of local villagers in line with sound nature conservation. Village leaders play an important role in village development and nature

conservation since they are usually better informed and have more involvement in capacity building. Finally, increasing the participation of the local population will provide a more stable social structural foundation of adaptation and transformation in overall SES sophistication (i.e., framing) [60].

Next, the vertical and horizontal networks also need to be developed further. At the vertical perspective, NRs should be supported from higher levels of government and foster stronger capacity for autonomy (i.e., self-organization) and collective choice below the village level. At the horizontal, multiple government departments should be organized to establish a cooperative management council for conflict resolution in CF management, reinforcement of NR management, and promotion of harmonious activities between village development and nature conservation. Additional NGOs should be engaged in promoting environmentally friendly development and furthering nature conservation by way of positive modelling via NR SES management. The integration of all actors will promote collaborative environmental governance to minimize environmental impact [61]. In terms of the dynamic characteristics of SES, a monitoring system is needed to understand the evolutionary process of NR SES as well as offer supplementary evidence for NR SES best practices and management.

This study developed the theoretic framing of SES by way of empirical research. Involvement of the social, economic, and political settings is a subtle extension of the practical application of a SES framework. Further studies are needed in the following two fields. First, social networks (GS^{3a}) at the village level are very complex intensive, in that informal social norms in rural China must be respected. Thus, villagers often originate from different clans and follow household (i.e., family) rules versus the village head. That is, the presence of multiple families and clans in one village can create a complex problematic horizontal network. Second, the analysis of relevant actors (AS^{1}) can be improved by enlarging the size and scale of the NR SES. This would enlarge the number of shareholders making direct and indirect use of natural resources, resulting in better system results. It should be noted that features from direct and indirect users differ from each other. Attributes with social and economic backing should be carefully assessed and differentiated. As such, we agree with Ostrom's [22] conclusion that no panacea solution for natural resource management exists; however, each case and relevant study, when treated uniquely, adds to the knowledge base and SES framework puzzle.

6. Conclusions

As a diagnostic study, we presented different CF management settings in NRs based on Ostrom's SES framework. The application of the hybrid psycho-economic model provided an explanation for the differing results of CF management for each SES. Among the three NR case studies reviewed, TNR had a harmonious relationship in terms of CF management; however, DNR experienced low-to-medium levels of conflict and GPR was severe. The different outcomes of CF management are determined by the interaction of villagers' psychological orientation and economic effect, which determines the dynamic processes of the SES. We explored typically important impacts on environmental policy—a third-tier variable of the social, economic, and political setting—regarding the formulation of villages' psychological orientation. We found that the increasing actors, especially new actors, along with the restriction of expanding resource utilization, lead to conflict as seen in DNR. For GPR, serious conflict occurred due to hostility by villagers toward the NR and the severe economic loss of mature forest plantations within the reserve area.

Different from a traditional study with a static review [23], the SES framework enabled this study to follow a dynamic perspective of the research, in which changing conditions may have influenced the CF outcome. Hence, this expanded the concept of resource use, patterns of interaction, and institutional interplay by illuminating influences within the NR management outcome [40]. Due to the weak governance capacity at the NR administrative level, e.g., the hostile attitude from DNR villagers, a lack of mitigation measures is a partial problem. As such, over the course of the study, the forest plantation increased in value, further aggravating hostility, and thus demanding that the NR administration prioritizes more resources in resolving the issue. At present, the NR administration is working on piecing together capable means of resolving this matter—creating something that is often

called a dead loop [62]. Conversely, a similar cycle existed in the SES for TNR. In all, the application of Ostrom's [22] SES framework addresses the issue of absence, a common analytical framework that natural resource managers have been improving upon for the better part of a decade. The selection of variables and tier settings has nuanced differences in empirically run experimentation, sparking research gaps in the SES framework as well as future development needs. Moreover, in terms of NRs in China, feasible economic compensation for villagers affected by CFs in NRs—accompanied by a sound environmental lifestyle—should be prioritized as the top issue.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/24/6929/s1, Table S1: Primary information of the sample nature reserves, Table S2: Questionnaire on collective forest management in national nature reserve, Data S1: Questionnaire on management and utilization of national nature reserve and surrounding communities and collective forests.

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Sustainable Transformative Economy: Community-Based Ecotourism

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Abstract: Ecotourism has a high potential impact on remote communities, by improving economic opportunity and natural resources conservation, and is increasingly accepted as an alternative livelihood for rural people. This study examines ecotourism development from the perspective of participation and economic impact for the Bousra people in Cambodia. A total of 237 households were selected as the sample size. Data collection was carried out with face-to-face interviews and analyzed using logistic regression and ordinary least square methods. Results revealed that local households depend mostly on agriculture (i.e., crop plantation and farming) and utilize ecotourism as a secondary source of income. Most households acknowledged ecotourism had a positive impact on environmental, social, and economic perspectives, while some signaled negative backlash due to depleted natural resources and impact on local culture. Household participation in ecotourism was not significantly affected from assistance issued by government or non-governmental organizations. However, causal relationships were found based on household demographic factors, attitude to environmental conservation, and village life. It was shown that the percentage of people involvement in ecotourism is high, but their income percentage is low due to education, skill, and capacity to expand. As a low-impact alternative to standard commercial tourism, community-based ecotourism has potential in becoming a transformative form of economics for local communities.

Keywords: ecotourism; community livelihood; participation; sustainable tourism; income; Cambodia

1. Introduction

Ecotourism is responsible travel to a natural area that conserves the environment, sustains the well-being of local people, and integrates interpretation and education [1]. The 2002 Quebec Declaration on Ecotourism recognizes the principles of sustainable tourism by incorporating the environmental, social, and economic impacts of tourism [2]. In this study, ecotourism is specified as community-based ecotourism (CBE) and identified with rural, sustainable tourism focused on rural livelihood. Manu and Kuuder [3] state that it has been considered one of the fastest growing sectors as an alternative means of tourism to improving rural livelihood. As one of the developing countries located along the Greater Mekong River Subregion, Cambodia, along with other countries like China, Myanmar, Thailand, Laos, and Vietnam, has utilized ecotourism in poverty alleviation strategies—key to securing biodiversity conservation and solving economic disparity [3,4]. The Ministry of Planning has put together three scoping principles which form the basis for ecotourism in the country: (1) sustainability and environmental development go hand-in-hand, (2) promote its nature-based and rich cultural and historical heritage, and (3) boost tourism arrivals, expenditure, and diversity of tourist destinations via international marketing and infrastructure development [5]. Moreover, the mechanisms to develop ecotourism should expand into the private sector and encourage private investment by, directly and indirectly, bringing financial and technical growth to the community. Compared with conventional

tourism, largely systematized by the government, ecotourism development obtained more support by non-governmental organizations (NGOs) [6]. The first ecotourism site in Cambodia was established in 1998 at Yeak Laom Lake in Ratankiri province and has become a successful, locally managed project. In 2002, the Cambodian Community-Based Ecotourism Network (CBET) was established acting as an ecotourism umbrella organization, registering as an NGO in 2005 [6,7]. Some 464,000 tourists visited CBET sites in 2007 [8]. In 2013, there were 56 ecotourism sites in various regions across Cambodia, spanning the northeast, the Tonle Sap area, along the south coast, and the southwest [6,9]. It is predicted that by 2020, ecotourism could attract one million international and five million tourists [9,10]. Some ecotourism programs, such as the Chambok CBET program, have won public recognition, including in 2013 for socially responsible tourism [11] for engaging with local people to protect forests and improve local livelihood [12]. However, a recent study on Chambok reveals that there was no significant difference between the total income of villagers having ecotourism income and villagers without ecotourism income [9]. The impacts of ecotourism seem ambiguous and need further investigation.

There is a large, emerging body of literature within the discipline of ecotourism [2,4,5]. Among them, environmental impact from ecotourism is of high concern. There is also a focus on its role in enhancing environmental quality and providing an alternative to the exploitative use of environmental resources [13,14], as well as serious concerns highlighting natural resource depletion, pollution (i.e., air, water, sound, and waste), soil erosion, and loss of wildlife habitat in conjunction with the risk of forest fires [15–18]. Ecotourism must also take into account visitor limitation to avoid negative environmental backlash and impact [19–21]. As such, environmental impact is interconnected with socioeconomics, having long-term detrimental effects on the economic status of local people [22]. Similarly, the benefits of infrastructure development should be properly managed (i.e., from visitor influx) to avoid environmental degradation [22–25]. Ecotourism has multiple types of socio-cultural impacts [2], including am increase in the standard of living of local residents, socio-political empowerment, and respect for cultural diversity and human rights. Indirect incentives include improved infrastructure (e.g., health facilities and schools), awareness and education from tourism development, and positive attitudes toward conservation [2,14]. Ecotourism income can also aid in uniting actors and strengthen co-existence (e.g., Cuyabeno Wildlife Reserve, a biodiversity rich area in northern Ecuador [13]). As part of the increase in extra income, investment focused on the education of children can lead to the development of human capital [26] and safe-keeping of future generations. Ecotourism has challenged traditional gender roles, and extended women's household roles of cleaning and serving others [26]. However, high numbers of tourists can cause cultural erosion, an increase in alcohol consumption, and disease risk [13].

In all, ecotourism can be seen as a double-edged sword. On the one hand, its contribution to poverty alleviation, livelihood improvement, and diversification signal a positive impact [27–31], while negative environmental impacts, the risk of inflation, and cultural degradation indicate concern [27,32]. Ferraro and Hanauer [33] found that ecotourism activity accounts for approximately two-thirds of poverty alleviation impact based on the Human Poverty Index (i.e., taken from residents' employment status, household appliances, and utility expenditure). As socioeconomic status increases the livelihood of local people taking part in ecotourism, services also become more available. However, very few studies correlate this baseline data. Much speculation, by way of observation, suggests that it does [34,35]. Contrary to the positive impact, ecotourism might increase the popularity of a destination, triggering inflated tourist prices for goods and services due to which local people often suffer [22,36–38]. Moreover, overpopulated tourist areas can transitionally turn from ecotourism into conventional tourism, which then varies from the eco-objectives established [39–42]. Ecotourism may also worsen income inequality in the local community, even though it may increase the income of those working within it [9,43,44]. As such, their still remains the challenge of employing ecotourism to achieve poverty reduction and livelihood improvement in the community [9].

Another controversial concern is local resident participation in ecotourism. Once local residents have a strong voice in shaping tourism development, sound community of practice (CoP) outcome can

be achieved (i.e., community participation and stakeholder intervention) [22,35,36]. Ven [45] stated that local participation and CoP are key factors in ecotourism success and improved community solidarity [46]. However, local residents who have no, or limited, access to the local tourism market have a limited capacity to benefit [3,47]. Hence, capacity is limited to the availability of benefits for enhancing livelihood. Among successful ecotourism programs, example employment for local residents include working as a tour guide, cook, homestay host, guesthouse host, boat driver, motorcycle driver, sanitation worker, and forest patrol [6]. Among the few quantitative assessments of local resident participation in ecotourism, Kimengsi et al. [48] explored the effect of resident livelihood capital from ecotourism in the Western Highs of Cameroon. It was found that access to education and training showed an inverse relationship versus cultural festivals and wilderness and museum visits by adopting a principle component analysis in combination with the ordinary least square (OLS) technique [48,49]. Further findings suggest the application of structural models that consider that resident environmental knowledge can positively affect attitudes towards ecotourism, which in turn directly and indirectly determines intention to participate in the activity [39,48,50,51]. The robust result of factors affecting resident participation demands further quantitative studies.

The aim of this paper is to assess what factors affect local peoples' participation in ecotourism and how ecotourism contributes to their livelihood. Critical factors examine institutional factors, multiple stakeholders, and local communities who are living and working inside and around the project site by taking into consideration key questions. (1) In terms of services provided from ecotourism, what is the state of art for local communities' livelihood? (2) What are the main forms of local people participating in ecotourism? (3) What is the local people's perception of the effect of ecotourism to living within sustainable grounds? (4) How do institutional factors reflect on local people's activities in ecotourism? (5) What contribution does ecotourism play in local people's livelihood in terms of family income? A breakdown of the paper is structured as follows: Section 2 contains the methodology, Section 3 illustrates the results, Section 4 elucidates the discussion, and Section 5 concludes with recommendations for best practices.

2. Methodology

2.1. Study Site

This study was carried out in villages surrounding Bousra Waterfalls located in Picheada District, Mondulkiri province (Figure 1). Mondulkiri province is located in eastern Cambodia, is relatively remote, and most sparsely populated with large tracts of forest. The province is chock full of natural beauty, with thickly forested mountains, a large waterfall and lush green hills on its western end. In spite of this, the province suffers from the risk of deforestation caused by mining [51]. Most of the population in Mondulkiri is made up of ten tribal minorities, with the majority of them being the Chunchiet from the tribe of the Phnong. Local people lead their livelihood through traditional ways of cultivation (i.e., shifting agriculture), hunting, and collecting fruits from the forest [50]. Bousra Waterfall is the specific ecotourism-designed site and the major tourist attraction in Mondulkiri province. Ecotourism is locally defined as providing goods and services at Boursa Waterfalls as well as off-site in nearby villages. The waterfalls are 20 to 40 m in height and divided over three levels [51,52]. Bousra Waterfalls has been a key investment example of private sector development, namely from the private company Mayura Hill, which has taken over the management, development, and conservation of the waterfalls. The study site incorporates seven villages (i.e., Pu Til, Pu Lou, Pu Tib, Bousra, Pu Rang, Lam Mes, and Pu Cha) which surround upland forest and mountainous terrain—connected with Namlear Wildlife Sanctuary. The villages' vicinity to the ecotourism site (i.e., Bousra Waterfalls), access to local people, and willingness to partake in the research, as well as investment by the private sector made for optimum site criteria. In addition, the Cambodian government in collaboration with donors (i.e., private sector entities and NGOs) assisted local communities, living around the ecotourism site, to participate in developing job opportunities with the idea of ecosystem and culture conservation.

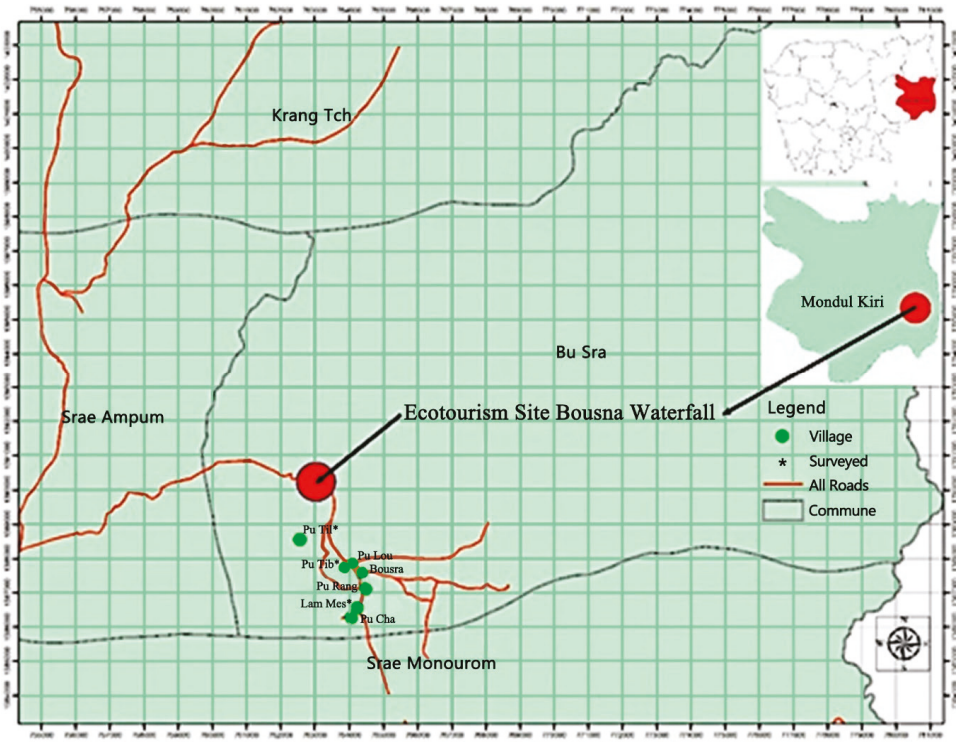

Figure 1. Map of study site.

2.2. Data Collection

The scope of this study examines three villages (i.e., Pu Til, Pu Tib, and Lam Mes) by adopting a stratified random sampling method, where all seven villages are stratified into three groups in terms of their distance to the ecotourism site (i.e., the nearest group was made up of only Pu Til, the medium group contained Pu Lou, Pu Tib, Bousra, and Pu Rang, and the farthest group Lam Mes and PuCha), followed by one village randomly being selected from each group. The three villages were composed of 581 households, with 2714 villagers (i.e., 1539 male and 1175 female). Most of the villagers are indigenous people (i.e., Bunong—an aboriginal Cambodian minority ethnic group), who, for the most part, survive via agriculture, off-farm income, ecotourism services, and non-timber forest products (NTFPs) collection. The Bunong people also perform a number of other activities such as small home-oriented businesses, scarf weaving, sold labor, and work as civil servants. Along with the development of ecotourism, traditional agriculture still dominates local peoples' livelihood throughout the area. Over 30% of the households base their livelihood on farming such as crop cultivation and livestock breeding.

For this study, 237 respondents of the sample households were selected randomly based on a list of names provided by the Bousra Commune administration as a sample size (i.e., 95% confidence interval with 5% marginal error) by using the Taro Yamane Formula [38,53], Equation (1).

$$n = \frac{N}{\left(1 + Ne^2\right)} \quad (1)$$

where n = sample size, N = total population of household, and e = allowable error (i.e., 5% = 0.05).

Questionnaires were designed to collect information regarding the demographic characteristics of the household head and family members, natural resource dependence, economic situation, ecotourism-related activities, attitude to environmental conservation, and impact of ecotourism (i.e., evaluation and outcome in terms of benefit and contribution received). A pilot questionnaire was performed in the village of Pu Til by testing the questionnaire with 10 households. This validation process assisted in refining the questionnaire format and pretesting the data collection process. Data was collected from September to October 2018. This study used primary and secondary data to analyze the results. Primary data was obtained from face-to-face interviews of each household in target villages performed via structural questionnaires that consisted of open-ended and multiple-choice questions. The questionnaire aimed to understand key livelihood activities, sources of income, and intervention-level from institutions. Secondary data was obtained from the Provincial Department of Tourism (PDoT), Provincial Department of Environment (PDoE), and relevant NGOs. Qualitative observation methods were also employed during the sample village interviews. Four additional measurements regarding the respondents' economic situation were noted, including clothing quality, sanitary conditions, house type, and transportation value.

2.3. Data Analysis and Method

Data analysis was interpreted by descriptive statistics and econometrics. The descriptive statistics were applied on the sampled household livelihood, participation in ecotourism, and perception on impact of ecotourism. Binary logistic regression conducted on the activities attributed to a binary stated-choice response; the applied results investigated how respondent participation is determined. Each variable in the model was coded as one if respondents answered "yes" to an ecotourism service, zero otherwise. Following the utilization maximization theory [54], respondents made decisions based on participation in ecotourism and their perceived utilization of it—jointly affected by their demographic characteristics (i.e., age, education, family size, and labor force) as well as other characteristics relating to ecotourism (i.e., distant to ecotourism site and native residential identification) [48,54]. A reduced form of the binary logistic regression model was applied, Equation (2).

$$\mathrm{PAR} = f(\mathrm{DEM},\ \mathrm{ECO},\ \mathrm{GOV}, \mathrm{NGO}, \mathrm{ATT},\ \mathrm{LOC}) \tag{2}$$

where PAR = household participates in ecotourism and specific forms, DEM = demographic factors (i.e., age, educational level, and residential identity of household head, and labor force), ECO = economic condition of household (e.g., income and sufficient funds), GOV = institutional impacts (e.g., government assistance), NOG = assistance from NGOs, ATT = household attitude to environmental conservation, and LOC = village location.

OLS regression analysis was used to investigate economic impact of ecotourism for the controlled demographic characteristics (i.e., age, labor force, residential identity), economic condition, and location. The dependent variable, economic impact, was used to specify family income, which is a continuous variable (i.e., allowing for the OLS regression application). As such, a reduced calculative form of the OLS regression was used, Equation (3).

$$\mathrm{INCOME} = f(\mathrm{PAR}, \mathrm{DEM},\ \mathrm{FUND},\ \mathrm{LOC}) \tag{3}$$

where PAR and LOC = similar definition but with different variables in comparison to the logistic model, DEM = same as the logistic model, and FUND = sufficient funds.

3. Results

3.1. Basic Characteristic of Households

Our total sample reviewed 237 households from three villages with different distances to the ecotourism site of Bousra Waterfall. We initially categorized residents into two groups, of which group

one consists of villagers participating in ecotourism (i.e., denoted as IN) and group two for villagers not participating in ecotourism (i.e., denoted as NOT). For those households participating in ecotourism (i.e., group one), further subcategorization was denoted for residents who only participated in ecotourism (i.e., denoted as ONLY) and for those who participated both in ecotourism and conventional tourism (i.e., denoted as BOTH). We then had 151 households in ecotourism and 86 households not in ecotourism, 32 households only in ecotourism and 119 household both in ecotourism and conventional tourism. Household characteristics showed that the age of the household head was approximated 39 years old, with slight differences among different groups. Nearly all household heads were male. The education levels of the household heads indicated only primary school levels were achieved, with mean levels ranging from the fourth to fifth grade. Most households are native and have lived in their villages for over 20 years. The results of the "IN" and "BOTH" groups indicate that native villagers have a higher participation rate both in ecotourism and conventional tourism.

The labor force of each household was the main factor that advanced the economics of the household—varying from two to five members, with a total mean value of 2.99. It was evident that some families did not have enough labor force to work their own agricultural land and thus earn enough money for livelihood enhancement. With limited education, their livelihood activities were weighed towards sold labor and survival skills as a basis for knowledge procurement. As a result, there was a correlative problem that isolated some of households from participating in social activities. Households mostly did not have good economic performance (i.e., average annual income per household equated to US$ 3510). Considering the average family size was six, the income per capita corresponded to US$ 2 per day. Over 70% of households faced insufficient funds for production activities. For the "ONLY" group, over 90% of households lacked sufficient funds.

Policy assistance from the government (i.e., PDoT and PDoE) had similar influential ratios with exception to a relatively low ratio reported by the "ONLY" group in regards to assistance from the PDoE. Compared to policy assistance from the government, assistance from NGOs resulted in a much higher influence. For all groups, over 80% of households received, at least once, assistance from NGOs.

Our sample was evenly distributed among the three villages. The distance from either of the three villages to the ecotourism site was seen as not a problem since the furthest is located only 7 km away. Problems were found with access and travel condition due to poor road conditions, especially during and after rain due to slippery, muddy roads and paths. The availability of food is also a concern as some respondents replied not having enough food—annually. A key issue was the availability of agricultural land used for planting crops other than rice; as such, farmers continue to believe yields from other crops are better and more economically advantageous than rice yields (Table 1).

Table 1. Household socioeconomic characteristics in the target villages[†].

Attribute	Definition	TOTAL	IN	NOT	ONLY	BOTH
Age	Age of head of household (1 = 39+ y.o.; 0 = otherwise)[‡]	0.49 (0.50)	0.47 (0.50)	0.51 (0.50)	0.31 (0.47)	0.51 (0.51)
Gender	Gender of head of household (1 = female; 0 = male)	0.01 (0.09)	0.01 (0.08)	0.01 (0.11)	0.03 (0.18)	0 (0)
Education	Education level of head of household (1 = primary school; 2 = middle school; 3 = high school; 4 = above high school)	1.15 (0.91)	1.04 (0.92)	1.35 (0.85)	1.66 (0.94*)	0.87 (0.85)
Resident	Whether native villager (1 = yes; 0 = no)	0.88 (0.32**)	0.96 (0.18***)	0.74 (0.44)	0.88 (0.34***)	0.99 (0.09***)
Year	Years of household living in the village (1 = 1–5; 2 = 6–10; 3 = 11–20; 4 = 20–30; 5 = 30+ y.o.) [‡]	4.32 (0.74***)	4.61 (0.58)	3.79 (0.72***)	4.28 (0.77***)	4.69 (0.47***)
Labor force	Numbers of adult labors	2.99 (0.99***)	2.79 (0.85***)	3.33 (1.09***)	3.12 (1.13***)	2.71 (0.74***)
Income	Family income in total (in USD$ 1000)	3.51 (2.53)	2.97 (2.09)	4.44 (2.93)	5.03 (3.02*)	2.42 (1.31)
Fund	Insufficiency of funds (1 = yes; 0 = no)	0.72 (0.45)	0.69 (0.46)	0.76 (0.43)	0.94 (0.25***)	0.63 (0.48)
Attitude	Importance of environmental conservation (1 = positive; 0 = otherwise)	0.81 (0.39**)	0.87 (0.34**)	0.69 (0.46)	0.93 (0.25***)	0.85 (0.36**)
PDoT	Policy assistance from tourism department (1 = yes; 0 = no)	0.19 (0.39)	0.21 (0.41)	0.16 (0.37)	0.16 (0.37)	0.22 (0.41)
PDoE	Policy assistance from environment department (1 = yes; 0 = no)	0.20 (0.40)	0.22 (0.41)	0.17 (0.38)	0.13 (0.34)	0.24 (0.43)
NGO	Obtain assistance from NGOs (1 = yes; 0 = no)	0.85 (0.36)	0.83 (0.37**)	0.88 (0.32***)	0.91 (0.29***)	0.82 (0.39**)
V1	Villagers of Pu Til (1 = yes; 0 = no)	0.33 (0.47)	0.40 (0.49)	0.21 (0.41)	0.22 (0.42)	0.45 (0.49)
V2	Villagers of Lam Bes (1 = yes; 0 = no)	0.33 (0.47)	0.23 (0.42)	0.5 (0.50)	0.31 (0.47)	0.22 (0.41)
V3	Villagers of Pu Tib (1 = yes; 0 = no)	0.33 (0.47)	0.38 (0.48)	0.29 (0.45)	0.47 (0.51)	0.32 (0.48)
	Observations	237	151	86	32	119

[†]Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; [‡] y.o. = years old; PDoT = Provincial Department of Tourism; PDoE = Provincial Department of Environment; NGO = non-governmental organization.

In the three sampled villages, it was found that the livelihood activities of the locals were primarily agriculture, followed by eco-based services, home businesses, livestock raising, government employment, and other miscellaneous sources. Most of them had residence in Bousra Commune, while all of them had access to their own personal piece of property (i.e., with land titling at the commune level). Land for housing, agriculture activities, and gardening were considered as land ownership by local people. Farming (i.e., mainly paddy rice cultivation) is the major source of livelihood in Cambodia but in this study, economic crop cultivation (i.e., cassava, pepper, coffee plantation, and cashew) was the major source. Besides farming (i.e., 36%), ecotourism activities made up the second source of income at 21%. As such, each household depended on different livelihood activities such as other miscellaneous sources (i.e., sold labor such as carpenter and other private sector jobs), home businesses, civil servant, and livestock—19%, 13%, 9%, and 2%, respectively.

3.2. Perception and Forms of Participation in Ecotourism

3.2.1. Perception of Ecotourism by Villagers

The concept of local people involved in fostering ecotourism has been modestly studied in developing CBE. Table 2 reports on the environmental, social, and economic impacts of ecotourism based on respondents' perception [2,46,48]. Results indicate the potential of ecotourism had both positive and negative impacts on local communities. It illustrates that ecotourism has brought the local community an increased level of opportunity (i.e., 95%), directly giving them access to earn extra income and increase market choice for their products. As such, besides selling at the local market, they can also sell to middlemen at the ecotourism site or they themselves (i.e., 97%). However, among respondents, approximately 80% stated it could be possible to improve the local infrastructure solely via ecotourism-means. For the "ONLY" group, there was significantly higher (i.e., almost unanimous)

agreement on the positive impact of ecotourism on infrastructure level. Important factors include government (i.e., institutional factors) and community-run programs directly from villagers as other viable systems for development (Table 2).

Table 2. Perception from the impact of ecotourism[†,]

C‡	Subcategory	Total	IN	NOT	ONLY	BOTH
Environmental impact	Awareness of natural resources conservation (1 = yes, 0 = otherwise)	0.79 (0.41**)	0.85 (0.36**)	0.69 (0.46)	0.84 (0.37**)	0.85 (0.36**)
	Increased waste management (1 = yes, 0 = otherwise)	0.74 (0.44)	0.74 (0.44)	0.76 (0.43)	0.88 (0.34***)	0.69 (0.46)
	Depleted local environment (1 = yes, 0 = otherwise)	0.34 (0.48)	0.26 (0.44)	0.48 (0.50)	0.06 (0.34***)	0.32 (0.47)
Social impact	Increased immigration (1 = yes, 0 = otherwise)	0.94 (0.24***)	0.91 (0.29***)	1 (0)	1 (0)	0.88 (0.32***)
	Impacted local culture (1 = yes, 0 = otherwise)	0.13 (0.34)	0.15 (0.35)	0.10 (0.31)	0.06 (0.25)	0.17 (0.38)
Economic impact	Extra income opportunity (1 = yes, 0 = otherwise)	0.95 (0.21***)	0.95 (0.21***)	0.95 (0.21***)	0.88 (0.34***)	0.97 (0.16***)
	Increased market of products (1 = yes, 0 = otherwise)	0.97 (0.17***)	0.99 (0.08)	0.93 (0.26***)	0.99 (0.18***)	1 (0)
	Improved infrastructure (1 = yes, 0 = otherwise)	0.78 (0.40**)	0.78 (0.41**)	0.83 (0.38**)	0.94 (0.25***)	0.74 (0.44)
	Observations	237	151	86	32	119

[†]Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; ‡C = category.

Ecotourism promotes a clean environment and natural resource protection to the host community [40]. Local communities responded by stating the awareness of natural resources conservation and increased waste management bettered in both the ecotourism site and their communities via ecotourism investors and educative dissemination from local authorities. However, some respondents noted ecotourism caused degradation and depletion to the environment due to road development, traffic, the clearing of forest for parking, and augmentation of visitors, which led to increased waste in both the ecotourism site and their community. The majority of households (i.e., 94%) agreed that the overall population of people living and working in Bousra Commune was too high, while some stated it had just started to develop—making it an easy place to live, work, and earn an income (i.e., in contrast to more crowded provinces). Consequently, ecotourism was not the sole reason for the increase in local population. Moreover, some visitors (i.e., tourists) visit the community to experience indigenous life and traditional people. Village tourists who stay within the host community bring direct income for the host family and local village.

3.2.2. Forms of Participation in Ecotourism

Results indicate that household participation in ecotourism occurred via multiple activities associated with the ecotourism site (i.e., Bousra Waterfalls). The selling of NTFPs was the most active selling option (i.e., accounting for 75% of households from the 'IN' group), followed by sales of souvenirs (15%), fruit and soft drinks (9.9%), food (7%), camp facility rentals (4%) and photograph services (3%). It was surprising that less than 1% of respondents said they had been working as a service supplier (i.e., ecotourism site staff) in Bousra Waterfalls.

Even though, in theory, ecotourism should provide job opportunities to local communities, the number of household heads had a very low level of formal education, translating so-called capacity to obtain higher-end employment within the ecotourism site as limiting—requiring expertise from outside the community. Regardless, the participation of the local people within a CBE framing still offered a wide array of selling opportunity, free for indigenous groups to expand, and niche market-driven.

3.3. Factors Affecting Participation in Ecotourism

Factors affecting participation in ecotourism utilized logistic regression modeling to identify linkages between dependent and independent variables, wherein assessed independent factors were considered not significant (i.e., at the 90%, 95%, and 99% significance level). We reported results for six models, of which the first set of three applied results from all the sample villagers and the latter set applied results from only the sample villagers participating in tourism, in general (Table 3). Models were tested to examine the robustness and impact of ecotourism and tourism, in general, on the communities. Both sets of models utilized the same variables and related significance levels.

Table 3. Logistic regression results of variables attributed to participation in ecotourism[†].

	Set 1			Set 2		
Variable	**Total/1**	**Total/2**	**Total/3**	**IN/1**	**IN/2**	**IN/3**
Gender	−0.46	−0.43	−0.44			
	(1.55)	(1.50)	(1.53)			
Education	0.11	0.17	0.11	−0.94	−1.01	−0.89
	(0.40)	(0.43)	(0.40)	(0.51*)	(0.51**)	(0.51*)
Resident	0.98	0.97	0.98	−0.72	−0.66	−0.74
	(0.17***)	(0.17***)	(0.17***)	(0.29**)	(0.28**)	(0.28***)
Labor force	−0.33	−0.34	−0.33	0.15	0.16	0.15
	(0.18*)	(0.18*)	(0.18*)	(0.28)	(0.27)	(0.28)
Fund	−0.79	−0.83	−0.79	2.31	2.27	2.35
	(0.44*)	(0.44*)	(0.44*)	(0.94**)	(0.90**)	(0.93**)
Attitude	1.49	1.52	1.49	0.87	0.78	0.89
	(0.46***)	(0.47***)	(0.46***)	(0.85)	(0.84)	(0.85)
PDoT	0.45		0.45	−0.67		−0.68
	(0.47)		(0.47)	(0.63)		(0.62)
PDoE	0.39		0.36	−0.69		−0.78
	(0.44)		(0.44)	(0.51)		(0.65)
NGO	−0.06	−0.06		0.51	0.67	
	(0.53)	(0.52)		(0.73)	(0.72)	
V1	−0.95	−0.97	−0.96	−0.78	−0.74	−0.74
	(0.52*)	(0.52*)	(0.52*)	(0.59)	(0.59)	(0.59)
V2	−1.76	−1.72	−1.75	0.21	0.26	0.26
	(0.51***)	(0.51***)	(0.51***)	(0.57)	(0.57)	(0.57)
Constant	−2.12	−1.91	−2.17	−0.66	−1.18	−0.22
	(1.09*)	(1.07*)	(1.09**)	(1.97)	(1.91)	(1.87)
Observation	237	237	237	151	151	151

[†]Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Results from all of the models indicate that policy assistance obtained by local residents from the PDoT and PDoE did not have a significant impact on their participation level in ecotourism—similar assistance findings from NGOs were observed. The education levels of household heads did not have a significant impact on household participation in ecotourism. However, for those households participating in tourism in general, the more education received, the more likely that both ecotourism and conventional tourism was employed. The length of household living, in the village as a native resident, was positively correlated to ecotourism activities (i.e., native residents resided in the village longer and had a larger probability of participating in ecotourism). However, for those residents in tourism in general, the longer residing residents had a smaller probability of participating only in ecotourism. Family labor size was negatively correlated with ecotourism access—the more family labor, the less likely it was involved with the ecotourism site or earned money via ecotourism.

Insufficient funds have adverse impacts on household participation in ecotourism when considering the total sample and the "IN" sample. For the total sample, insufficient funds made households less likely to be involved in ecotourism, whereas for the "IN" sample, insufficient funds made households only more likely to be involved in ecotourism and not tourism in general. Household attitude to environmental conservation had a positive and significant impact on their participation in ecotourism. When households recognized the importance of environmental conservation, there

was a larger chance they would be involved in ecotourism. However, household attitude did not have a significant impact on participation when focused on the "IN" sample. Distance is negatively correlated with ecotourism access. The nearest target village (i.e., Pu Til) located in the forest faces travel concerns due to its vicinity (i.e., off the main road) and road condition (i.e., poor and muddy). In contrast, the medium and furthest villages (i.e., Pu Tib and Lam Mes) have direct access to the main road, which is very well built and easily accessible via vehicle services. Furthermore, qualitative observation indicates that the nearest village was significantly underdeveloped in comparison to the other two villages as well as villagers giving the impression as being more isolated, conservative, and less approachable to speak to and less likely to go out to earn money, especially women.

3.4. Factors Affecting the Economic Impact of Ecotourism

We employed OLS estimate factors affecting the economic impact of ecotourism. To avoid the subjectivity of household perception on economic perception (Table 2), we applied household income to indicate economic impact. We report the result of five models, of which the first three models (i.e., set 1) apply to all sample villagers and the latter two models (i.e., set 2) only apply to sample villagers participating in tourism. These models were applied to capture the detailed economic impact of ecotourism (Table 4).

Table 4. Ordinary least square (OLS) regression of variable-to-income results of local residents.

	Set 1			**Set 2**	
Variable	**Total/1**	**Total/2**	**Total+/3**	**IN/1**	**IN/2**
Gender	0.96 (0.35***)	0.91 (0.35**)	1.02 (0.34***)	1.03 (0.43**)	1.46 (0.40***)
Education	−0.55 (0.08***)	−0.55 (0.08***)	−0.51 (0.08***)	−0.53 (0.09***)	−0.41 (0.09***)
Resident	−0.18 (0.03***)	−0.18 (0.03***)	−0.18 (0.02***)	−0.15 (0.04***)	−0.14 (0.04***)
Labor	−0.06 (0.03*)	−0.07 (0.03*)	−0.08 (0.03**)	−0.06 (0.04)	−0.08 (0.04**)
Fund	0.14 (0.07**)	0.12 (0.07**)	0.11 (0.07)	0.09 (0.07)	0.06 (0.09)
IN	0.02 (0.08)				
ONLY		0.15 (0.09)		0.19 (0.09**)	
Ecotourism Food			0.28 (0.15*)		0.44 (0.16***)
Ecotourism Drinks			0.08 (0.15)		0.19 (0.13)
Ecotourism Souvenirs			0.01 (0.12)		−0.02 (0.16)
Ecotourism Camping Rental			0.58 (0.19***)		0.63 (0.17***)
Ecotourism Photography			0.64 (0.23***)		0.78 (0.19***)
Ecotourism Tour			0.39 (0.28)		0.31 (0.23)
Ecotourism NTFP			−0.06 (0.08)		0.05 (0.13)
V1	0.04 (0.09)	0.05 (0.09)	0.06 (0.09)	0.17 (0.09*)	0.11 (0.09)
V2	0.28 (0.09***)	0.28 (0.09***)	0.23 (0.09**)	0.48 (0.09***)	0.41 (0.10***)
Constant	2.36 (0.15***)	2.37 (0.15***)	2.41 (0.15***)	2.16 (0.24***)	2.03 (0.25***)
Observation	237	237	237	151	151

†Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

For the total sample models, results indicate that neither households in ecotourism or "ONLY" in ecotourism have a significant impact on family income. For the "IN" sample, results indicate that if households were "ONLY" in ecotourism, they will have a higher income. When considering the detailed impacts of each form of participation in ecotourism, we found that for both the total sample model and "IN" sample model, participation in selling food and renting camping facilities had significant and positive economic impact. The larger the activity, the higher the family income. Gender of household head had positive impact on family income in all five models, which correlated to if families had a female household head, family income tended to be higher. Moreover, the education levels of the household head had significant and negative impacts on family income in all models (i.e., due to very low levels). Length of the households living in the village as a native resident was negatively correlated with family income, which meant aged native householders earn lower income levels. The family labor force had a significant and negative impact in four models. Counterintuitively, the more labor force a household had, the smaller income levels they might have. In two total sample models, insufficient funds corresponded to higher income. Results also indicated that households from the village Lam Wes were likely to have a higher income than villagers from the other two when controlling for other variables. However, in one "IN" sample model, households from village Pu Til were likely to have higher income, respectively.

4. Discussion

This study aimed at examining the development of ecotourism from the perspectives of local participation, perception, and economic impact. As expected, ecotourism is one of the alternative sustainable income sources that the local community shares—directly and indirectly via the ecotourism site. As such, the study showed that ecotourism helped to protect local natural resources, the environment, and develop socioeconomic enhancement; most of the households thought that the ecotourism sector had a positive impact on household status and the community at large [45]. This study also suggests that household livelihood strategies are diversified, and most livelihood-oriented activities have benefitted, including agriculture activities, raising of animals, off-farm activities, employment, forest product collection, and home businesses. The study from Heinen and Shrestha-Acharya [41] and Das [42] found that villagers living in forested areas depend on NTFP collection and agriculture as their main source of income. Similarly, we concurred in this study that the majority of Bousra Commune practice agricultural activities (i.e., farming) and livestock ranging.

At present, there is a growing market, eight months of the year (i.e., from November to June), of popular tourist destinations throughout Cambodia for national and international visitors. In 2018, Mondulkiri province attracted 66,352 visitors, of which 8507 were foreigners [55]. It was observed that a growing number of visitors are opting to spend their holidays and leisure time in nature, so it can be assumed that the potential industry to develop ecotourism throughout Mondulkiri province and Cambodia is high. We have established that ecotourism can increase the market for local products, improve the local environment (i.e., especially waste management and nature protection), and develop infrastructure. Recently, the Cambodian government's new ecotourism policy put in place the mechanism that encourages private investors and local communities to gain capacity and ability to control ecotourism sites and invest in the sector [55]. Hence, we found that government assistance plays an important role in further developing the whole of the industry by offering individual households incentives and opportunities to participate without obligation. Activities such as selling souvenirs, fruit and soft drinks, food, NTFPs, camp facility rentals, photograph services, and jobs relating to security are among some of the current mechanisms being pushed forward. Among these activities, selling NTFPs (i.e., wild fruit, vegetables, traditional medicinal plants, rock, and honey) makes up 49% of the share. In Bousra Commune, a growing number of villagers depend on ecotourism as it continues to grow and make up a higher percentage of households' direct and indirect income. However, direct access to the ecotourism site showed that revenue shares from ecotourism activities are still somewhat limited in terms of replacing agriculture as a form of subsistence.

Ecotourism was regarded as an additional source of income for local households. It not only provided the opportunity to earn extra income, but also conserved nature and environmental enhancement in conjunction with bettering livelihood status [21,56–58]. Our results indicate that ecotourism activities are complementary to other livelihood activities. For those households with more labor force, they were less likely to participate in ecotourism, implying ecotourism is not a labor heavy activity and requires less family members. This deduction is supported by our observation in the field, where over 50% of the local people engaged in major ecotourism activities such as NTFPs and food sales were older-aged people and children (i.e., who we did not include as a part of the adult labor force). The negative impact of insufficient funds on participation implied that local villagers are less likely to participate in ecotourism when faced with this issue, and ecotourism activities, for the most part, cannot be performed without some sufficient startup funds. However, for those already in ecotourism, when funds were insufficient, they were also more likely to participate in conventional tourism.

There are some obstacles for local people to fully benefit from ecotourism's goods and service. Household participation in ecotourism does not ensure that they will have a higher income. This implies that the profitability of ecotourism is not a guaranteed formula for success. Furthermore, comparing incomes from households within ecotourism and those not within indicates that ecotourism was less profitable. However, those villagers only in ecotourism had the highest income. At present, throughout Bousra Commune, community involvement in ecotourism is not yet significantly developed, since most provide only NTFPs which are not very lucrative. Other services, however, such as food sales, renting camping facilities, and photography services are fully feasible in generating higher income levels. Regarding the low participation of these three activities, it can be inferred that since these activities were provided by fewer villagers, there may be an untapped niche market. As noted, the impact of labor force on income was a counterintuitive finding. One possible reason is that most ecotourism activities are by in large not labor intensive (i.e., such as in farming or construction) and household family size may be an important factor on whether participating in ecotourism is profitable. It can be inferred that a smaller family nucleus (i.e., less labor force) working in agriculture, for example, might veer towards ecotourism activities to offset insufficient funds. The impact of insufficient funds also noted, somewhat paradoxically, that results for households with higher economic status demanded higher levels of income and reported higher levels of insufficient funds than lower strata households.

Poverty alleviation is one of the main goals of establishing ecotourism throughout Cambodia [33,51]. Livelihood enhancement and nature resource awareness are the conditions needed to reach poverty alleviation through livelihood activities, jobs opportunities, and solidarity via society. The balance between natural resource management, economic development, and benefit sharing are other important factors when considering the participation of stakeholders and the community as a whole [18]. With the potential of developing ecotourism in Bousra Commune, we need to consider the activity (i.e., mechanism-oriented) and pay special attention to any sudden increase in population (i.e., migration) into the community. Upholding community safety, identity, and cultural conservation as indigenous people are important dynamics local authorities, NGOs, and relevant institutions need to closely attend to when considering gaps in the economy.

5. Conclusions

There is a high percentage of rural participants engaged in ecotourism on- and off-site in Bousra Waterfalls. As such, the local village economy is still dominated by traditional agriculture in which ecotourism income accounts for only a small percentage of family income. This implies potential and merit evaluation. At the moment, there are multiple participatory forms of ecotourism which are not economically viable on a mass village-scale level. Most local people positively evaluate the impact of ecotourism on their livelihood, while a few stated negative impacts on depleted natural resources and culture loss. Local peoples' participation in ecotourism tends to be autonomous without significant impact or assistance from government departments or NGOs. From our perspective, ecotourism plays a conditional role on local peoples' livelihood. Notedly, our results are highly-correlated to the local

villagers and the economic impact of ecotourism in relation to the ecotourism site selected; therefore, the citation of our findings when interpreting other cases needs to be cautious.

We propose three recommendations as vital sustainability-oriented factors in developing ecotourism in Bousra Commune. (1) Since, ecotourism provides extra income to local people in the form of direct and indirect access, local people who go into ecotourism (i.e., mostly selling NTFPs) should be provided with vocational training and skills to produce NTFPs that are not solely raw material based [59,60]. (2) Exploring the option of niche market opportunities, villagers should be encouraged to place value on additional forms of wealth creation via ecotourism. The collaboration of investors and the community at large can be initiated with formal group discussions to develop a community-based organization to establish participatory decision making for any activity including development, services, and management [8,51]. (3) Though ecotourism is market-oriented in practice, a governmental monitoring system is still needed to establish and avoid potential negative impacts on the environment and culture. Education for local villagers is needed as well, especially for those who rely highly on natural resources for income extraction, since ecotourism also depends on a sound environment for tourists [61]. As an intended low-impact and small-scale alternative to standard commercial tourism, CBE can be a transformative form of economics, directly benefiting the economic development and political empowerment of local communities. Considering a lack of quantitative analyses on the development of ecotourism, we suggest further comparative research between ecotourism and conventional tourism within the same region to measure the economic and institutional factors and long-term dynamics of the various ecotourism activities. Further comparative research with similar ecotourism sites in the region would also be recommended.

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Article

Bike-Sharing Systems in Poland

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Abstract: Bike-sharing is widely recognized as an eco-friendly mode of transportation and seen as one of the solutions to the problem of air pollution and congestion. As there is little research exploring the performance of bicycle-sharing systems (BSS), many municipal authorities invest in their development without knowledge of their effectiveness. Therefore, the aim of this article is to identify factors that correlate with BSS performance. Data related to BSS and urban characteristics were collected for the 56 cities in Poland, which is the population of BSS systems in this country. The Ordinary Least Square regression model was used to estimate the model. Additionally, to support our findings, a survey of 3631 cyclists was conducted. Our main findings show that BSS performance was positively related to cities' population, tourism, number of bike stations per capita, congestion, bicycle pathways' length and higher temperature, and negatively related to precipitation. We have also found that one BSS operator was more effective compared to the others.

Keywords: bicycle-sharing systems; bike-share; performance; determinants; ridership

1. Introduction

Bicycles are an example of an eco-friendly means of transport [1]. Using no fossil fuels and producing no noise or air pollution, bikes help to improve sustainable urban mobility. Moreover, riding bicycles have a positive impact on health, they are relatively inexpensive, and do not cause traffic congestion [2]. The idea of bike-sharing systems (BSSs) makes bicycles more available and used more frequently within urbanised areas, helping to improve urban transport systems [3–5]. However, to have such an impact, BSS have to be efficient and attract many users. Recently, de Chardon et al. [6] summarized 75 BSS case studies across the world, examining attributes that correlate with BSS performance. Another stream of literature used surveys to examine the motivating factors associated with a BSS's use [7]. The aim of this article is to identify factors that correlate with BSS performance in Poland. To achieve this goal, we used a unique approach of combining quantitative data on all 56 existing BBSs in Poland with a survey of Polish BSS users. As this is the first study that uses such extensive and multiple sources of data from Poland, we use exploratory methods. As a measure of BSS performance, we use the number of trips per day per bike (TDB), which is the most common measure of performance (or success) used in previous literature [6,8–11]. Thus, our first contribution is to examine whether factors found to be effective in BSS performance in other countries relate to the success of BSSs in Poland. Our second contribution is to examine the relationship between tourism and BSS performance, the factor that has not been studied before, but may be an important aspect of BSS performance. Finally, we contribute to the BSS literature by confirming that our exploratory quantitative results match the results from our survey of cyclists.

An increasing number of studies on BSSs has been conducted in recent years, especially since 2010 [12], but only a few studies consider bike-sharing-related issues in Central and Eastern Europe,

including Poland, the focus of this study. In Poland, the most popular means of transportation in both urbanised and rural areas is a private car. The car ownership index has been increasing since the 1990s, and in 2016 has reached the level of 571 cars per 1000 inhabitants, according to the Eurostat database [13]. It places Poland among the seven most motorised countries in Europe [14]. Thus, solutions for reducing air pollution and road congestion in Polish cities are urgently needed and this article focuses on one kind of sustainable means of transportation: bike-sharing systems.

Since the 1960s, when the concept of sharing public bicycles first emerged in Europe (The White Bike programme in Amsterdam, Netherlands) [15], many factors of BSSs have changed. First, the coin deposit scheme based on docking stations had been introduced in Copenhagen in 1995. This innovation allowed BSSs to avoid theft and vandalism, which caused the failure of the first generation of BSSs [16]. Second, at the turn of the 1990s and 2000s, BSSs started to be equipped with smart solutions in the form of magnetic stripe cards, electronically locking racks, and bike locks. Finally, telecommunication technology became an inseparable part of contemporary bike rental systems, which made the bike-sharing idea more popular all over the world [17]. The third-generation systems, which are accessible by smart cards or mobile phones and equipped with on-board computers, have been recently upgraded (2015 in China) with Global Positioning System (GPS) tracking and by mobile payment systems via smartphone applications. New, dockless bike-sharing schemes have revolutionized the market, allowing a person to rent and return a bike not at a designated docking station, but at any reasonable location. Dockless systems are also described as free-floating and recognized as the fourth generation of BSSs [18].

Besides technological upgrades, the main difference between the third and the fourth generation of bike-sharing is the funding scheme. For over 50 years of development in Europe, the bike-sharing services' financing model has been changing, but has always depended on public funds [15]. On the other hand, dockless systems in China were financed by the private sector (the basic sources of funding are investors' funds, rental fees, loans, revenues from advertising, and users' deposits). However, many Chinese bike-sharing start-ups bankrupted in 2017–2018. Thus, this model of financing proved to be unsustainable. Despite this, the private sector's financial contributions had a significant impact on the spread of the fourth-generation systems in China and other countries [19].

Previous studies have tried to identify factors that affect the BSS ridership. In many cases, this kind of analysis requires an analysis of travel patterns [3,18,20,21]. The effects of demographic and built environment characteristics, such as population, job density, or income level, at specific locations were investigated and proved to be positively corelated with ridership [22]. Furthermore, several studies focused on such factors as bicycle infrastructure, land use, seasons of the year, weekdays, weather conditions, and users' type [23–26]. Next, we discuss the most impactful papers on this subject in more detail.

Fishman et al. (2014) [7] conducted a survey of members and non-members of BSSs in Melbourne and Brisbane (Australia) and identified two types of barriers affecting BSS usage. The first type of barriers refers to riding a bicycle in general (e.g., distance to overcome, safety perception), and the second refers directly to BSSs' features (e.g., docking stations density). Regular bike riders are not affected by the first category, thus have fewer barriers to use BSSs in general. The authors concluded that BSSs' membership depends on convenience and distance to the closest docking station (the shorter the distance, the higher the probability of membership) [7].

Another interesting study by El-Assi et al. [24] was conducted in Toronto (Canada) and was focused on weather conditions, socio-economic and demographic factors, land use, and the built environment. Their results showed a positive correlation between higher temperatures, lower humidity levels, and lower amounts of ground snow with bike ridership. Also, more trips were observed near specific places, such as universities and strategic transit stations. The safety perception was examined, and the study found a positive correlation between the ridership and bicycles' infrastructure and a negative correlation between the ridership and the number of intersections with main roads [24].

Two Chinese studies conducted using data from Ningbo's and Nanjing's BSSs also focused on explaining factors determining the BSS ridership. The first one was based on a survey (986 valid samples) and examined the usage of and satisfaction from BSSs. The cross-equation correlation helped to prove that a higher degree of satisfaction with a BSS increases the probability of bike-sharing usage [27]. The second article presented the results of a survey conducted on a sample of 4939 citizens of Nanjing about a free-floating (dockless) BSS that has been developed there. In the conclusions, the authors presented results for three different travel patterns. They found that college students and employees were more likely to use a dockless BSS when transferring between a bicycle and other means of transport (Transfer Pattern) and when reaching the destination directly (Origin to Destination Pattern) compared to going to the destination and returning (Travel Cycle Pattern). They also showed an inclination to choose Transfer Pattern during the morning peak and choose Origin to Destination Pattern and Transfer Pattern during the evening peak, with the evening peak being overall more significant than the morning peak. Additionally, the authors found that price had an impact on residents' travel patterns and recommended that prices should be set according to demand and travel distance or riding time of users [3].

In yet another study, a station-level analysis of the Pronto BSS in Seattle showed the causes of its failure. The study investigated factors potentially discouraging citizens from the use of BSSs, including roadway design, land use, bus trips, elevation and weather conditions. The authors identified that elevation and weather conditions were the main causes of system closure in 2017, after three years of operation [28]. However, BSS failures are not very common and, except for the above example, the literature does not describe any other examples. A recent review conducted by de Chardon et al. [6] uses data from 75 case studies across the world. The authors found that one-third of studies reported less than one trips per day per bike (TDB). The authors estimated models with independent variables, such as system attributes and station density, as well as weather, geography and transport infrastructure to examine their correlation with TDB.

The first Polish BSS was introduced in Cracow in 2008. Since then, only a few studies have been conducted to analyse BBSs in Poland. One of them focused on the identification of factors affecting users' safety in traffic [29]. Another study presented the most important features of bike-sharing schemes by conducting a case study analysis of selected Polish services [30]. Statistical methods, such as network analysis and graph theory, were used in other research to help formulate recommendations for the decision-making process concerning the creation and modification of a bike-sharing network in the Polish city of Bialystok [31].

2. Materials and Methods

2.1. Data Used for Regression Model

To achieve the goal of this article, two kinds of data have been collected. For the first part of the research, data from 56 Polish cities have been collected, which covers all BSSs in Poland. The dataset includes data provided by systems' operators combined with data published by the Polish Central Statistical Office, Poland's largest database of the economy, society and the environment: Local Data Bank. This dataset contains information about the number of users registered in bike-sharing systems until the end of 2018, the total number of journeys in every system in 2018 and the duration of the systems' activity in 2018 (in days). It also includes basic information concerning the bike-sharing infrastructure parameters, information about the built environment and demographic characteristics of each city and settlements equipped with a BSS in the country (including data on tourism and environment, wages and number of registered cars). Historical indicators describing weather were collected from the meteorological services company WeatherOnline Ltd. The data enabled the calculation of indicators used in this study (e.g., bicycle network density, number of cars registered per person, average temperature and number of rainy days during the time the system was functioning). Some of the data on urban characteristics retrieved from the Local Data Bank, such as population,

length of bicycle pathways or average wages, were from 2017. However, since such information does not change often, we assumed that we could use it for our research along with the data on BSS characteristics and weather conditions from 2018.

2.2. Survey Data

To support our findings from the regression model, we have used a second type of primary data. The second dataset used in the research is the result of the travel- and bike-sharing-oriented survey collected in nine Polish cities between 1 November 2018 and 5 February 2019. It was conducted on a random sample of 3631 respondents: cyclists and citizens of the following cities: Bydgoszcz, Katowice, Cracow, Lublin, Lodz, Poznań, Szczecin, Warsaw and Wrocław, where the largest BSSs were developed. Data collection has been carried out by the MRC Consulting company using the Computer-Assisted Personal Interviewing technique (CAPI). The survey has been conducted by professional interviewers using electronic devices (a tablet or a smartphone). Interviewers questioned random cyclists on the streets of abovementioned cities. As some of the cyclists did not want to participate in the survey, the rejection rate was 20%. Each interviewed cyclist was provided with a participant information form and consent was implied if the prospective participant chose to proceed. The survey was developed using LimeSurvey software and it is the authors' own elaboration. A series of preliminary in-depth interviews with cyclists (bike share users and non-users) conducted by the authors helped in developing the survey questions used in this study. Once the survey design was completed and prior to distribution to the sampling frame, a pilot study was undertaken on 21 people. The questionnaire included questions about basic traveller's features and choices in daily travel around the city. The main purpose of the survey was to identify disincentives for cycling in general and in relation to BSSs. The data was processed using SPSS software.

2.3. Method

We used the ordinary least square (OLS) regression method to estimate the model explaining the association of various factors to performance of bike-sharing schemes measured by TDB. The following model was estimated:

$$\begin{aligned} TDB_i = \beta_0 + \beta_1\, log(Population)_i + \beta_2\, Nextbike_i + \beta_3\, log(Years)_i + \beta_4\, \#StationsPerPop10K_i + \\ + \beta_5\, \#CarsPerPerson_i + \beta_6\, PathsKmPer10KPop_i + \beta_7\, PaytoAvg_i + \beta_8 Temp_i + \beta_8 Rain_i + \\ + \beta_9\, TuristsPer1000Pop_i + \varepsilon_i \end{aligned}$$

where TDB_i is the trips per day per bicycle in city i; other variables are clearly defined and described below; βs are coefficients to be determined; and ε_i is the error term. R software was used to perform the regression analyses.

2.4. Dependent Variable

We used trips per day per bicycle (TDB) in a given city as our measure of BSS effectiveness. The higher the TDB, the more effective the system. This is the most common measure of BSS performance used in previous studies [6,8–11], including a recent literature review performed by de Chardon et al. [6].

2.5. Independent Variables

Regarding the independent variables, potential factors that might affect BSS performance fall into three major categories: (1) urban features (Population, Congestion, Infrastructure, Income, Tourism); (2) BSS characteristics (Years open, Operator, Stations); and (3) weather (Temperature, Rain).

2.5.1. Urban Features

Population (*log(Populaiton)*): We control for population of a BSS's primary city or settlement, since ridership typically rises with the number of people that can use the system. It also controls for the congestion and parking costs of riding a car. For the purpose of our study, we used the population in 2017, which was the latest available data in the Polish Central Statistical Office's Local Data Bank. We use the logarithm of the population since this variable was heavily skewed. Most of the previous studies controlled for population of the city offering a BSS [23,24,32].

Congestion (*#CarsPerPerson*): We used the number of cars registered per person in the region to control for congestion. As car ownership statistics in Poland are much higher than the E.U. average, many cities struggle with the problem of congestion. Public bicycles enable commuters to avoid losing time in traffic, so a high number of cars registered in the region should result in a higher ridership of bicycles, including public ones. One limitation connected with this variable is that the data includes all cars registered in the region, not only in the given city or settlement, and some of the cars may not contribute to congestion in the given location. Moreover, cars registered in other regions may appear in the streets of many cities. Car ownership's influence on BSS ridership as well as the modal split changes between BSS and private cars have been discussed previously by Fishman et al. [8] and Ricci [9].

Infrastructure (*PathsKmPer10KPop*): We use kilometres of bicycle pathways per 10,000 of population as a measure of bicycle infrastructure density. Many BSS users do not own a bicycle, so they are not experienced cyclists. It is crucial for such people to feel safe when they are using public bicycles, and that is only possible on separate pathways. The importance of pathway density for bicycle ridership was proven in previous studies [23,24].

Income (*PaytoAvg*): Public bicycles are the most affordable mode of transportation in Polish cities. The majority of BSSs offer the first 15–30 min of usage free of charge. Therefore, public bicycles could be more popular in the regions where salaries are lower compared to other regions. We used an average salary in the region compared to the national average as a measure of income. Other studies that controlled for income include El-Assi et al. [24], Noland et al. [23] and Zhao et al. [10].

Tourism (*TuristsPer1000Pop*): We believe that the number of tourists visiting a given destination will be positively related to TDB. Some BSSs in Poland function in locations that are important tourist destinations. Tourist information centres usually inform travellers about local BSSs. Many visitors are cyclists that could not bring their own vehicles to their destination, so they are willing to use public ones instead. Therefore, we test if there is a significant positive correlation between tourism and TDB. We used the number of tourists purchasing hotel services in a given city per 1000 population. To our knowledge, this has not been explicitly tested in previous studies.

2.5.2. BSS Characteristics

Operator (*Nextbike*): Nextbike is a binary variable that takes a value of 1 for systems operated by Nextbike company and 0 otherwise. Since Nextbike operates 80% of BSSs in Poland, we expect that they are more effective and perform better compared to their competition. Other studies controlled for the major operator of the system as summarized by de Chardon et al. [6].

Years Open (*log(Years)*): Time since the launch of operations was also incorporated into our model because people may initially not know about the existence and functions of BSSs. Operators and municipalities promote their systems, but it takes time before a BBS is accepted as a means of transportation in the collective consciousness. Additionally, with experience, the system may be optimized to the city's conditions. We used the log of years, as some systems had been operating much longer than others, which made the distribution very skewed. Ricci [9] and Zhao et al. [10] found that, with time, more people register to BSSs and more people are familiar with a BSS's features.

Stations (*#StationsPerPop10K*): We use the density of stations defined as the number of stations per 10,000 of population. A BSS with a high density of stations is comfortable to the user, as an average walking distance to the station is shorter. It enables customers to plan their trips more efficiently and reach destinations faster. This variable has also been examined previously [10,22,32].

2.5.3. Weather

Average temperature (*Temp*) and the number of rainy days (*Rain*) during the time the system was functioning are the two variables used in the model that control for meteorological conditions. Cyclists are more exposed to elements than public transportation passengers or drivers. Therefore, we expect fewer people to use BSSs in cities and times when temperatures are lower and there are more rainy days. This was also shown in research by El-Assi et al. [24] and Gebhart et al. [33].

3. Results

3.1. General Information and Basic Data on Bike-Sharing Systems in Poland

Table 1 presents definitions and descriptive statistics. The number of bike-sharing systems in operation worldwide increased at the average annual rate of 28.5 percent between 2008 and 2018 [34]. Following that global trend, bike-sharing in Poland grew rapidly in 2018. In 2017, there were 1.3 million users registered in 31 BBSs in Poland. The number of BSSs increased to 56 in 2018, and the number of registered users reached over 1.8 million (39.1% growth). The country's fleet of shared bicycles has grown by 14.5%, from almost 16,000 to over 18,000. The number of rides increased from 12 to 15.5 million (28.7%). The bike-sharing market in Poland in 2018 was dominated by the company Nextbike Polska, which had an 80% share in the market. Nextbike Polska systems were station-based. Other companies developed BSSs that were hybridized with GPS locks but with preferred parking locations (e.g., Cracow). For the purpose of this study, these locations were counted as stations. All bike-sharing systems in Poland were at least partially financed by local authorities. Only 27% of Nextbike Polska revenues in 2018 were based on sales to private customers. Revenues from private sources included advertising, rental fees and sales of stations financed by corporate clients [35]. In 2018, shared bicycles were available to people living in the settlements of a joint population of 9.9 million, which is 26.2% of the Polish population.

Table 1. Variable definitions and descriptive statistics.

Code	Variable Definition	Mean/Proportion	SD	Min	Max
TDB	Trips per day per bicycle	1.93	1.34	0.12	4.89
Population	Population of BSS's primary city or settlement	177,666	276,217	2495	1,764,615
Nextbike	Operator of the BSS (dichotomous variable)	0.80	-	0	1
Years	Number of years since the system was launched	2.68	2.70	1	11
#StationsPerPop10K	Density of stations: the number of stations per 10,000 of population	2.01	1.49	0.34	8.02
#CarsPerPerson	Number of cars registered per person in the region	0.57	0.07	0.43	0.72
PathsKmPer10KPop	Kilometres of bicycle pathways per 10,000 of population	3.76	2.33	0.00	11.93
Pay to Avg	Ratio of an average salary in the region to the national average	95.45	14.15	76.10	146.00
Temp	Average temperature during the time the system was functioning	14.29	2.74	6.40	20.10
Rain	Number of rainy days during the time the system was functioning	52.18	28.30	10.00	146.00
TouristsPer1000Pop	Number of tourists that used hotel services in a given city or settlement per 1000 population.	865.08	1230.72	130.22	8517.22

Although most BSSs are managed by the same company, they vary in performance. The mean TDB in Polish bike-sharing systems in 2018 was 1.93. The best performing BSSs were the ones located in relatively big cities: Poznań (4.89 TDB) and Wrocław (4.88 TDB), and the worst performing were the new, small BSSs in Marki and Żory (0.12 TDB). The range of estimated TDB values, 0.12–4.89, is slightly lower than those observed in a review of 75 BSS case studies across the world (0.22–8.4 [6]) and 69 Chinese case studies (0.7–9.5 [10]), and with a lower mean of 1.93 compared to [6] of 2.42 and [10] of 4.2. Exactly matching de Chardon et al. [6] study, 30% of Polish cities had an estimated usage below 1.0 TDB. This indicates that, in one-third of the cities, some bicycles remain unused each day.

3.2. Regression Analysis of the Factors Influencing BSS Performance

Table 2 presents the estimation results. We were able to explain 55% (Adjusted R squared) of the variation in TDB. The variance inflation factors (VIFs) were analysed to check for multicollinearity. If the (VIF) value is larger than 5, multicollinearity is a problem [36]. As presented in Table 2, multicollinearity was not an issue in our estimation.

Table 2. Regression analysis of factors influencing trips per day per bike (TDB) in the given bicycle-sharing system (BSS).

Code	Estimate	SE	*p*-Value	Significance Code	VIF
(Intercept)	−15.00	2.52	0	***	
Log(Population)	1.08	0.18	0	***	3.37
Nextbike	0.84	0.33	0.02	**	1.26
Log(Years)	−0.41	0.25	0.11		2.71
#StationsPerPop10K	0.30	0.12	0.02	**	2.19
#CarsPerPerson	3.39	1.98	0.09	*	1.45
PathsKmPer10KPop	0.10	0.06	0.08	*	1.26
Pay to Avg	0	0.01	0.92		2.23
Temp	0.11	0.05	0.04	**	1.20
Rain	−0.01	0.01	0.09	*	1.76
TuristsPer1000Pop	0	0	0.09	*	1.24
Adjusted R squared	0.55				

Note: Dependent variable: TDB; * significant at the 0.10 level, ** significant at the 0.05 level; *** significant at the 0.01 level. VIF, variance inflation factor.

Our regression results suggest that tourism is positively related to TDB. No previous research has explicitly examined the effect of tourism on TDB. Intentions to use bike-sharing for holiday cycling were previously investigated with promising results [37]. Some researchers have seen the development of BSSs as an opportunity to develop urban tourism [38], but variables measuring tourism were never included as a factor in studying the efficiency of BSSs. In our survey, we have found that 26.3% of surveyed cyclists have rented a bike or have used a BSS while visiting other cities, and 8.6% of them did that more than once. This percentage is much higher than domestic BSS usage, which is only 4.8% among respondents of our survey.

TDB is also positively related to city population (Table 2). This variable has been previously used by Zhao et al. and de Chardon et al. [6,10]. Our results are consistent with their findings.

Another factor important for BSS success is the number of docking stations (Table 2). Some practitioners argue that the number of stations increases performance (TBD) by creating a so-called "network effect" (expanding the system's size increases performance). The relationship between the number of stations and TBD is also presented in Figure 1.

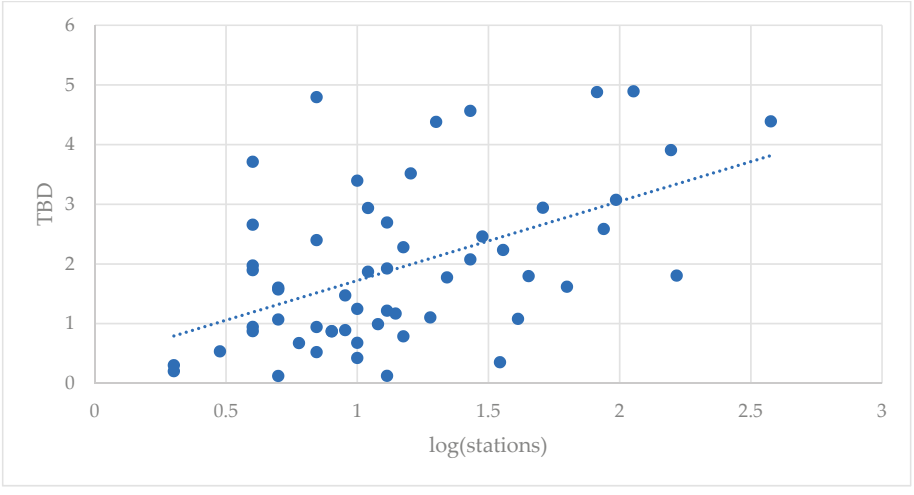

Figure 1. The TBT and number of stations scatter plot and correlation.

This relationship was put into question by de Chardon et al. [6], who claimed that the effect was endogenous: systems that had better performance increase their stations and number of bikes as a result. However, Fishman et al. [7] identified the distance to the nearest docking station as a barrier for BSS membership. According to our survey, some cyclists in Polish cities are discouraged from using BSSs because there are not enough stations (Figure 2). Most of the Polish cyclists that we interviewed were not highly discouraged by the number of available stations; however, for many of them, it was an important factor that stops them from using BSSs: 25.5% ranked this problem as 6 or higher on the scale of 1 to 10. Therefore, we conclude that the number of stations is a factor that influences BSS performance. This finding is important for policy-makers and BSS operators that can influence the development of BSSs in urban areas.

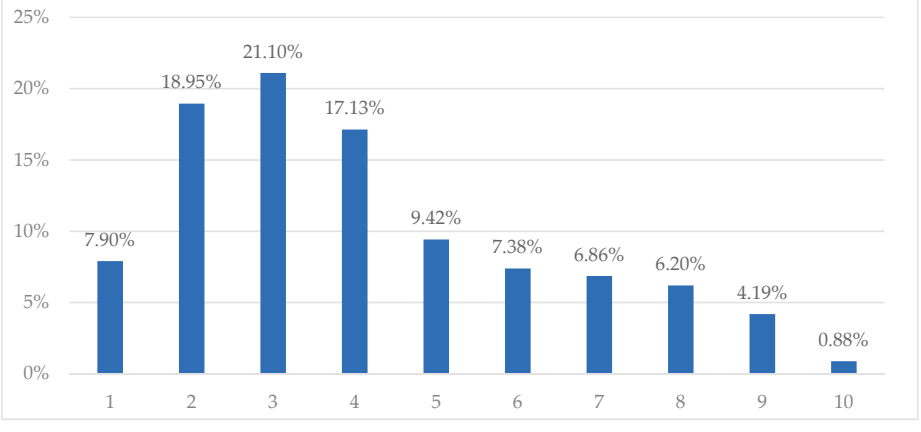

Figure 2. The answers to the question of whether the small number of stations in the city is demotivating for BSS usage, 1: it does not discourage me, 10: it discourages me a lot. N = 3631.

BSS performance was also found to depend on its operator (Table 2). In Poland in 2018, there were six companies operating BSSs. The company Nextbike Polska has a dominant position, operating 45 out of 56 BSSs in the country. The company is a branch of the multinational enterprise Nextbike, operating in

200 cities in 25 counties. We have found that BSSs operated by Nextbike Polska have a higher TDB, which may result from better technology, know-how and support from the mother company.

We found TDB to be positively related to car ownership (cars per person), which was our proxy for car congestion (Table 2). Traffic congestion arises near more populated areas where the car ownership index is higher [39,40]. BSS services are the alternative for car trips, especially in urbanised areas where the travel time loss caused by congestion is significant. This result matches many other studies' conclusions concerning the BSSs' role in reducing traffic congestion in cities [5,11]. Well-organised and properly managed bike rental services are the tool to change citizens' transport behaviour and reduce the consequences of a high car ownership index. In our survey, we asked cyclists to rate on a 10-point Likert scale the importance of using a BSS as a time saver and 54.3% of respondents rated this motivation 6 or higher, while 26.7% rated it 9 and 10. Thus, people use BSSs to generate travel time savings within highly congested urbanised areas.

A positive correlation between TDB and a higher temperature (Table 2) and a negative correlation between TDB and precipitation during the systems' operation match results presented in the study conducted by El-Assi et al. [24] for a BSS in Toronto. They showed that BSS ridership was positively related to higher temperatures and was intensified when the perceived temperature was between 20 and 30 degrees Celsius. Levels of 0–10 and 10–20 degrees were also positively correlated to ridership, unlike the temperature lower than 0. El-Assi et al. [24] found precipitation, snow and humidity to be negatively correlated with ridership. Thus, our results confirm that it is reasonable to keep Polish BSSs in operation from spring to autumn when the weather encourages ridership. In our survey, respondents indicated the importance of good weather with the median rate of 6 on a 10-point Likert scale. It is worth noting that weather conditions are related not only to cyclists' comfort but also to safety [24].

Additionally, our study indicates that the presence of a bicycle infrastructure, such as pathways, is a factor associated with the BSS ridership (Table 2). We used a variable measuring kilometres of paths per 10,000 inhabitants and found it to be positively related to TDB. Respondents of our survey answered two questions concerning the presence of dedicated bicycle pathways, rating them as a motivation, and separately a lack of them as a disincentive for using bicycles. An existing path network was not a significant motivating factor for 50.6% of our respondents, as they marked it with 5 or less points on the 10-point scale. Less than half of cyclists see existing infrastructure as an incentive for riding bicycles. This may suggest that more bicycle pathways could encourage more ridership. Interestingly, for 56.1% of respondent cyclists, a lack of bicycle infrastructure is an important barrier: they rated it at 6 or more with a median of 6 and mode of 8 (18.2% of answers). As Fishman et al. [7] presented in their paper about factors influencing BSS membership, paths are a guarantor of bicycle trip safety. They conducted a survey and asked respondents to rate how safe they would feel in three different bicycle riding environments. In general, people pointed to riding a bike on a road without a bike lane as very unsafe, at the same time choosing riding on a separate path as the safest option [7].

As we showed, cyclists' road safety perception is related to the weather conditions, as well as to the presence of infrastructure. It is worth mentioning that, in our survey, we asked respondents to rate if feeling unsafe in a road traffic discourages cycling. The median rate for this disincentive was 6, and 52.7% of respondents rated it at 6 or more. Therefore, creating favourable conditions for cycling (building pathways and adequate maintenance) can be perceived as a tool to increase BSS ridership.

As presented in Table 2, years since the system was launched and average pay in the region did not have a statistically significant correlation with TDB.

The literature review suggested that the second most important use of parks in the cities (after walking) is cycling [41]. Accordingly, we have tried to include this measure in our model, but we have found no correlation of percentage of parks and green areas in cities with TDB. This may be explained by the structure of the BSS fee. For most BSSs, the rental fee depends on the time the bike is used, therefore, discouraging leisure cycling in parks.

Finally, we asked participants of our survey for their preference for the dockless BSS. As presented in Figure 3, most of the respondents claimed that the possibility to use a dockless system would motivate them to use shared bicycles (68.30% of respondents answered 6 or more on the 10-point scale). Obviously, the hypothesis that popularisation of dockless BSSs would increase the TDB of the systems can only be verified after their implementation, so we could not include it in our regression.

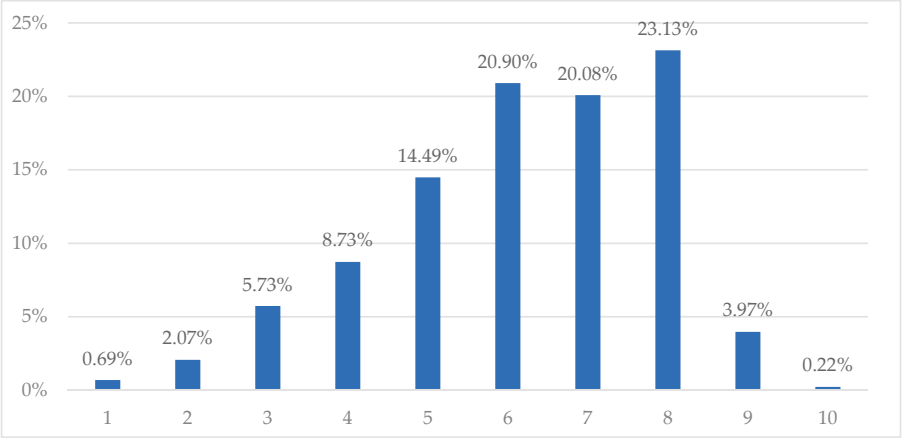

Figure 3. Answers to the question: Would the possibility of using a public bike that you can leave anywhere (not necessarily at the docking station) motivate you to ride a bike more often? 1: it would not motivate me, 10: it would be a very important motivation. N = 3631.

4. Discussion

4.1. General Discussion

We advance the sustainability literature by examining factors associated with BBS performance in Poland. At times when cities struggle with congestion and pollution, policy-makers and urban planners look into more sustainable transportation strategies. A promising strategy to help relieve these problems is public bike-sharing: a solution that has become particularly popular since the mid-2000s [10]. Correspondingly, research on the BBS topic is growing [12]. However, there are no studies examining the relationship between various factors on BBS effectiveness in Poland, which is the key contribution of this study. Moreover, the unique approach of our analysis is the combination of quantitative data on all BBSs in Poland with a qualitative survey conducted on the subject. The need for understanding the success of BBSs is directly related to being able to design effective policies involving expanding BBSs to other Polish cities and worldwide.

Our findings suggest that tourism is significantly related to the BBS effectiveness: cities with more tourists per capita had higher trips per day per bike. This was confirmed by our survey, where significantly more respondents reported using a BBS while vacationing. This is a unique contribution of this research as, to our knowledge, no previous BBS studies examined the tourism effect.

We also found evidence that bigger Polish cities enjoy a higher TDB, which is consistent with studies for other countries [23,24,32]. We also confirmed the relation of weather conditions to TDB, previously tested by El-Assi [24], Rixey [22] and Gebhart [33]. Higher temperatures and less rain are favourable to BBS effectiveness. We found that Polish cities that provide more bicycle infrastructure (including bike lanes and paths) have a higher TDB, which was also shown by Noland [23], El-Assi [26] and Fishman [7] for other regions. Our findings about station density's positive relation to ridership are in line with research published by Faghih-Imani [32] and Rixey [22]. The effect of car ownership on

TDB was not tested before, but Fishman found that in Beijing, Shanghai and Hangzhou, bike-sharing users have a higher level of car ownership than non-users [8], which is consistent with our results.

Our literature review did not reveal any research that would contradict our findings. Therefore, we can conclude that factors correlated with the effectiveness of Polish BBSs do not differ much from other regions. This is a premise for a conclusion that our finding relating tourism to a higher TDB may also be applicable in other countries.

4.2. Implications

Our research suggests that tourists are actively using BSSs as a tool of transportation. As many BSS stations are located in city centres and points of public interest, it makes this mode of transportation especially convenient for tourists that rarely bring their own bicycles to the cities that they visit. This finding may be important for policy-makers and BSS operators. In Poland, many of the BSSs were not compatible with each other even though the vast majority (80%) were operated by the same company. For example, a person that was already registered in the BSS system in Poznan, with the Nextbike's application already installed on their mobile phone, could not use the same company's BSS in Warsaw. That would require a second registration and installation of another application on that person's mobile device. Making systems compatible would allow for elimination of a potential barrier to use BSS for tourists, for the benefit of both visitors and citizens that would be relieved from additional traffic caused by tourists using cars or taxies. This conclusion is also supported by our survey's results, in which 50.9% cyclists marked 8 or more on the 10-point Likert scale when asked if using a BSS is complicated (the median rate was 8). In conclusion, as they are popular among visitors, BSSs can become a tool for the transportation policy in cities that are important tourist destinations to fight traffic congestion and air pollution. Our recommendation is to make BSSs across cites compatible with each other to enable easy usage of bicycles by travellers. Additionally, municipal authorities and operators can utilize our research when designing BSS marketing strategies. Such strategies should include well-designed offer information for tourists.

Another consideration for operators and policy-makers is the times BSSs are open. Some BSSs are only open seasonally while others are open year-round. Our results clearly suggest that BSSs that have more months with enjoyable cycling weather will have an advantage as measured by TBD. This suggests that it may not be cost-efficient to keep BSS open for the whole year. However, TBD is only one measure of effectiveness. Being open all year may be beneficial in terms of consistency as only BSSs that operate year-round can become an alternative to a private car. Additionally, there are costs associated with the need to advertise resumed service and repeatedly motivate a modal shift in order to build up usage each spring, as noticed by de Chardon et al. (2017) [6]. Thus, the decision on opening a BSS all year or seasonally may be dependent on local conditions. This trade-off has to be further investigated in future research using different dependent variables.

Overall, the results of our study suggest that if a BSS was to be successful and efficient, it should be implemented in urbanized areas with relatively big populations or prevalent travel destinations. BSS are more popular in urban areas where there are more registered cars per capita. This may suggest that BSSs are becoming an alternative way of transportation in highly congested areas. Also, the performance of a BSS relates to the cycling infrastructure. Thus, a policy of building bicycle pathways may improve ridership of public bicycles. BSSs perform better if there are more stations where the bicycles can be rented. This problem can be overcome by the introduction and popularisation of dockless systems. By 2018, only a few systems in Poland allowed for parking bicycles outside docking stations. Our survey results suggest that dockless systems would motivate more people to use BSSs.

4.3. Limitations and Future Research

We followed most of the previous literature to use TDB as a BSS performance measure (see review by de Chardon et al. [6]). It is a preferred measure as it controls for the variation in the number of bikes

and therefore enables comparison of systems that differ in size. Whilst TDB in Poland is the focus of this paper, we do not wish to imply this is the only measure of benefits of bike share. Obviously, TDB has its limitations. For example, it does not take into consideration the time of the trip. Further studies could consider other indicators of performance, i.e., the number of people registered in the system or the cost of bike-sharing as compared to public transportation. This kind of analysis needs to take into consideration different types of BBS financing schemes and costs of infrastructure for each mode of transportation. Also, the performance of a BBS could be measured by reduction in CO_2 emissions or air pollution. However, this would require much more complex data and would also need to take into consideration emissions from the production of bicycles, other means of transportation, and the carbon footprint connected with building necessary infrastructure. Another limitation of this study is a lack of comparable data about marketing and BBS prices, the effect of which we leave for future studies.

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Article

Stakeholder Collaboration on Policymaking for Sustainable Water Management in Singapore's Hotel Sector: A Network Analysis

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Abstract: Stakeholder collaboration has become a critical issue in sustainable tourism policy due to the increasing complexity and interdisciplinary nature of the domain. Policymaking should reflect tourism values through a dynamic system in which stakeholders come to a consensus on sustainability issues via ongoing interactive engagement. Taking Singapore's hotel sector as a case, this study explores how stakeholder relationships contribute to participatory policymaking on sustainable water management. Based on a survey of 33 relevant organisations, this research applies network analysis to investigate stakeholder collaboration within this policy domain. While the policymaking process is derived from a complex web of actors and their formal and informal interactions, the national water agency of Singapore and some private businesses were found to be centrally located in the policy network. The aforementioned government body is also perceived to hold the greatest legitimacy, power, and urgency over others in the policy domain. Central stakeholders were found to play an important "bridging" role in terms of the interconnectedness of policy actors across boundaries of the public, private, and third sectors. These prominent political and industry players were also likely to exert control over the policymaking process and access to important resources based on their favourable network positions.

Keywords: policy making; stakeholder collaboration; sustainable tourism and hospitality; sustainable water management; network analysis

1. Introduction

Tourism is widely regarded as an essential social activity because of its economic, social, and environmental significance [1]. Although tourism development is an important destination process, over-exploitation of crucial resources can lead to breakdown of the resource base and threaten ecosystems [2]. Frustratingly, "progress towards sustainable development of tourism is hardly satisfactory while sustainable practices are restricted to a few niche markets, with the rest of the tourism industry keeping its priorities clearly on profit" rather than sustainability [3] (p. 13). To address this shortcoming, recent studies have stressed that sustainable tourism development is dependent on developing "futuristic policies" [1] (p. 148). Importantly, such policymaking will need to acknowledge the interdependencies and interconnectedness within the tourism system [4] as "bring[ing] societal actors into joint projects" [5] (p. 20). A challenge facing stakeholders concerns how the complex and dynamic principles of sustainable tourism development can be translated into a destination's tourism policy framework [6].

Water is one such crucial tourism development resource, a prominent aspect of various tourist activities fundamental to the scenic beauty of a landscape and necessary to promote accommodation environments [7]. According to the World Tourism Organisation (UNWTO) [8], the rise in the number of international tourists is expected to continue. For the foreseeable future, more tourism-supporting systems (e.g., hotels, restaurants, golf course, spas, and other consumptive water-related recreation activities) will inevitably exert pressure on water availability [9]. The potential for increased water demand from tourism will exacerbate any current water shortage problems and potentially result in conflict over access to existing water resources. Thus, water availability and conservation, wastewater management, and drinking water quality constitute the UNWTO's top three baseline criteria for sustainability [10]. However, researchers have paid little attention to water management policies in the tourism industry, especially in water constrained destinations [11].

The hotel sector deserves detailed investigation in this regard because hotels are one of the tourism industry's largest drivers of employment and economic revenue [12] and a critical water consumer in many destinations [13]. As a key component of the tourism industry, the hotel sector is often identified as having the potential to make optimal use of water and other natural resources in the quest for more sustainable forms of development [14]. The confluence of a growing hotel sector concomitant with water shortages could culminate in a crisis in the absence of comprehensive water management strategies [15]. Yet, policymaking for water demand management (WDM) in the hotel sector is a relatively new research area with a limited body of knowledge [16–18].

Using Singapore as a case of best practice, this study seeks to examine the current contact network of inter-relationships of organisational stakeholders (in this study, policy stakeholders are in the public, private, and third sectors. The public sector refers to government authorities; the private sector includes private businesses; and the third sector (or host community) consists of non-governmental institutions, educational establishments and other citizen groups) representing multi-sectors and their perceptions of critical policy stakeholders in a tourist destination. Specifically, this research is guided by three key questions. Firstly, what are the characteristics of the current structure of contact network of WDM policymaking in Singapore's hotel sector? Secondly, how does the current network structure facilitate water policymaking in the hotel sector? Thirdly, to what extent can the Singapore's experience be learned by public policymakers?

2. Water Policy Research in the Tourism Industry

Water has been taken for granted as a low-cost renewable resource [19]; as such, tourism and many other economic sectors have arguably neglected to protect the environmental and natural assets on which they rely [20]. Two broad policy categories of polices have been proposed to better manage water resources in the tourism and hospitality industry: supply-side policies, which are aimed at "increasing water provisions" [21] (p. 11); and demand-side policies, which manage "consumptive demand itself to postpone or avoid the need to develop new [potable water] resources" [22] (p. xiii).

Water is critical to the hotel sector, yet provisions of the resource are becoming challenging, particularly in water-stressed regions. Consequently, demand-side water resource management in hotels has become central to ensuring the viability and sustainability of tourist destinations [16]. WDM policies comprise numerous approaches, including pricing strategies, management, and regulatory solutions, engineering and technical interventions, education and community involvement, and alternate water sources for non-potable purposes [23]. However, research on sustainable (demand) management of water within a tourism context remains a relatively low priority compared with residential, industrial, and agricultural water uses [21].

Scholars have pointed out that the design and implementation of WDM measures involve multiple stakeholders, such as water authorities, other government bodies, water consumers, educational establishments, professional associations, and non-governmental organisations (NGOs) [24]. Without stakeholder involvement, sustainability would "just be a marketing slogan or, at best a topic for theoretical debate" [25] (p. 12). Haywood [26] introduced an approach to examining tourism

stakeholders via a one-way, relatively independent economic (or particularly consumptive) relationship between various tourism stakeholders and the business sector. Later, Jamal and Getz [27] applied stakeholder constructs to tourist destination planning. The authors acknowledged the complexity of stakeholder relationships at a tourist destination, noting that the destination domain is characterised by an "open system" of multiple stakeholders. Other researchers have found that as "the tourism system context becomes increasingly fragmented and volatile" [28] (p. 19), stakeholder analysis of sustainability issues in tourism reflects increasing recognition of the extent to which stakeholders can or should influence policymaking [29].

Although stakeholder analysis can identify, characterise, and prioitise stakeholders [29], this approach has been criticised for underestimating the importance of structural characteristics of water policy actors' relational patterns at a destination level [15,30]. One contribution of the present study is that our integrated network approach provides an analytical tool to systematically and quantitatively examine the relationship structures of given network nodes (i.e., policy stakeholders). Treating a social structure as a network is the cornerstone of network analysis [31]. According to Burt [32], a social network, as an embedded social system, comprises a collection of multiple actors (i.e., nodes). Policy networks are linkages between actors with common interests in public policymaking (including policy formulation and implementation) [33]. Mathematically, a policy network is a graph that provides a lens through which to comprehend structures and collaborative destination policymaking between government bodies, private tourism firms, and civil society. Sustainable tourism policy networks may serve as frameworks to understand the engagement of diverse policy communities and their influences on policymaking in a tourism context [34]. Essentially, a network analysis extends beyond the attributes of individual policy actors to investigate how they are positioned within a policy system [35].

3. Methods

3.1. Study Area: Singapore as Case

Singapore was selected as the study area of this case study. Situated between Malaysia and Indonesia (Figure 1), the Republic of Singapore is located in the rain belt of the equator (130 km north) [36]. Owing to its geographical location, Singapore has a tropical climate with consistently high temperatures and humidity [37] and average annual precipitation of 2497 mm [38], more than twice the global average of 1050 mm per year [39]. However, Singapore is also a finite land mass, with unfavourable topographic constraints that limit the collection and storage of rainfall [40], and no freshwater lakes or underground aquifers [41]. Thus, Singapore faces substantial physical obstacles related to natural freshwater supply. The limited land mass of 720 km^2 with a population of 5.6 million [total population consists of Singapore citizens, permanent residents, and non-residents (e.g., work permit holders, dependents of residents, and student pass holders)] [42] together with the recent rapid growth in population and urbanisation only compounds Singapore's water challenges [43].

In spite of Singapore's water vulnerability, it remains one of the top tourist destinations in the world [44]. In 2017, inbound travellers to Singapore rose by over 6% to 17.4 million, reflecting a period of continued growth (Figure 2). Total visitor numbers are projected to rise by over 20% in the three years ahead [45]. Nearly 50% of international visitors to Singapore stay at hotels [46–48], and with an average length stay of approximately 3.5 nights [48], 28 million annual hotel guest nights were recorded in 2017.

Studies have shown that water-related conflict has arisen between the hotel sector and other non-household consumers worldwide [7,50,51], and Singapore is not an exception. Water consumption in Singapore's hotel sector totaled 6.56 million m^3 (based on the number of hotel guest nights (i.e., 12.15 million in 2001) (Figure 2) and average water use per guest night (i.e., 0.54 m^3) [52].) (1.44% of national potable water use (as of the total potable water use of 455.2 million m^3 in 2001 [53].)) in 2001, which increased sharply to approximately 15.13 million m^3 (based on the number of hotel guest nights (i.e., 28.01 million in 2017) (Figure 2) and average water use per guest night (i.e., 0.54 m^3) [52].) (3.03%

of national potable water use (As of the total potable water use of 499.4 million m^3 in 2017 [42]) in 2017. The average water use per guest night in Singapore was recently reported to reach 0.54 m^3 [51]; by contrast, the average Singapore household water use per capita per day was as low as 0.14 m^3 in a comparable year [54].

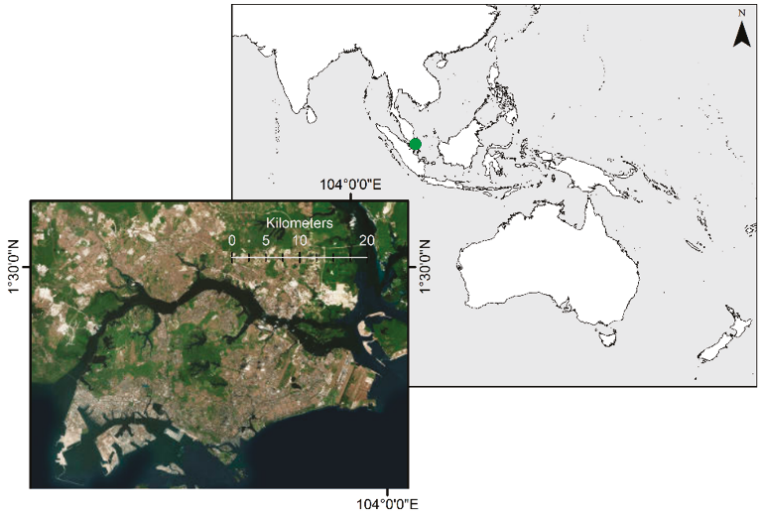

Figure 1. Location of Singapore.

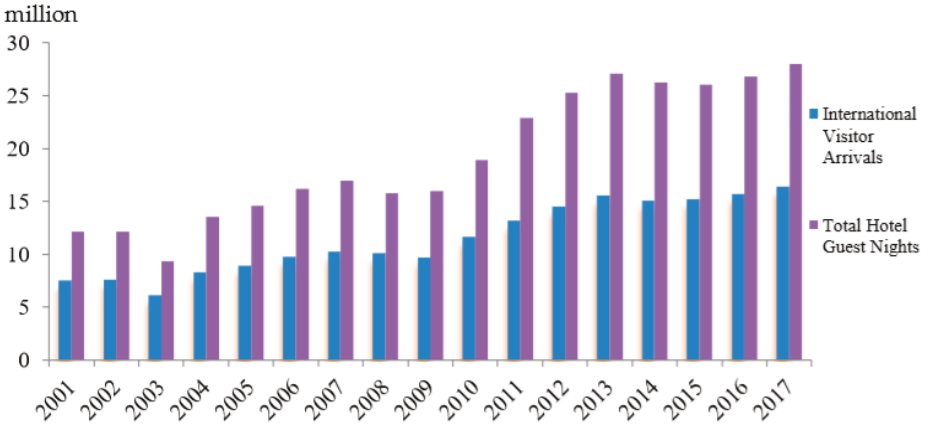

Figure 2. International arrivals to Singapore (2001–2017). Source: [46,49].

Despite the challenges associated with water resource management, it is essential to the long-term viability and sustainability of the hotel sector and greater tourism industry [21]. Singapore has launched a sustainable water management strategy that contributes to its overall sustainable tourism development goals [55]. The island is considered a success story in water policy and a paragon of water management in megacities, particularly in offering an integrated WDM policy system that includes diverse policy stakeholders [39].

3.2. Data Collection and Analysis

3.2.1. Name Generation

Given the aims of this study, the unit of analysis was set at the organisational level to examine the relationships and network structure among stakeholders in the policy arena. To identify the "seed" stakeholders involved in hotel-sector WDM, approximately 50 public policy documents at the Central Library of the National University of Singapore were reviewed. Sources include sustainable development blueprints, hotel entities' annual reports, and newspaper reports. An interview process immediately started with the identified "seed" stakeholders, including some government agencies, hotel property developers, hotel entities, water service companies, plumbers, industry associations, and educational establishments. Selected interviews with boundary-spanning personnel (i.e., senior management or delegates responsible for policymaking regarding WDM in Singapore's hotel sector) also provided "a first impression of [the] policy field" [56] (p. 12) and local background information, contributing to a preliminary understanding of the research issues [57]. During the interview, a "snowballing" technique was adopted to identify other organisational stakeholders who were considered relevant to the purpose of the study. [58]. To minimise misunderstanding and ambiguity of the concept of WDM, the scope of WDM in Singapore's hotel sector was presented to the respondents. They were asked the following "name generator" question using the "free recall approach" [59] (p. 70).

> Which organisation(s) located in Singapore do you think have either an actual or potential effect on policy formulation and implementation of water demand management (WDM) in Singapore's hotel sector? Please list as many names as you can recall.

Newly nominated policy actors were sent an invitation email to participate in the study. Then, they were also asked the same "name generator" question to identify additional potential stakeholders for the study [29]. This procedure continued until no more new organisational stakeholders were recommended, and the researchers felt that saturation had been achieved [60]. Ultimately, 33 policy stakeholders/stakeholder groups (stakeholder groups refer to stakeholder groups in the private and third sectors (e.g., hotel entities and universities). The following statistical analyses were based on average levels of respondents from these stakeholder groups) (see Table 1) from the public, private, and third sectors were identified (including "seed" actors along with nominees).

It was clear that it would be almost impossible to achieve a complete network by including all the WDM policy stakeholders in Singapore's hotel sector. Presumably, there were a finite number of public and third sector players. Thereafter, all pertinent public authorities and third-sector entities were included in the survey. On the other hand, there could be a potentially infinite number of private sector members. The private-sector actors were categorized into seven homogeneous stakeholder groups (i.e., consulting and advisory service providers, the corporate headquarter/parent company of hotel groups, hotel building owners/equity investors, hotel entities, hotel property developers/architects/builders, water service companies/water solutions, and water-wise fixture suppliers/plumbers). The sample in each of these stakeholder groups was purposefully selected. For instance, there were 149 member hotel entities registered at the Singapore Hotel Association (SHA) as of 30 April 2017 [61]. Thus, questionnaires were mailed to all the exiting member hotels. In the third sector, the sample included all the identified individual organisational stakeholders [e.g., Singapore Water Association (SWA)] and three stakeholder groups (i.e., media/press, universities, and polytechnics) with infinite members.

Table 1. Profile of Policy Stakeholders.

Stakeholder	Acronym
Public Sector	
Building and Construction Authority	BCA
Centre for Liveable Cities	CLC
Economic Development Board	EDB
Ministry of the Environment and Water Resources	MEWR
National Environment Agency	NEA
National Parks Board	NParks
Public Utilities Board	PUB
Sentosa Development Corporation	SDC
Singapore Accreditation Council	SAC
Singapore Tourism Board	STB
Standards, Productivity and Innovation Board	SPRING
Urban Redevelopment Authority	URA
Private Sector	
Consulting and advisory service providers	Consulting
Corporate headquarter/Parent company of hotels	HQ oh hotel groups
Hotel building owners/equity investors	Hotel building owners
Hotel entities	Hotel entities
Hotel property developers/Architects/Builders	Hotel property developers
Water service companies/Water solutions	Water solutions
Water-wise fixture suppliers/Plumbers	Fixtures/Plumbers
Third Sector	
Media/Press	Media/Press
Universities (in Singapore)	Universities
Institution of Engineers Singapore	IES
Singapore Institute of Architects	SIA
Singapore Environment Council	SEC
Singapore Green Building Council	SGBC
Singapore Hotel Association	SHA
Polytechnics (in Singapore)	Polytechnics
Singapore Water Association	SWA
Waterways Watch Society	WWS
Singapore Plumbing Society	SPS
Real Estate Developers' Association of Singapore	REDAS
Singapore Sanitary Ware Importers and Exporters Association	SSWIEA
Association of Consulting Engineers, Singapore	ACES

3.2.2. Survey Questionnaire Development and Administration

In the next stage, a total of 235 structured questionnaires were mailed to all the identified organisations individually in June 2017. The respondents were those who held leading positions, including the top management, heads of departments/units responsible for sustainable water management, sustainable tourism, and/or stakeholder relations of the identified organisations. The survey contained four questions exploring current stakeholder relationships and three widely recognised stakeholder salience attributes: legitimacy, power, and urgency [62]. More than 120 questionnaires were returned by 31 December 2017. After removing incomplete cases, the final sample consisted of 101 participating organisations (12 from the public sector, 59 from the private sector, and 30 from the third sector).

Questions were adapted from the works of Ahmed [63], Timur [64], and Wang [65]. To examine the existing stakeholder interconnectedness, the first question was designed to investigate whether or not policy stakeholders are in contact with one another vis-à-vis policymaking on WDM in Singapore's hotel sector. A standardised stakeholder list was presented to participants, and they were asked to check off stakeholders with whom their organisation had engaged in formal and/or informal contacts

(including via postings, newsletters, conferences, on-site visits, surveys, workshops, public forums, joint programmes, co-membership, and casual conversations) within the last 12 months (a recent 12 months is considered valid for surveying participants' up-to-date opinions on stakeholder salience [64]).

To identify and evaluate salient policy stakeholders who were particularly critical to policymaking, the three main stakeholder attributes, (i.e., legitimacy, power, and urgency) were also examined. These three critical factors, borrowed from Mitchell, Agle [62], may provide valuable insight into which stakeholders are considered particularly important relative to others. Participants were asked to assess the "acceptability" (legitimacy), "problem-solving capacity" (power), and "trustworthiness" (urgency) stakeholders in policymaking. Specifically, three structured questions are included:

- Which stakeholder(s) on this list should be involved in policy formulation and implementation of WDM in Singapore's hotel sector? Using the scale, please circle the relevant *degree of acceptability* of for each of the following stakeholders.
- How much power (i.e., problem solving capacity) do the stakeholders below exercise over others with regard to policy formulation and implementation of WDM in Singapore's hotel sector? Using the scale, please circle the relevant *degree of problem solving capacity* of for each of the following stakeholders.
- With regard to policy formulation and implementation of WDM in Singapore's hotel sector, claim from some stakeholders might be considered to be trustworthy. Using the scale, please circle the relevant *degree of trustworthiness* of for each of the following stakeholders.

Respondents were instructed to use a 5-point Likert-type scale to indicate the level of legitimacy/power/urgency [66], ranging from 1 (*extremely low*) to 5 (*extremely high*) for each entry on the standardised stakeholder list.

Quantifiable data were analysed in two main steps. First, once relational data had been gathered from the first question, an adjacency matrix was constructed to depict relationships among policy stakeholders in the policy network. Specifically, basic analysis intended to focus on presence (or absence) rather than the strength of connections among policy actors. Relationships between policy stakeholders were coded, and a squared matrix of 33 × 33 elements was constructed. To visualise stakeholder interconnectedness (i.e., formal and/or informal contacts), the policy stakeholder network was mapped in Netdraw. Several network measures were calculated thereafter with the assistance of UCINET VI, allowing for a structural understanding of how network actors were interconnected [35]. Also, statistical analyses were conducted to determine relative stakeholder importance on the aforementioned three stakeholder attributes [67]; the proportions of respondents with scores of either 4 (*high*) or 5 (*extremely high*) were calculated and examined (the scales of 1 *(extremely low)*, 2 *(low)*, and 3 *(neutral)* are not relevant to the purpose of data analysis) to uncover the legitimate, powerful, and urgent stakeholders.

4. Results

4.1. Policy Stakeholder Network Visualisation

The undirected dichotomous (binary) ties of all 33 identified policy stakeholders in the three sectors and their structural linkages from a whole network perspective are summarised in Figure 3, which illustrates the ego-centric links for each stakeholder. Although the network linkages map does not explicitly display inter-sector relationships, legends differentiate multiple stakeholders among different sectors.

Figure 3 presents the overall composition of policy stakeholders within the network. The map indicates that consulting and advisory service providers, Singapore's Public Utilities Board (PUB), and hotel entities comprise the network hub, closely surrounded by the following actors: the Building and Construction Authority (BCA); Ministry of the Environment and Water Resources (MEWR); National Environment Agency (NEA); Standards, Productivity, and Innovation Board (SPRING); hotel building owners/equity investors; hotel property developers/architects/builders; water service companies/water

solutions; water-wise fixture suppliers/plumbers; SHA; polytechnics; and Singapore Water Association (SWA). Peripheral actors in this network include the Centre for Liveable Cities (CLC), Economic Development Board (EDB), Sentosa Development Corporation (SDC), Singapore Accreditation Council (SAC), Urban Redevelopment Authority (URA), Singapore Environment Council (SEC), Waterways Watch Society (WWS), and Real Estate Developers' Association of Singapore (REDAS). Although no organisational stakeholder/stakeholder groups were entirely isolated in the network (i.e., having no ties with other actors in the network), those outlying policy actors were found to exert less influence than others in the realm of WDM policymaking.

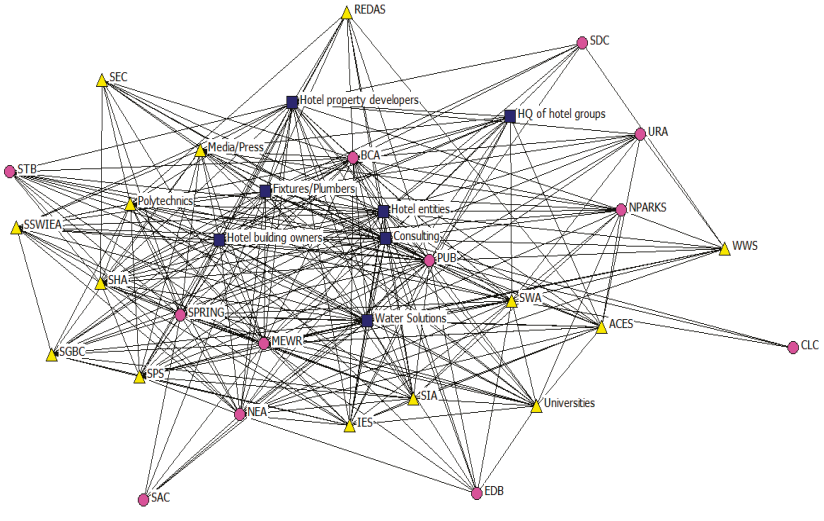

Figure 3. Structure of Policy Stakeholder Network. Legends: Public Sector; Private Sector; Third Sector.

The network map also illustrates contacts between sectors. Nearly all the members of the private sector exhibited formal and/or informal relationships with most of the government bodies. In particular, every private-sector member had established contacts with the PUB and BCA. The PUB collaborates with private businesses to optimise the use of Singapore's strategic water resources. The BCA frequently communicates with industry members to ensure water efficiency in commercial buildings. Likewise, nearly all private businesses demonstrated relationships with most of third-sector members. Consulting and advisory service providers had ties with all third-sector actors. Hotel entities, water service companies/water solutions, and water-wise fixture suppliers/plumbers also exhibited contacts with an overwhelming majority of third-sector actors. SWA and SHA had contacts with every private business. Polytechnics in Singapore had relationships with nearly all private businesses. Conversely, stakeholders in the third sector did not exhibit strong linkages with government authorities; neither SDC nor SAC had ties with any third-sector actors given the absence of prominent collaborative programmes between these sectors. Ties between the public and third sectors manifested through two primary channels—most of the third-sector members had ties with BCA, MEWR, PUB, and SPRING, whereas public-sector actors tended to demonstrate relationships with SWA due to routine events in the water industry.

Overall, the network map can be used to interpret relationships based on recent contacts between policy stakeholders in the three sectors. The interconnectedness of diverse stakeholders representing governmental authorities, businesses, and wider society regarding sustainability issues is promising for sustainable tourism policy development. Given the sampled stakeholders, the map identified

different patterns of stakeholder relationships from a whole-network perspective. These patterns indicate a degree of network-based policymaking around WDM in Singapore's hotel sector.

The characteristics of whole-network analysis and ego-centric network analysis have been addressed in previous research [33]. Whole-network analysis presents certain pitfalls related to sampling limitations. Thus, the focus of our study was on the ego level—that is, networks connected to a single node (i.e., an individual policy stakeholder) were investigated to describe the total population. A crucial characteristic of contact networks involves relationships among individual nodes scattered throughout the network [68]. Network measures of individual stakeholders (e.g., consulting and advisory service providers, PUB, hotel entities, and SHA) were therefore considered in this work. The following section presents an analysis of the ego-centric network measures and structure of the network to facilitate a clearer understanding of structural patterns behind stakeholder relationships in the policy network.

4.2. Underlying Structure of Policy Stakeholder Network

One way to assess the network structure of organisational stakeholder relationships in the policy domain is to evaluate network centrality and density, which respectively reflect the prominence of actors in the network and the level of connectedness (or cohesion) between them [33].

Degree centrality is generally considered the most intuitive pattern of centrality [69], referring to the total number of others to whom a focal node is directly tied, ignoring the direction and value of ties. The in-degree centrality measure has been deemed a remarkably stable indicator of network position "even at a low sampling level" [70] (p. 291). Furthermore, Freeman [71] developed a method to convert centrality measures into "normalised" centrality measures. In other words, degree centrality scores can be converted into proportions, thus enabling researchers to compare the centrality of actors from one network to another. Those who exhibit numerous ties and high in-degree centrality are significant, as many other nodes will attempt to establish direct connection with them to receive information, resources, and similar benefits. The in-degree centrality measure in this study revealed that consulting and advisory service providers, PUB, and hotel entities had the highest number of contacts in the network; all three groups were policy partners with over 90% of stakeholders/stakeholder groups (see fourth column in Table 2). That is, they shared contacts with more than 90% of respondents through postings, newsletters, official conferences, on-site visits, surveys, workshops, public forums, joint programmes, or co-membership. Active policy actors included water service companies/water solutions, BCA, water-wise fixture suppliers/plumbers, MEWR, SPRING, hotel building owners/equity investors, hotel property developers/architects/builders, and SWA. These actors had contacts with at least 70% of policy stakeholders in the network. Although these stakeholders also demonstrated more contact ties than others, CLC and SAC as well as SDC and EDB had far fewer contacts (see third column in Table 2). These four organisations were connected with less than 30% of others (see fourth column in Table 2), suggesting that not all policy stakeholders were actively involved in the network—some were more central, whereas others tended to be peripheral. Nonetheless, results imply that no policy actors were entirely isolated in this network. All respondents had contacts with another actor in the policy context.

Another characteristic of a network is density, defined as the number of ties existing in a network relative to the number of relationships theoretically possible [72]. Analytically, density is the coefficient between the number of actual ties and the number of maximum ties calculated on the basis of network size [73]. To investigate the number of ties linking policy actors in a network, UCINET VI was used to calculate density measures for the 33 stakeholders/stakeholder groups in this study. Density was used to determine the structural characteristics of contacts, denoted by a value ranging from 0 to 1. A network (based on contacts) can be dense (with numerous ties) or sparse (with few ties).

For the present study, a high-network density suggests a high degree of cohesion or connectedness among stakeholders in the policy context. The density of the network is 0.56, considered relatively high. This density may indicate a high overall cohesion in the network along with some potential to

connect to more policy stakeholders via future contacts. Relatedly, the degree centralisation index of 42.29% indicates a relatively flat network structure. Thus, certain policy actors (if not a single one) in the network tend to be much more central than others. As the score approached 50%, certain (more collaborative) policy actors (e.g., consulting and advisory service providers, PUB, and hotel entities) tend to have high core-periphery structure, and thus would exert stronger influences over the outer layer in the network [69]. Optimally, however, a decentralised network structure makes the diffusion of information relatively efficient—once any one of the actor(s) has news of the innovation, the rest of the network can quickly hear [31].

Table 2. Network Measures of Current Contacts.

Rank	Stakeholders	In-Degree Centrality	Normalised In-Degree Centrality (%)	Stakeholders	Density (%)
1	Consulting	31	96.88	CLC	100
2	PUB	30	93.75	SAC	100
3	Hotel entities	30	93.75	SEC	97.78
4	Water solutions	28	87.50	EDB	97.22
5	BCA	26	81.25	STB	96.97
6	Fixtures/Plumbers	26	81.25	SSWIEA	91.43
7	MEWR	25	78.13	SPS	89.54
8	SPRING	24	75.00	REDAS	88.89
9	Hotel building owners	23	71.88	HQ of hotel groups	87.18
10	Hotel property developers	23	71.88	SDC	85.71
11	SWA	23	71.88	URA	84.44
12	NEA	21	65.63	SGBC	83.52
13	SHA	21	65.63	SIA	81.87
14	Polytechnics	21	65.63	IES	81.70
15	Media/Press	19	59.38	Universities	80.00
16	SIA	19	59.38	SHA	78.57
17	IES	18	56.25	NPARKS	78.21
18	SPS	18	56.25	Polytechnics	78.10
19	Universities	16	50.00	Media/Press	77.78
20	ACES	16	50.00	WWS	73.33
21	SSWIEA	15	46.88	Hotel building owners	70.75
22	SGBC	14	43.75	NEA	70.00
23	NPARKS	13	40.63	SPRING	68.84
24	HQ of hotel groups	13	40.63	Hotel property developers	67.98
25	STB	12	37.50	ACES	67.50
26	URA	10	31.25	MEWR	66.67
27	SEC	10	31.25	SWA	66.01
28	WWS	10	31.25	BCA	64.00
29	REDAS	10	31.25	Water solutions	62.69
30	EDB	9	28.13	Fixtures/Plumbers	62.15
31	SDC	7	21.88	Hotel entities	58.85
32	SAC	6	18.75	Consulting	55.48
33	CLC	3	9.38	PUB	54.71

Note: See Table 1 for full titles of abbreviated organisation names.

In light of cohesion at the whole-network level, it was difficult to identify how and to what extent a specific policy stakeholder was embedded in the entire network. An actor-centred (or ego network) analysis was therefore required to clarify a policy actor's condition in establishing connections with others in current contacts. In this study, ego-network analysis of density was performed on all 33 stakeholders/stakeholder groups (see the last two columns of Table 2).

Consulting and advisory service providers, PUB, hotel entities, water service companies/water solutions, BCA, and water-wise fixture suppliers/plumbers demonstrated the largest ego networks according to the number of ties received (see third column in Table 2). These actors were directly linked to more than 26 (81%) of the 33 stakeholders/stakeholder groups listed (see fourth column in Table 2). The degree of linkage among the 33 network members for these six stakeholders was lowest (roughly between 55% and 64%) (see fifth and sixth columns of Table 2).

The normalised in-degree centrality measure is also included in Table 2 to clarify the difference between in-degree centrality and density. Taking the stakeholder group of hotel entities as an example, the number of hotel entities' ties with other stakeholders indicates an in-degree centrality of 30 (see third column of Table 2). Because 33 stakeholders/stakeholder groups were identified, the number of ties in the hotel entity group was divided by the number of other stakeholders in the network (i.e., 32) to obtain the normalised degree centrality measure. The result, 93.75%, indicates that hotel entities had contacts with 93.75% of network members related to WDM in Singapore's hotel sector; however, hotel entities did not exhibit a dense individual (or ego) network. The level of linkage among the other 32 network members (i.e., density) for hotel entities was 58.85%. Accordingly, nearly 60% of all possible ties were present. A figure of 0.59 cannot be considered an absolutely weak density measure, as the density measure could be any number between zero and one [69]. Nevertheless, this density measure was relatively low compared with that of most others. Stakeholders with the highest density measures (one) for all possible ties were depicted in the ego networks. Both actors exhibited small-sized ego networks (CLC: 3; SAC: 6). SEC, a third-sector member, had the third-highest density measure of 97.78%, demonstrating nearly all possible ties in its individual network. SEC also had a small ego network size (10) based on the number of received links (i.e., formal and/or contacts) with regard to in-degree centrality (see third column of Table 2). Contrastingly, the third-sector member, SWA, with a relatively large ego network size of 23, had a relatively low density measure (66.01%) [59]. Network analysis studies have shown that network density tends to decline when network size increases and vice versa [31]. Our findings strongly support this argument. Highly dense (ego) networks tend to prevent ties with others outside this "small world", thereby limiting new information exchange and potential collaboration [74].

To sum up, policy stakeholders with high degree centrality measures (e.g., consulting and advisory service providers, PUB, and hotel entities) tended to comprise the core of the network. They were pivotal policy actors with considerable influences in terms of network information flow. No actors from the third sector were found to make prominent policy-related contribution. By contrast, actors with high centrality measures often exhibited a relatively low density score in their individual networks. These factors suggest that policy actors with favoured structural positions (e.g., consulting and advisory service providers, PUB, and hotel entities) should strive to ensure stakeholder interaction and engage actively in cross-sectoral collaboration in policymaking, the absence of which presents a major policy challenge to sustainable tourism development.

4.3. Stakeholder Salience

To locate legitimate, powerful, and urgent policy stakeholders of WDM in Singapore's hotel sector, questionnaire data were analysed to determine whether central stakeholders were among the salient stakeholders. If an actor is well connected with others, one can be arguably critical, as it is more likely to have access to different non-redundant sources of information [33]. Three measures were combined via a 3-D scatter plot (Figure 4). When scaled to 100%, the x-axis denotes policy stakeholders' problem-solving capacity (power), the y-axis denotes their acceptability (legitimacy), and the z-axis denotes trustworthiness (urgency). The relative position of each policy stakeholder in this 3-D space provides an overview of their overall salience in the network.

Figure 4 reveals PUB and BCA as salient policy stakeholders. Both were highly involved in policy composition, enabling them to assert government control over policymaking. SHA exemplified a highly balanced policy actor according to the stakeholder attribute criteria. Therefore, the hotel industry association was the only representative of the third sector to achieve a relatively high overall ranking in the scatter plot. After SHA, hotel property developers/architects/builders, hotel entities, and consulting and advisory service providers were relatively balanced policy stakeholders per the chosen criteria.

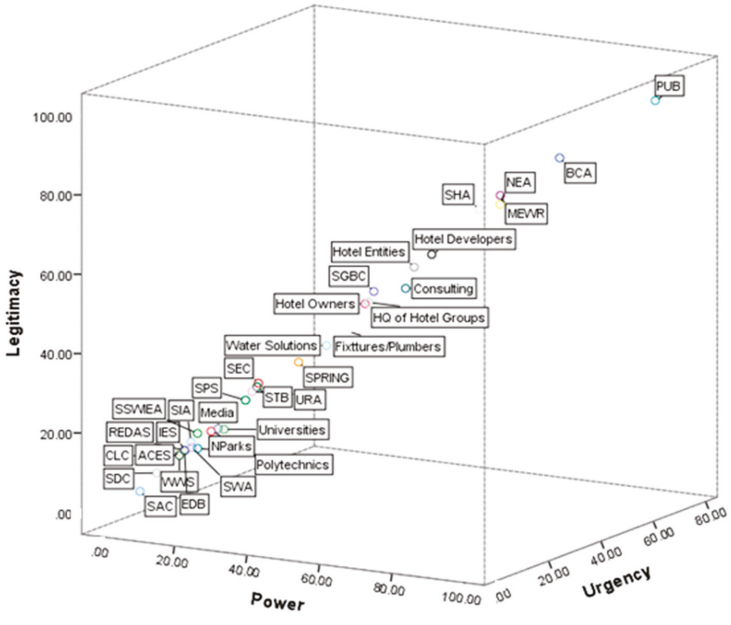

Figure 4. 3-D scatter plot of stakeholder salience. Note: See Table 1 for full titles of abbreviated organisation names.

By contrast, many third sector members, as well as some public authorities, could be considered less salient stakeholders. As can be observed in Figure 4, the Singapore Sanitary Ware Importers and Exporters Association (SSWIEA), WWS, REDAS, Association of Consulting Engineers, Singapore (ACES), media/press, universities, and polytechnics were relatively close to zero on all three axes. None of them were centrally located in the network either.

Overall, all policy stakeholders/stakeholder groups with high salience except for NEA and SHA were among the top 10 policy stakeholders with relatively high levels of in-degree centrality (Table 2). Respondents' overall scores revealed PUB to be the most prioritised stakeholder with the highest centrality. PUB also played a bridging role in inter-sector networking, enabling contacts between clusters to be established and maintained. Developing contacts with less connected or peripherised policy actors could alleviate inter-sector isolation while improving the legitimacy and acceptability of sustainable tourism policies. Moreover, respondents did not appear to consider any private- or third-sector policy actors to be the most salient ones, although some private-sector members (e.g., consulting and advisory service providers and hotel entities) occupied the central positions accordingly to the survey results. Comparatively, four policy actors with relatively high levels of centrality (i.e., water service companies/water solutions, water-wise fixture suppliers/plumbers, SPRING, and hotel building owners/equity investors) were not found to be highly salient stakeholders. This pattern concurs to some extent with the assertions from Prell [59] that "degree centrality is . . . seen as a measure for an actor's level of involvement or activity in the network. It does not consider whether or not an actor is seen as influential or popular" [59] (p. 17). Again, it is observed that only the stakeholders with high levels of centrality and with access to or possession of critical resources are perceived to be salient in the policy network.

5. Discussion

Stakeholder collaboration in pursuit of common goals in sustainable tourism is determined by the stakeholder relationships established in a policy network [75]. To create an environment

where collaboration on sustainable tourism policy formulation and implementation could be realised, a policymaking framework for WDM in Singapore's hotel sector was introduced (Figure 5). Our findings suggest that although different stakeholders can play crucial roles in developing sustainable tourism policies, some public sector bureaucracies (e.g., PUB) are expected to assume prominent roles in the policy field. Naturally, this government player scored high on stakeholder attributes given its oversight of Singapore's water sustainability. Sustainable tourism policymaking may therefore appear subordinated to administrative or political priorities. Also, the government bodies had been well-connected with other policy actors within the past 12 months. Considering the fragmented nature of tourism, participation and involvement of broker stakeholders is crucial for the achievement of sustainable tourism development goals [35].

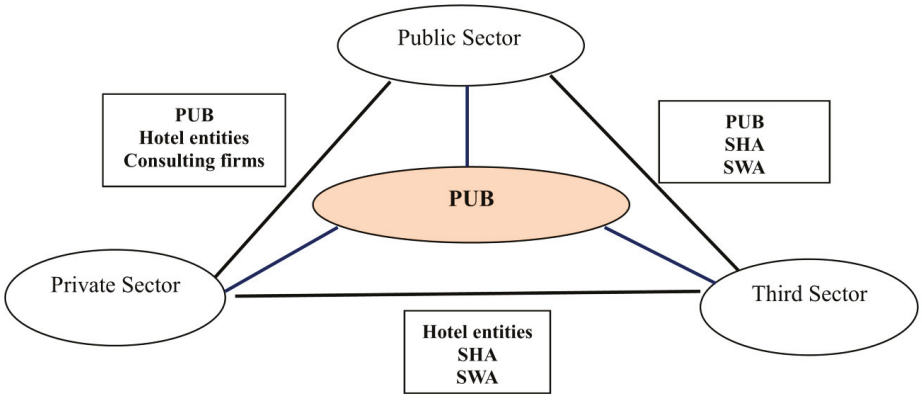

Figure 5. Policymaking framework for water demand management (WDM) in Singapore's hotel sector. Note: See Table 1 for full titles of abbreviated organisation names.

Notably, no dominant public authorities were typical players in the tourism and hospitality industry. For instance, the role of PUB pertained to sustainable water management in Singapore. The following commentary from Mr. Lee Kuan Yew, Singapore's founding father, could explain why diverse stakeholder respondents expected the PUB to assume a prominent role in the policy domain: " ... [water] dominate[s] every other policy. Every other policy [must] bend at the knees of water survival" [55] (p. 189) as Singapore's demand for water far exceeds its naturally occurring supply [76]. In addition, our findings empirically confirm the multidisciplinary and complex nature of sustainable tourism and the significance of environmental government agencies' roles in sustainable tourism policymaking [1,75].

As Singapore's "government cannot be expected to solve our public problem in isolation" [77] (p. xviii), some private sector members, including consulting and advisory service providers and hotel entities, are also important in policymaking. Although the island's hotel sector has achieved robust growth in the last decade or two [44], sustainability challenges in water-intensive sectors are becoming increasingly evident [78]. Therefore, other policy stakeholders may have numerous ties to consulting and advisory service providers and hotel entities during the design, construction, operation, and occupation stages related to WDM matters.

Unlike in the public and private sectors, no third-sector member necessarily played a consistently important role in sustainable tourism policymaking. From a policy network perspective, it is essential to cooperate with various sectors; achieving sustainable tourism would be rather difficult otherwise [75]. As greater integration in the tourism policy domain is considered a prerequisite to more sustainable outcomes [79], it is crucial for central policy actors to link other actors in the network. The ability to act as a "broker" relies heavily on central players' abilities to forge connections among other network

entities [68]. For example, SHA, the umbrella body for hotels in Singapore, could be considered an emerging third-sector member in the policy context.

These findings highlight that policy stakeholders from all three sectors perceive sustainable tourism policymaking to be more than a tourism-sector responsibility. Instead, many other (non-tourism) organisations concerned about sustainability issues may be incorporated into relevant discussion. Some scholars have supported decentralised policymaking, especially through combining the government, industry, and community [15,80]. However, governmental authorities can appear irresponsible if they work alone to devise solutions to integrated economic, environmental, and social problems. For instance, other policy stakeholders' greater dependence on PUB increases the likelihood that they would regard PUB as powerful. This attitude could then allow the national water agency to hold a more central position and become even more influential in the policy context. Ideally, policy networks for sustainable tourism development would be non-hierarchical [75]. Yet, this case study of WDM in Singapore's hotel sector suggests that an ideal policy network "occurs very rarely, if at all" in reality [81] (p. 5).

6. Conclusions

This study applies classical stakeholder analysis and a network analysis approach to investigate relationships among stakeholders in a sustainable tourism policy context. Focus is given to a specific policy arena, namely WDM in Singapore's hotel sector, as this is considered an exemplar domain for the development of sustainable tourism.

Stakeholder analysis provides valuable insights into policymaking, as stakeholder involvement is integral to sustainable tourism development [1]. In tourism policymaking, various stakeholder perspectives must be taken into account, including those of responsible government authorities, industry players, and NGOs [75]. A depiction of a policy framework through which sustainable tourism policymaking may be realised was generated by identifying key stakeholders through questionnaires, after which three core characteristics (legitimacy, power, and urgency) were employed to distinguish important and less important policy stakeholders in sustainable tourism policymaking.

Through the use of social network analysis in this study, central stakeholders in policy development were identified. The existing structural positions of stakeholders displayed that consulting and advisory service providers, PUB, and hotel entities possess extremely high centrality. The network size and cohesion further revealed the apparent openness and vibrancy of WDM in Singapore's hotel sector as a policy system. Although the policy system was found to include collaborations centred around some stakeholders, the interrelatedness of multiple stakeholders denotes a trend in cross-sector collaboration in sustainable tourism.

This study also investigated whether an actor's central position is well-established because that actor is considered a salient stakeholder, or is an actor considered a salient stakeholder because it has connections to numerous policy actors? In the case of Singapore, both statements appear to apply. The leadership role of national water agencies in the sustainability-related policy domain—in this case, PUB—is of relevance to practitioners in this case study destination but also other water constrained destinations and other natural resource management issues.

Is the current structure of policy stakeholder network good? This research does not provide the answer, and causes and consequences of policy network attached to environmental and organizational antecedents are to be discussed elsewhere. However, the network analysis does strongly suggest that sustainable tourism in particular does not represent a traditional public policy domain. The complexity of tourism's interactions with the "natural" environment (e.g., water resource) and the inclusion of other concerns (e.g., social, cultural, and economic) have become critical issues to address [14]. Governments, businesses, and non-government organisations are looking for ways to minimise the environmental impacts of tourism while simultaneously continuing to enjoy the socio-economic benefits that tourism can generate [82]. Therefore, embeddedness of policy stakeholders echoes the nature of sustainability-driven policymaking. In other words, policymaking has to stretch beyond

sectoral boundaries to devise solutions that are acceptable and responsive to challenges in sustainable tourism [75]. The interaction of multi-stakeholders reflects different patterns of network structures, which influence the relative salience balance between central policy stakeholders and others. The central stakeholder should be the one with highest centrality measure and the most important one perceived by others. In the long-term, increased participation of cross-sectoral stakeholders with mitigated "structural holes" are likely to become fully interconnected. This study argues that sustainable tourism is a process of interaction and an outcome of collaboration. Achieving sustainable tourism would rely on the extent to which a destination creates a participative model in which policy stakeholders are involved, and their interests and concerns should be included in a sustainable tourism policy system. Thus, there is a need for establishing and maintaining sustainability policy networks at destinations to improve the process of sustainable tourism development at destinations. Despite the valuable and interesting findings of this research, the causes and consequences of network structures and stakeholder salience have yet to be examined. We recommend that further studies incorporate qualitative methods to supplement the quantitative results; qualitative findings may reveal and justify additional stakeholder attributes and the interactional nature of relevant relationships. For example, open-ended questions may facilitate more in-depth interpretation of the quality and content of interaction between and among public-, private-, and third-sector members. Although social network analysis serves a useful analytical tool for the scrutiny of structure of current contacts networks in this study, little has been done to compare it with that of other natural resources management. Also, the diverse WDM policy themes (e.g., pricing and non-pricing mechanisms), their linkages, policy preferences of divergent stakeholders, and longitudinal analyses of structural changes in stakeholder collaboration deserve stronger attention in another research.

Further, this study concentrates on the outcome, rather than the communication channel, per se. Formal and informal contacts are considered to be equally important in providing an in-depth insight into how a divergent group of policy stakeholders interact at a destination. Future research could focus on the possibly different functions that formal and informal contacts may respectively serve, as comparative studies of different types of relationships would further increase the validity of the test results [75].

Another limitation was related to plenty of responses that came from certain stakeholder groups (e.g., hotel entities). The stakeholder analysis was examined at an average level, thus no specific individual variables were taken into consideration. Further, larger-sized stakeholder groups are highly likely to have contacts with other policy actors, which would favour "normalised" centrality of these stakeholder groups. The results could reflect biases from these stakeholder groups.

Finally, attempting to ameliorate criticism of the generalised case study to theory, this study is conceptually framed within a blended network approach, which allows a logical investigation of a "real-life phenomenon in depth" [75] regarding stakeholder network structure, the pattern of stakeholder relationships, and how the structure of relations among stakeholders can influence water policymaking system in Singapore's hotel sector.

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sustainability

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Article

Developing the Urban Thermal Environment Management and Planning (UTEMP) System to Support Urban Planning and Design †

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Abstract: Mathematical Climate Simulation Modeling (MCSM) has the advantage of not only investigating the urban heat island phenomenon but also of identifying the effects of thermal environment improvement plans in detail. As a result, MCSM has been applied worldwide as a scientific tool to analyze urban thermal environment problems. However, the meteorological models developed thus far have been insufficient in terms of their direct application to the urban planning and design fields due to the preprocessing task for modeling operations and the excessive time required. By combining meteorological modeling and Geographic Information System (GIS) analysis methods, this study developed the Urban Thermal Environment Management and Planning (UTEMP) system that is user-friendly and can be applied to urban planning and design. Furthermore, the usefulness of UTEMP was investigated in this study by application to areas where the heat island phenomenon occurs frequently: Seoul, Korea. The accuracy of the UTEMP system was verified by comparing its results to the Automatic Weather Systems (AWSs) data. Urban spatial change scenarios were prepared and air temperature variations according to such changes were compared. Subsequently, the urban spatial change scenarios were distinguished by four cases, including the existing condition (before the development), applications of the thermal environment measures to the existing condition, allowable future urban development (the maximum development density under the urban planning regulations), and application of the thermal environment measures to allowable future development. The UTEMP system demonstrated an accuracy of adj. R^2 0.952 and a ±0.91 Root Mean Square Error (RMSE). By applying the UTEMP system to urban spatial change scenarios, the average air temperature of 0.35 °C and maximum air temperature of 1.27 °C were found to rise when the maximum development density was achieved. Meanwhile, the air temperature reduction effect of rooftop greening was identified by an average of 0.12 °C with a maximum of 0.45 °C. Thus, the development of UTEMPS can be utilized as an effective tool to analyze the impacts of urban spatial changes and for planning and design. As a result, the UTEMP system will allow for more efficient and practical establishment of measures to improve the urban thermal environment.

Keywords: urban climate; mathematical climate simulation modeling; GIS; urban planning and design

1. Introduction

The urban thermal environment is increasingly worsening as climate change, urbanization, and human activities increase [1]. These thermal environmental problems are the cause of a variety of

urban problems, including decline in the health of citizens, increasing energy consumption, decline of ecosystem service functions, and deterioration of air quality [2,3]. In the case of Korea, if greenhouse gas is emitted as BaU (Business as Usual), it is expected that temperatures of about 4–5 °C will increase in most metropolitan cities after 100 years. Not surprisingly, various attempts have been made to improve the thermal environment through planning and design techniques, including the introduction of heat reduction infrastructures and the creation of wind corridors.

Meanwhile, it would be ideal to utilize long-term observational data throughout the entire urban area in order to investigate urban climatic characteristics and to analyze the effects of thermal environment improvement measures. However, this is practically impossible due to space constraints, installation time, and expensive operating costs [4]. Therefore, a Mathematical Climate Simulation Model (MCSM) that interprets natural phenomena as a mathematical equation using computers has been mainly applied to urban thermal environment analysis [5].

The MCSM is capable of quantitative analysis of complex urban thermal environments and has advantages in that similar iterative analyses can be conducted and verified relatively quickly at a lower cost than field observations or wind tunnel tests [6]. With recent advances in analytical techniques and computer processing speeds, the use of mathematical modeling continues to increase in urban planning and design [4,7].

On the meso-scale level, energy balance models such as WRF (Weather Research and Forecasting Model) and MM5 (Mesoscale Meteorological Mode version 5) have been applied to investigate overall meteorological phenomena (temperature, wind direction, wind velocity, etc.) of large urban areas, and to analyze the effects of heat environment improvement with the introduction of large parks and green areas [8–10]. In addition, a guideline map to plan and manage the thermal environment throughout urban areas has been developed that takes into account MCSM results and urban spatial characteristics [11].

On the other hand, on the micro-scale (building unit or block scale), climate variations due to the introduction of heat reduction infrastructures (vegetation and cool pavements expansion) or changes of building form and arrangement have been analyzed by applying computational fluid dynamic models (CFD) such as Envi-met, Fluent, and so on. Roth and Lim [12] investigated the usefulness and limitations of Envi-met as an urban thermal planning tool. Gromke et al. [13] identified the heat reduction effects of introducing trees and green roofs by applying the Fluent Model. Wang, Berardi, and Akbari [14] established thermal environment improvement scenarios combining albedo control, cool roofs introduction, and vegetation expansion, and their heat mitigation effects were investigated using the Envi-met model. On the pedestrian level, Ng et al. [15] analyzed the heat reduction effects of green roofs by applying the Envi-met model. In addition, Nararian, Sin, and Norford [16] simulated outdoor comfort resulting from urban spatial changes, by applying a micro scale model.

Although the utilization of MCSMs is increasing in the urban planning and design field to improve the thermal environment, in order to apply urban planning and design alternatives mainly created by Computer-Aided Design (CAD) or Geographic Information System (GIS) to the MCSM, complex pre-processing is required. In particular, most models use the model input database provided by the country where the model was developed, so important spatial characteristics are often ignored when applying climate modeling to other countries. Therefore, there are challenges for non-specialists related to climate model research to operate MCSMs. In addition, despite the progress of computer processing speed, it takes a relatively long time to identify model results [5,17], which makes it difficult to compare the alternatives that are changed frequently in the process of urban planning and design.

Furthermore, most of the climate modeling that has been developed so far is limited to either the meso-scale or the micro-scale depending on the characteristics of the model such as assumptions on meteorological phenomena. Therefore, in order to establish effective measures to improve the thermal environment, as Shuzo [18], Mirzaei [17], and Mirzaei and Haghighat [4] have emphasized that it is necessary to develop a model that integrates the meso-scale and the micro-scale.

The applicability limit of the MCSM increases the need for system development that can be usefully applied to urban planning and design to effectively improve the thermal environment. The objective of this study is to develop a SDSS (Spatial Decision Support System) to foster urban thermal environment improvement through urban planning and design, and to verify the usefulness of the developed system. Thus, this study developed the Urban Thermal Environment Management and Planning (UTEMP) system that integrates a MCSM and a GIS engine to improve the urban thermal environment through planning and design. In addition, to verify the accuracy of the MCSM that integrates meso-scale and micro-scale spatial characteristics, air temperatures were simulated on the district-scale level (between meso-scale and micro-scale), and the simulated results were compared with observed air temperatures. Finally, its usefulness for urban planning and design were identified by investigating air temperature variations according to urban spatial changes.

2. Materials and Methods

2.1. Developing the UTEMP System

The UTEMP system was established by combining a GIS engine and a thermal environment analysis engine, both of which were developed by a private Korean company. The GIS engine of the UTEMP system has technological characteristics that are internationally compatible (meeting the open geospatial consortium standard) and provides over 80 types of geo-processing tools. Meanwhile, the thermal environment analysis engine is a kind of morphological model that integrates a meso-scale and a micro-scale model. This engine is capable of performing one-hour climate analysis of large-scale urban space (about 605.24 km^2) in 30 m × 30 m resolution within 20 min and securing an accuracy FAC2 (Fact of two) of more than 80%.

2.1.1. Main Functions of the UTEMP System

The UTEMP system consists of seven main functions and 27 sub functions. The main functions are as follows: (1) File, (2) Home, (3) Urban Planning Regulation and Climate Conditions, (4) Urban Spatial Change Simulation, (5) Thermal Environment Improvement Alternatives, (6) Thermal Environment Analysis, and (7) Thermal Environment Improvement Plan Assessment (Table 1). File and Home provide elementary GIS functions such as project creation and management, data input and removal, and geo-processing. In the case of urban planning and climate inventories, the UTEMP system provides basic information of the study area to establish thermal environment alternatives such as zoning information, urban climate zones, topography, and land cover.

Table 1. Main and sub functions of the Urban Thermal Environment Management and Planning (UTEMP) system.

Main Functions	Sub Functions
File	Project (project creation, open project, save), data (add data, remove data, export data), conversion data, map creation
Home	View (pan, zoom in/out, etc.), selection (attribute/location selection), geo-processing (buffer, clip, intersect, union, etc.), measurement, view mode change
Urban Planning Regulation and Climate Conditions	Urban planning and management (zoning, urban facilities, land use, road, building, etc.) climate information (air temperature, wind direction, wind speed, atmospheric pressure, relative humidity, cloudiness, etc.), climate characteristics (urban climate zones), topography, statistics
Urban Spatial Change Simulation	Maximum development density simulation, input alternatives, applying urban development patterns, editing, statistics
Thermal Environment Improvement Alternatives	Creation of wind corridor (roads, buildings), heat reduction infrastructures introduction (urban parks, vegetation, cool pavements, green roofs, water spaces), establishing thermal environments scenarios
Thermal Environment Analysis	Climate modeling (air temperature, wind speed, wind direction), thermal comfort modeling, urban spatial statistics
Thermal Environment Improvement Plan Assessment	Alternatives assessment (air temperature reduction, thermal environment improvement), alternatives comparison

The most important functions of the UTEMP system are as follows: Urban Spatial Change Simulation, Establish Thermal Environment Improvement Plan, Thermal Environment Analysis, and Thermal Environment Improvement Plan Assessment. The Urban Spatial Change Simulation function can predict whether the individual buildings of the study area can be changed to the maximum development density under urban planning regulations. In addition, if an urban development alternative plan is expected in the study area, this plan can be inputted for thermal environment analysis. The application of the typical planning and design techniques to improve the thermal environment, such as the creation of a wind corridor and the introduction of heat reduction infrastructures, is possible through the Establishing Thermal Environment Improvement Alternatives function. Finally, the Thermal Environment Analysis and Thermal Environment Improvement Plan Assessment functions enable data pre-processing for MCSM and analyze climate variations according to urban spatial changes. In other words, the UTEMP system was developed to implement both climate modeling functions and thermal environment improvement measures (Figure 1).

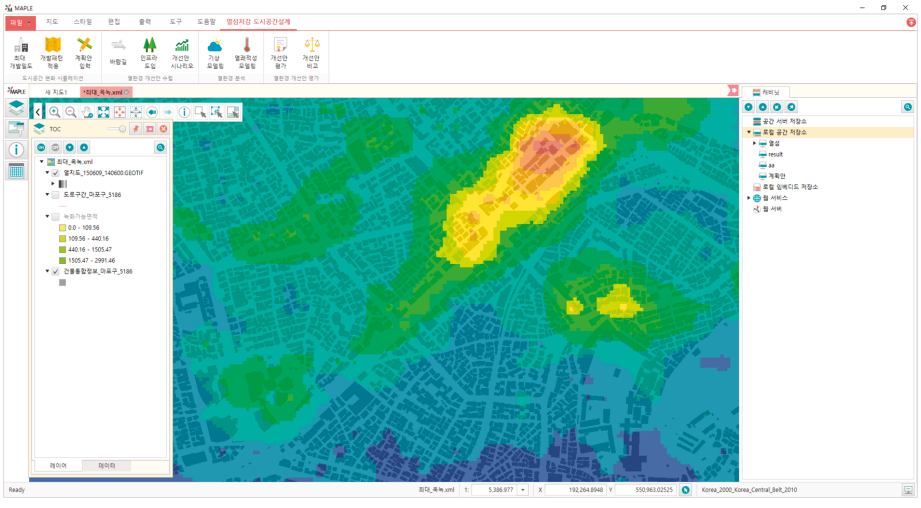


Figure 1. User interface of the UTEMP system.

2.1.2. Developing the Thermal Environment Analysis Engine

The thermal environment engine included in the UTEMP system is classified into the meso-scale climate model and the thermal dispersion model. The meso-scale climate model consists of a flat terrain model, urban model, and complex terrain model. To create a meteorological field that reflects the urban spatial structure of the modeling area, assuming that the model areas are a flat terrain, the first meteorological field was established based on the Automatic Weather System's (AWS's) observation data. Next, an urban model was created reflecting building information including location and shape, and a final meteorological field was generated reflecting the elevation information of the urban model through a complex terrain model.

On the other hand, the temperature field model was composed of a Heat Source Tag Model (HSTM) and the Lagrangian Particle Dispersion Model (LPDM). Applying Equation (1) developed by Nunez and Oke [19], the HSTM calculated the energy balance of the model area based on the meso-scale climate model.

$$Q^* + Q_F = Q_s + H + E \quad (1)$$

Q^*: *Net radiation*,
Q_F = *Artificial heat*

Qs = Storage heat flux
H = Sensible heat flux
E = Latent heat flux.

Considering the shade effect, net radiation was calculated based on the shadow factor and the sky view factor. In order to estimate the storage heat flux, Equation (2) was applied and parameters for land covers were selected. They are presented in Table 2.

$$Q_s = \sum_{i=1}^{n} f_i a_{1i} Q^* + \sum_{i=1}^{n} (f_i a_{2i}) \frac{\partial Q^*}{\partial t} + \sum_{i=1}^{n} f_i a_{3i} \quad (2)$$

f_i: *Area ratio of land cover*
Q_i: *Net radiation*
a_1, a_2, a_3: *Coefficient determined by land cover type*
t: hour

Table 2. Parameters of land cover to estimate net radiation.

Land Cover Type	a_1	a_2	a_3	Sources
Green	0.34	0.31	−31	Grimmond and Oke [20]
Building	0.07	0.06	−5	
Impervious	0.83	0.4	−54.2	Mean value of research results of Doll et al. [21] and Asaeda and Ca [22]
Water	0.5	0.21	−39.1	South et al. [23]
Road	0.61	0.41	−27.7	Mean value of research results of Doll et al. [21] and Asaeda and Ca [22]

Next, to apply LPDM, the climate phenomena including air temperature, wind direction, and wind speed of the model area was predicted based on the sensible heat flux, which was calculated by HSTM. The entire model process was coded by FORTRAN (FORmular TRANslator) and was included in the UTEMP system as sub-functions.

2.2. The Case Study

The usefulness of the UTEMP system was verified by applying it to the Seogyo-dong area in Seoul. Although this area is not representative of the more common high-rise neighborhoods in Seoul, urban thermal environmental planning and management has been required because of Seogyo-dong's high potential for urban development. The study area is dominated by impervious surfaces with building coverage, and vegetation is very insufficient. In addition, although the Han River is adjacent to the area, ventilation is very poor due to the indiscriminate mix of both high-rise and low- rise buildings. As a result, as presented in the research results by Lee and Oh [24], this area has spatial characteristics that are likely to lead to the heat island phenomenon that is frequent among the urban climate zones in Seoul. In order to verify the UTEMP system's usefulness as a MCSM that integrates meso-scale and micro-scale characteristics, a district scale area (0.8 km^2) with mixed commercial and residential areas including high-and low rise buildings and frequent human activity (very active due to a nearby subway station) was investigated. In addition, to consider the boundary effect, the modeling area in the simulation was set to a much bigger area (3.5 km × 2.5 km, 8.75 km^2), shown as the entire air photomap in Figure 2.

To verify the usefulness of the UTEMP system to improve the urban thermal environment in urban planning and design, the case study consisted of (1) preparing and pre-processing variables to mathematical climate simulation modeling, (2) verifying the accuracy of the modeling results, and (3) identifying air temperature variations according to urban spatial changes (Figure 3).

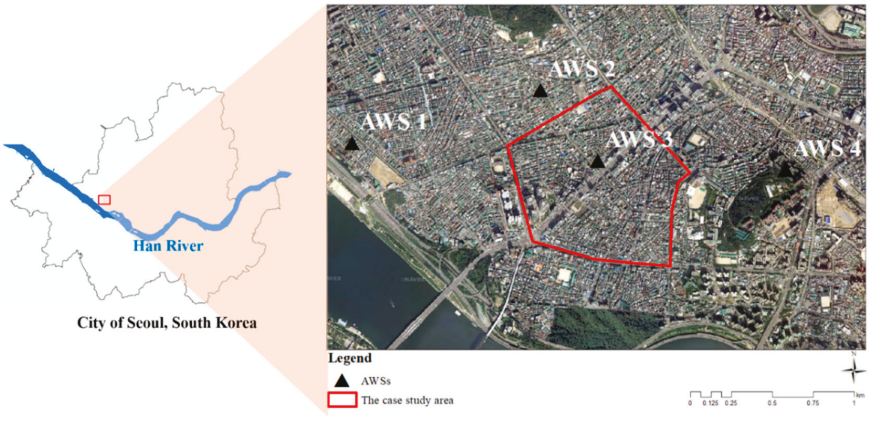


Figure 2. The case study area.

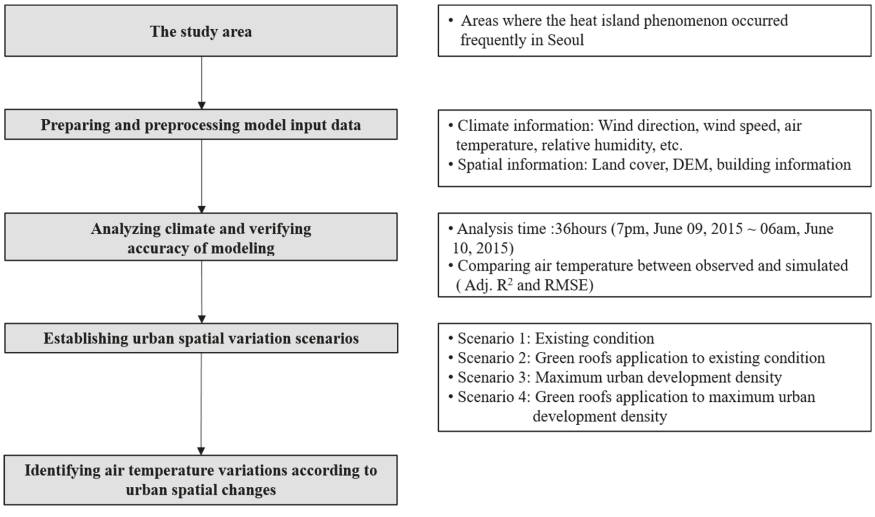


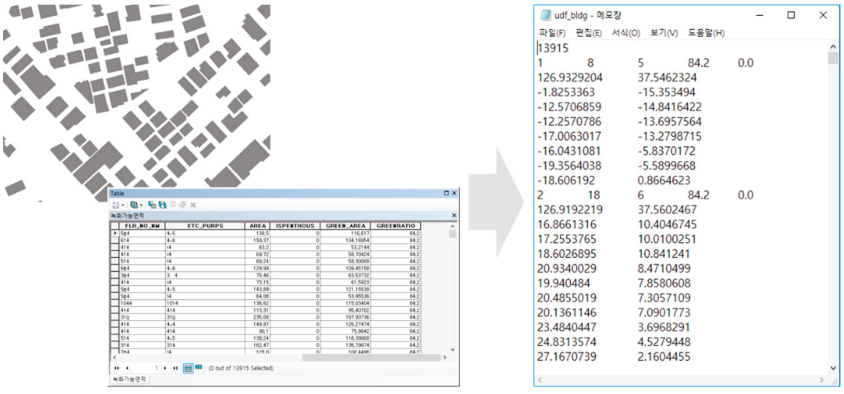
Figure 3. The flow of the case study. DEM = digital elevation model. RMSE = root mean square error.

2.2.1. Preparing and Pre-Processing Variables for MCSM

To analyze the thermal environment of urban space, inclusion of climate information, land cover, terrain, location, and shape information of buildings are essential. The national DBs (DataBases) that include climate information and spatial information provided by a Korea portal DB website were inputted as elementary DBs of the UTEMP system and were pre-processed for MCSM. Table 3 shows the elementary DBs applied to the UTEMP system. In addition, Figure 4 shows the results of converting the building information of the vector format into the ASCII (American Standard Code for Information Interchange) format for climate modeling.

Table 3. Input variables of the UTEMP system for urban thermal environment analysis.

Input Data		Usages	Spatial/Time Resolution	Sources
Climate information	Wind direction, wind speed, air temperature, coldness, relative humidity, precipitation	Meteorological field creation	Hour	Korea Meteorological Administration
Spatial information	Land cover	Heat balance estimation (Sensible heat flux, net radiation)	1:25,000	Ministry of Environment, Korea
	DEM	Wind flow analysis	10 m × 10 m	Ministry of Land, Infrastructure and Transport, Korea
	Building information	Climate modeling analysis considering complex urban structures	1:1000	Ministry of Land, Infrastructure and Transport, Korea



Vector format

Pre-processed ASCII format for modelling

Figure 4. The pre-processed results of building information (Vector to ASCII).

2.2.2. Accurate Verification of the Climate Model Results

In order to verify the accuracy of the MCSM, it is necessary to select a day that has minimal external effects, including clouds, precipitation, and high wind speed. In general, the summer season in the study area is June to August, and this study selected the least cloudy day with gentle wind speed during that period. As a result, it was found that 10 June 2015 was appropriate to verify model results. This study simulated climate phenomena for 36 h from 19:00 on 9 June 2015 to 06:00 on 11 June 2015. To create a meteorological field, climate information including wind speed, wind direction, air temperature, relative humidity, and cloudiness near the AWS were inputted. In addition, to identify the air temperature results in different urban spatial characteristics, data from AWSs which are located in different urban spatial characteristics were obtained. As presented in Figure 2, the AWS 1 is adjusted with rivers, and AWS 2 is located in a mixed land use area (commercial and residential) with diverse building heights. ASW 3 is located in commercial areas with mid-rise build up. AWS 4 is located among apartment residences. The simulated results were obtained with a spatial resolution of 30 m × 30 m in one-hour units. The accuracy of the modeling results was verified by confirming the adj. R^2 and RMSE (Root Mean Square Error) with observed data of the four AWSs in the case study area.

2.2.3. Application of the UTEMP System

In order to identify the applicability of the UTEMP system as a tool to improve the thermal environment, four scenarios were established and variations of air temperature due to urban spatial changes were investigated (Table 4 and Figure 5). The first scenario was an existing condition in which no urban spatial change has occurred. There are 1700 buildings in the case study area, and the average building to coverage ratio (BCR) and floor area ratio (FAR) are 41.3% and 258.8%, respectively.

Table 4. The urban spatial change scenarios.

	Building (BCR [(1)], FAR [(2)])	Heat Mitigation Measures (Applied Area)
Scenario 1	Existing condition (41.3%, 258.8%)	None
Scenario 2	Existing condition (41.3%, 258.8%)	Applying green roofs (99,467 m^2) to existing condition (scenario 1)
Scenario 3	Maximum development under urban planning regulations (54.8%, 412.0%)	None
Scenario 4	Maximum development under urban planning regulations (54.8%, 412.0%)	Applying green roofs (235,545 m^2) to maximum development (scenario 3)

(1) BCR: Building to coverage ratio; (2) FAR: Floor area ratio.

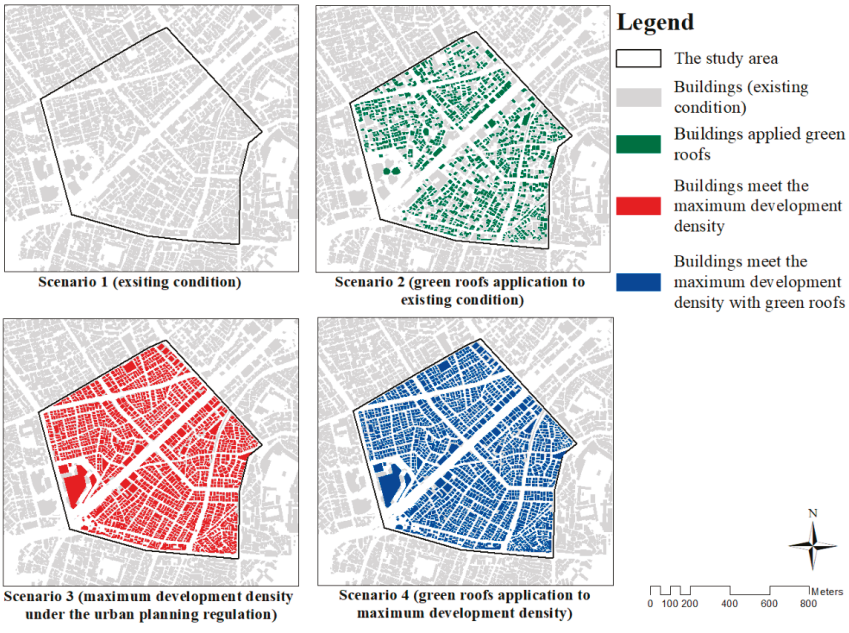


Figure 5. The urban spatial change scenarios.

The second scenario applied maximum green roofs to existing conditions (scenario 1) in order to improve the thermal environment. The applicability of green roofs could be determined by the roof shape and the age of the buildings [10]. Therefore, green roofs were applied only to buildings that satisfy both of the two conditions, namely the roof type was flat and the age of the building was less than 30 years. The applicable green roof areas were identified by the heat reduction infrastructure's introduction function that is included in the UTEMP system. From the results, green roofs were found to be applicable on 1096 buildings (64%) among the 1700 buildings. The total green roofs area was 99,467 m^2.

As a virtual urban development situation, the third scenario assumed that the individual buildings were developed with a maximum development density according to urban planning and architectural regulations. In other words, scenario 3 is a condition in which the urban thermal environment is likely to deteriorate to the maximum by urban development. This was analyzed by applying the function of a maximum development density simulation included in the UTEMP system. The simulation results revealed that the average BCR and FAR in the case study area could be increased by 54.8% (about 13.5%) and 412% (about 153.2%), respectively.

The final scenario applied green roofs to maximum development conditions (scenario 3). The reason for establishing the fourth scenario was to measure how much the thermal environment could be improved by the urban thermal environment improvement measures under the worst thermal environment conditions. Since all the buildings in scenario 3 were assumed to be newly constructed, it was assumed that the green roofs were applicable to all buildings. However, because it is impossible to introduce green rooftops in all areas of the roofs (considering the roof structures of Korean buildings), it is assumed that 70% of individual buildings could be introduced as green roofs. The results determined that green roofs could be introduced to a total of 235,454 m^2 in scenario 4.

3. Results

3.1. Accuracy Verification of Simulated Air Temperature

Figure 6 shows the distribution of simulated air temperatures at 00:00, 04:00, 08:00, 12:00, 16:00, and 20:00 on 10 June 2015. The average temperature of the case study area was 27.37 °C and the range was from 22.05 to 33.05 °C. As the Han River is located in the southern part of the study area, the air temperature of the southern part was relatively lower than other areas. On the other hand, it was found that the air temperature of the central parts in the case study area where it is considerably urbanized and where impervious wide roads are located, is relatively high.

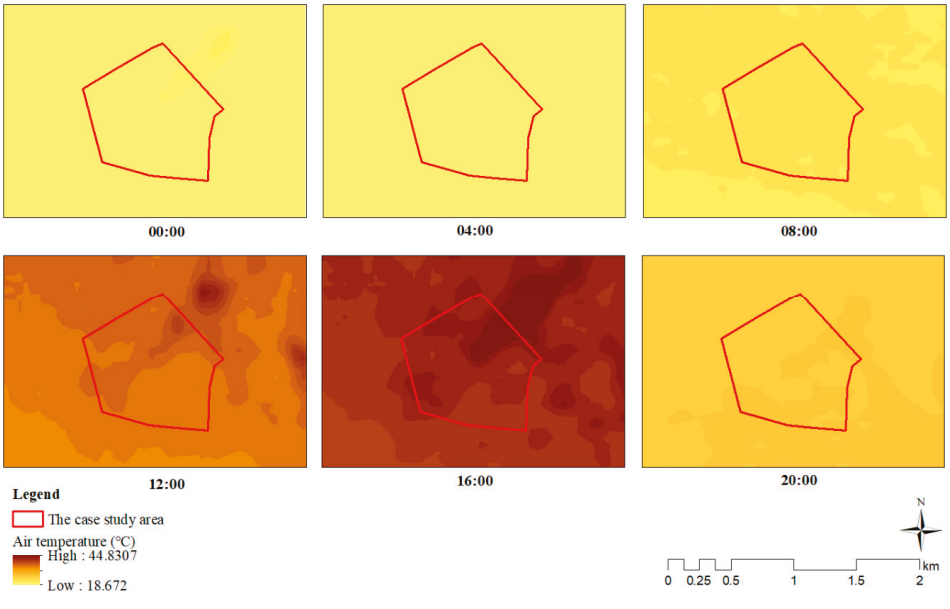


Figure 6. Air temperature analysis results by the UTEMP system (00:00, 04:00, 08:00, 12:00, 16:00, and 20:00, 10 June 2015).

As a result of comparing simulated air temperature and observed air temperature by the four AWSs, Adj. R^2 ranged from 0.923 to 0.978 with a mean of 0.952 and RMSE ranged from ±0.75 to ±1.26 °C with a mean of ±0.915 °C (Figure 7 and Table 5). The Adj. R^2 and average RMSE are similar to those of Roth and Lim [12] (R^2: 0.77~0.98, RMSE: 0.52~1.41 °C) Yang and Bou-Zeid [9] (R^2: 0.97, RMSE: 1.36 °C), Emmauel and Fernando [25] (R^2: not presented, RMSE: 1.06~2.61 °C), and He et al. [26] (R^2: not presented, RMSE: 1.95 °C). However, it was observed that the air temperatures at a certain time (afternoon) were somewhat higher, and such an occurrence had been discussed in many studies related to MCSM [12]. The MCSM of the UTEMP system is an initial version and accuracy verification is underway to reduce errors with the actual data.

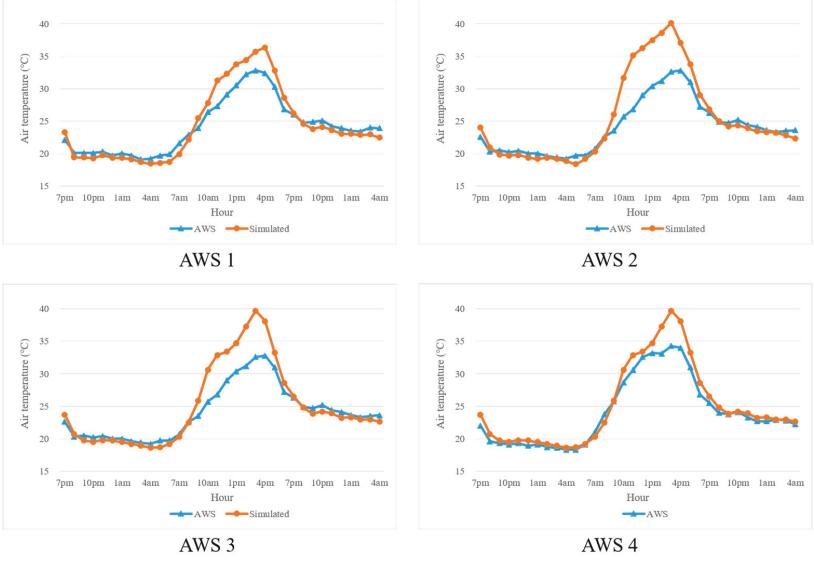


Figure 7. Comparison of air temperature between simulated results and observed data (Automatic Weather Systems (AWSs)).

Table 5. The accuracy verification results of the UTEMP system.

	AWS 1	AWS 2	AWS 3	AWS 4	Mean
Adj. R^2	0.941	0.966	0.923	0.978	0.952
RMSE	±1.00	±0.75	±1.15	±0.76	±0.91

3.2. Identifying Air Temperature Variations According to Urban Spatial Changes

From the analysis of the variations of air temperature due to urban spatial changes, the air temperature of scenario 1 (existing condition) ranged from 18.57 to 37.03 °C with an average temperature of 25.82 °C, and scenario 2 (applying green roofs) ranged from 18.62 to 36.69 °C with an average temperature of 25.77 °C. In the case of scenario 3 (maximum development), air temperature was distributed from 19.04 to 38.05 °C with an average temperature of 26.24 °C, and in scenario 4 (applying green roofs to maximum development), the air temperature was distributed from 18.48 to 37.20 °C with an average temperature of 26.11 °C (Figure 8).

When the maximum green roofs were introduced in the study area, the average temperature decreased by 0.07 °C and the maximum temperature reduction effect was the highest at 11:00 with 0.45 °C (Figure 9). Such an air temperature reduction effect due to green roofs application is similar to the other research results of Gromke et al. [13], Wang, Berardi, and Akbari [14], Kim and Oh [10],

and Ng et al. [15]. On the other hand, if the individual buildings in the study were developed to the maximum density, the difference of the average temperature was estimated to increase by about 0.35 °C. Such an air temperature difference was highest at 04:00 with 1.27 °C (Figure 10).

Additionally, when the green roofs were applied to a maximum development condition (scenario 4), the average temperature increased by 0.08 °C compared with scenario 1, and the maximum difference of average temperature was the highest at 17:00 with 0.92 °C. On the other hand, when compared with scenario 3, the average temperature was reduced by about 0.34 °C, and the effect was the maximum at 16:00 with 0.98 °C (Figure 11). In particular, the temperature reduction effects were identified mainly during nighttime (00:00 to 06:00 and 20:00 to 23:00), whereas the average nighttime temperature was lower than that of scenario 1. In the case of daytime, although the maximum temperature reduction effect was identified at 16:00, the average daytime temperature was higher than the average daytime temperature of scenarios 1 and 2. This means that the temperature-decrease effects due to the increase of the green roof area is lower than the increase effects due to the increase of the urban development density (increase of FAR and BCR) during the daytime. On the other hand, at nighttime, as the green rooftop area increases, the latent heat flux effect increases significantly [27,28], and the air temperature-reduction effect was higher than the air temperature-increase effect due to urban development.

Through scenario analyses, this study investigated air temperature variations according to urban spatial changes. The case study results suggest that to improve the thermal environment of the study area, additional urban development should be strictly controlled and green roofs should be expanded as much as possible.

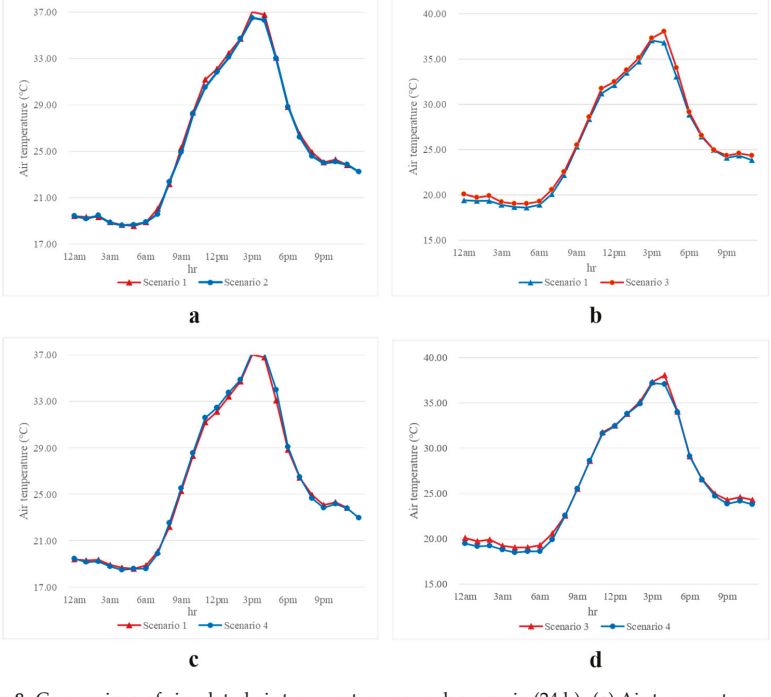


Figure 8. Comparison of simulated air temperature on each scenario (24 h). (**a**) Air temperature ranges of scenario 1 and scenario 2, (**b**) Air temperature ranges of scenario 1 and scenario 3, (**c**) Air temperature ranges of scenario 1 and scenario 4, (**d**) Air temperature ranges of scenario 3 and scenario 4.

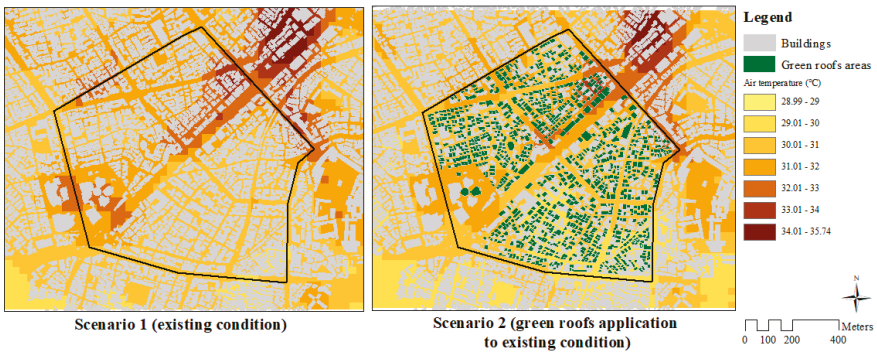


Figure 9. Comparison of simulated air temperature between scenario 1 (**left**) and scenario 2 (**right**) (at 11 a.m.).

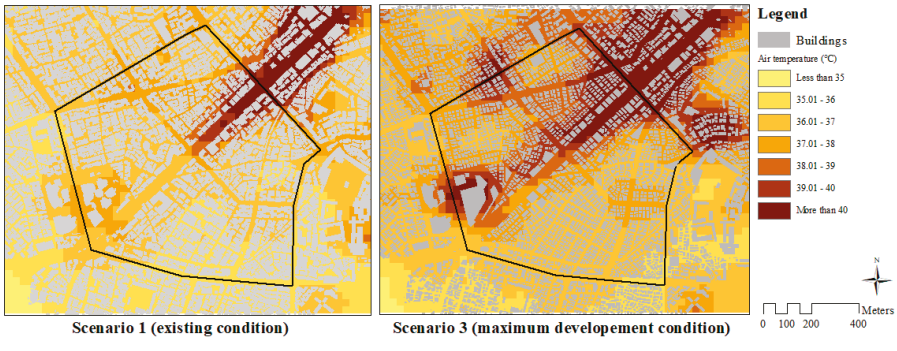


Figure 10. Comparison of simulated air temperature between scenario 1 (**left**) and scenario 3 (**right**) (at 16:00).

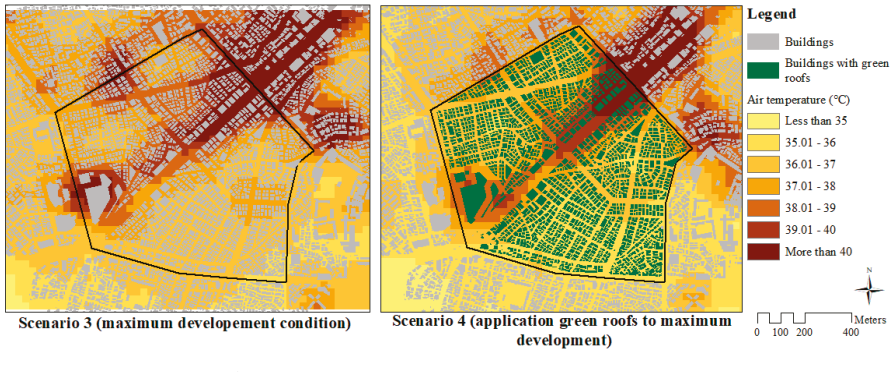


Figure 11. Comparison of simulated air temperature between Scenario 3 (**left**) and Scenario 4 (**right**) (at 16:00).

4. Discussion and Conclusions

As a result of applying the UTEMP system to the area where the heat island phenomenon occurs frequently in the city of Seoul, it was found that the air temperature simulation results were fairly similar to real observations. In addition, this study identified air temperature variations according to characteristics of urban spatial changes.

Based on the case study results, the UTEMP system was found to be useful in the following three ways: Firstly, the UTEMP system showed a simulation error of RMSE ± 0.91, so it can be sufficiently utilized for urban meteorological analysis. Previous MCSMs including the urban canopy model or meso-scale model assumed an urban area has a homogeneous array of buildings or an urban canopy layer that has even roughness. The thermal environment analysis engine of the UTEMP system considers urban structure to be a variety of morphological types on the district scale-level (between meso-scale and micro-scale), so it reflects urban spatial characteristics more concretely.

Secondly, the UTEMP system enables analysis of differentiated results of air temperature both for the change of land cover types such as rooftop greening, and the change of microscopic urban spaces such as the location and the shape of building. In order to achieve practical improvement of the thermal environment in urban spaces, introduction of thermal environment improvement measures as well as future urban spatial changes including urban development density should be considered. The results of temperature variation analyses by diverse urban spatial change scenarios suggest that it can be used as a scientific and practical planning tool that considers thermal environment improvement of urban planning and design.

Thirdly, by combining a GIS engine and thermal environment analysis engine, the UTEMP system developed in this study makes it easier for non-expert users related to the climate field to analyze urban meteorological phenomena. Unlike previously developed climate modeling tools, GIS files that are mainly used in the urban planning and design field can be directly inputted to the system without tedious pre-processing, and such an abbreviated process allows climate analysis to be more efficient. Such characteristics of this system have the advantage of instantly reflecting the changed alternatives by the urban planning and designing process to the modeling and confirms the results.

As negative environmental problems such as extreme heat events caused by urban activities and climate change intensify, the importance of scientific technology development that can effectively analyze the problem of the urban thermal environment is continuously increasing. The UTEMP developed through this study is expected to contribute to the development of MCSMs on the district scale as an initial attempt to integrate the meso- and micro-scales, which have been continuously discussed in MCSM review studies. In addition, while previous MCSMs focused on meteorological modeling, the implementation of functions for urban planning and design has been insufficient. The UTEMP is expected to contribute to the establishment of alternatives to improve the urban thermal environment by integrating the urban planning design functions and the MCSM function into one system.

On the other hand, the following three study limitations should be overcome to apply the UTEMP system to urban planning and design.

Firstly, the accuracy of the UTEMP system should be improved and multiple model time should be considered in model verifications. The analysis results presented are based on an analysis performed on a specific date. After the system has been sufficiently improved, more verification analysis of multiple dates including the winter season (rather than limited to specific days) could be possible. In that case, the error range is expected to be improved.

Secondly, the applicability of UTEMP to diverse urban spatial characteristics (e.g., different land cover, building type, road patterns, etc.) should be verified in order to secure usefulness for urban design usage. Although the study area in this study is where the heat island phenomenon occurs frequently among the representative heat island cities in Korea, there are many other areas that cause heat islands with different urban spatial characteristics. The model parameters for calculating air temperature were chosen based on previous empirical studies. In addition, LPDM (which has been applied around the world to predict wind simulation) was applied to create the wind field. As such, we expect to develop UTEMP to be applied to other cities. If the verification process is performed sufficiently for spaces composed of different land cover and diverse building heights and densities, the parameter values applied in this study could be more precisely adjusted.

Finally, it is necessary to analyze and verify the effects of urban thermal environment improvement measures. In this study, only the change of development density and the application of green roofs were considered as the urban space change scenario. In addition to rooftop greening, it is necessary to investigate the effects of other heat reduction measures (wind corridor creation, cool roofs and pavements, etc.), which have recently been attracting attention as countermeasures to reduce urban heat islands.

Author Contributions: This article is the result of the joint work by all authors. K.O. supervised and coordinated work on the paper. All authors conceived, designed, and carried out the methods selection and analyzed the data. All authors prepared the data visualization and contributed to the writing of this paper. All authors discussed and agreed to submit the manuscript.

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

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Classifying Urban Climate Zones (UCZs) Based on Spatial Statistical Analyses †

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Abstract: The objective of this study is the classification of urban climate zones (UCZs) based on spatial statistical approaches to provide key information for the establishment of thermal environments to improve urban planning. To achieve this, using data from 246 automatic weather stations (AWSs), air temperature maps in the summer of the study area were prepared applying universal kriging interpolation analysis. In addition, 22 preliminary variables to classify UCZs were prepared by a 100 m × 100 m grid. Next, six influential urban spatial variables to classify UCZs were finalized using spatial regression analysis between air temperature and preliminary variables. Finally, the UCZs of the study area were delineated by applying K-mean clustering analysis, and each spatial characteristic of the UCZs was identified. The results found that the accuracy of the air temperature of the study area ranged from ±0.184 °C to ±0.824 °C with a mean 0.501 root mean square predict error (RMSPE). Elevation, normalized difference vegetation index (NDVI), commercial area, average height of buildings, terrain roughness class, building height to road width (H/W) ratio, distance from subway stations, and distance from water spaces were identified as finalized variables to classify UCZs. Finally, a total of 8 types of UCZs were identified and each zone showed a different urban spatial pattern and air temperature range. Based on the spatial statistical analysis results, this study delineated clearer UCZs boundaries by applying influential urban spatial elements that resulted from previous classification studies of UCZs mainly based on pre-determined spatial variables. The methods presented in this study can be effectively applied to other cities to establish urban heat island counter measures that have similar weather observation conditions.

Keywords: urban climate zones; spatial statistical analysis; air temperature; urban spatial variables

1. Introduction

The urban heat island (UHI) phenomenon has been recognized as a negative side effect of rapid urbanization. The main causes of the urban heat island phenomenon include trapping of short and long wave radiation between buildings, decreasing of long-wave radiative heat losses due to building construction, increasing storage of sensible heat in the construction materials of buildings and structures, anthropogenic heat released from human activities, and reduction of evapotranspiration potential [1,2]. Various attempts have been made to mitigate UHI through urban planning and design. In order to achieve effective urban heat island mitigation, it is necessary to understand and apply urban climatic information in urban planning [3].

In this regard, the urban climate zone (UCZ) concept is useful as a UHI mitigation measure because it offers integrated information on climate characteristics and related spatial elements [4]. UCZs are homogeneously classified areas that distinguish climate characteristics based on urban structure, land cover, urban fabric, and urban metabolism [5]. Considered fundamental research on UCZ, Chandler [6], Auer Jr. [7], Ellefsen [8], and Oke [5] established the concept of UCZ and suggested major variables including topography, land cover, building forms, etc., to classify UCZs. Recently, as empirical studies, Houet and Pigeon [9] investigated the usefulness of the UCZ concept as a tool to understand climate phenomena, and Lee and Oh [3] identified influential variables to classify UCZs and delineated UCZs boundaries based on statistical analyses.

Meanwhile, in order to analyze the urban heat island phenomenon, precise air temperature maps should be prepared as much as possible. In the case of Korea, due to its complex topographical situations and diverse meteorological elements with much spatial and temporal variations, a large number of stations are needed to quantitatively sense local climate characteristics. Since it is practically difficult to prepare high resolution meteorological data by installing observation stations, interpolation methods have been frequently employed. Generally, they calculate point data by weighing inversely and proportional to the square of distance, assuming that the homogeneity of meteorological elements decreases with distance. However, these methods alone have limitations in obtaining good quality, precise, and high-resolution data. Most of the meteorological elements, including air temperature, are affected not only by distance but also by the surrounding topographical environment, such as elevation. Therefore, in order to prepare a precise and high-resolution air temperature map that can represent local climate characteristics, it is necessary to develop a more effective spatial interpolation method considering the influence of diverse meteorological elements such as topography in addition to distance [10,11]. In this regard, interpolation methods that consider topographical factors such as elevation, slope, and aspect are needed for urban heat island research [11].

Meanwhile, statistical approaches applying multiple regression analysis have been applied to identify the relationship between UHI and urban spatial characteristics. However, the statistical approach has limitations in presenting several physical phenomena [12]. The major reason for the limitation is that installing climate measurement devices in entire urban areas is impossible due to space constraints, installation time, and expensive operating costs. This lack of observational data makes it difficult to analyze the relationship between the urban heat island phenomena and urban spatial characteristics. Another reason is that conventional regression analysis, such as the ordinary least squares (OLS) model, is based on the assumption that observations are independent, resulting in a failure to capture the spatial dependence of data when they are applied to geo-referenced datasets [13]. Therefore, spatial regression analysis has been recently used to explain UHI, according to spatial neighborhood effects [1].

In order to classify UCZs more accurately, it is essential to conduct in-depth investigation on the relationship between urban climate changes and urban spatial elements through systematic and scientific analysis. Therefore, the aims of this study are to: (1) identify influential urban spatial elements to classify UCZs based on spatial statistical analyses, (2) delineate UCZs boundaries, and (3) provide key information for urban planning and design to establish UHI mitigation measures.

2. Materials and Methods

This study consists of four parts and each process is presented in Figure 1. First, observation data were obtained from 246 automatic weather stations (AWSs), which were observed on cloudless days with a gentle breeze speed (less than 5.4 m/s, based on Beaufort Wind Scale). Using these data, air temperature maps of the study area were prepared by a universal kriging interpolation method. Next, preliminary independent variables were prepared, including topography, land use, land cover, urban form, human activities, and locational characteristics, to predict air temperature. Third, influential urban spatial elements were identified to classify UCZs by spatial regression analysis. Finally, UCZ

boundaries in the study area were delineated by K-mean clustering analysis. In addition, the spatial characteristics of each UCZ were investigated.

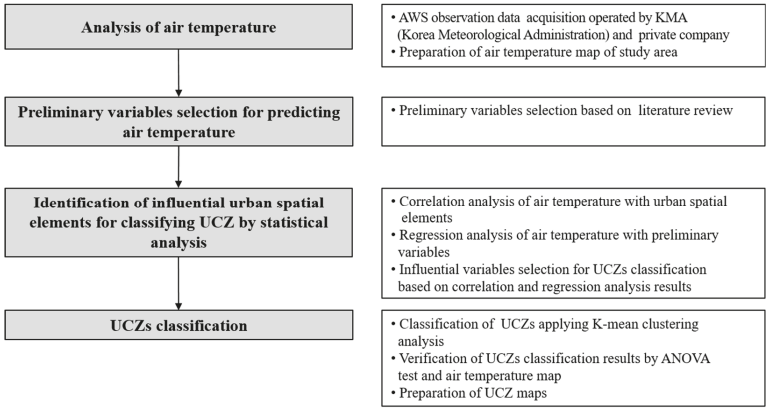

Figure 1. Study workflow. UCZ is urban climate zone, AWS is automatic weather station.

A case study was conducted for Seoul, the capital of South Korea. Seoul is one of the densest cities in the world in which 21.5% (about 11 million inhabitants) of the country's total population reside. Seoul is also a representative heat island city that has diverse spatial characteristics including land cover, land use, building form, etc. In the case of South Korea, weather information was investigated by 26 AWSs (automatic weather stations), which are operated by the Korea Meteorological Administration (KMA), and the average distance of each weather station is approximately 3 km in the study area. It is very difficult to classify UCZs of metropolitan cities using such a resolution. Therefore, additional weather data collected by 220 AWSs of a Korean private company (SK Weather Planet) were integrated into the analysis in this study (Figure 2). Among the 246 weather stations, 26 of the AWSs were used to verify the air temperature analysis results. Eventually, 220 of the AWSs were actually used to prepare the air temperature map.

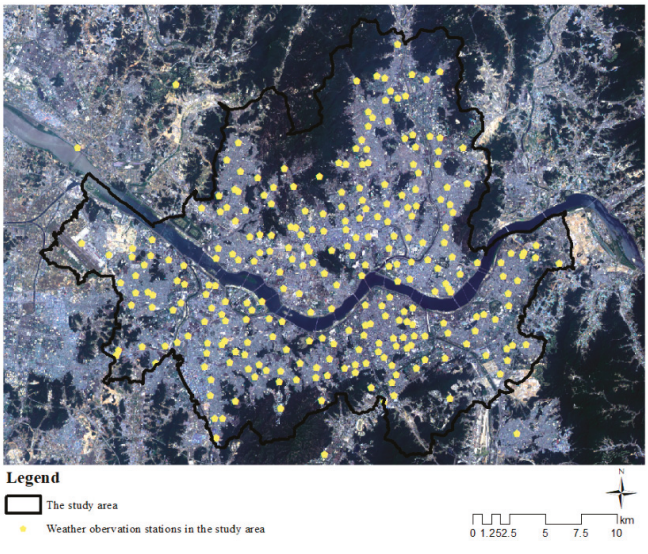

Figure 2. The study area and automatic weather stations (AWS).

2.1. Analysis of Air Temperature

Urban heat island intensity has commonly been defined as the temperature difference between urban and rural places [14]. In a metropolitan city, the air temperature based UHI is reported to be high and positive during nighttime (2–3 h after sunset) for cloudless days and light winds [15,16]. Considering such characteristics of an urban heat island, analysis time points were selected to classify UCZs. In order to take into account the climate characteristics, three days per month in summer (from June to August) with the lowest cloudiness and the lowest wind speed were investigated. Subsequently, considering sunset times and weather conditions (under a cloudless sky and gentle breeze wind speed), 10:00 p.m. and 11:00 p.m. of 9 days in each summer in 2015 and 2016 were chosen for statistical analyses (Table 1).

Table 1. Weather conditions for the 18 days in 2015 and 2016.

		Min Air Temperature	Max Air Temperature	Mean Air Temperature	Mean Wind Speed	Mean Amount of Cloud (1–10)
2015	6 June	18.8 °C	31.1 °C	24.4 °C	2.4 m/s	1.4
	14 June	18.3 °C	37.7 °C	22.5 °C	3.3 m/s	3.9
	30 June	21.2 °C	30.2 °C	25.3 °C	2.7 m/s	3.4
	4 July	21.6 °C	32.3 °C	26.8 °C	2.4 m/s	3.6
	27 July	21.4 °C	30.6 °C	25.0 °C	1.9 m/s	4
	29 July	30.1 °C	33.5 °C	28.6 °C	2.5 m/s	2.5
	8 August	26.1 °C	30.6 °C	26.1 °C	3.8 m/s	2.1
	28 August	19.8 °C	30.7 °C	25.1 °C	2.2 m/s	1.6
	30 August	19.9 °C	30.7 °C	24.6 °C	1.9 m/s	2.4
2016	5 June	17.3 °C	32.2 °C	24.7 °C	1.7 m/s	3.5
	9 June	17.8 °C	31.3 °C	24.1 °C	2.0 m/s	1.4
	19 June	20.3 °C	29.3 °C	1.90 °C	2.7 m/s	4.4
	8 July	27.3 °C	21.2 °C	2.4 °C	1.8 m/s	0.1
	9 July	27.7 °C	23.2 °C	33.1 °C	1.8 m/s	3.1
	19 July	20.9 °C	32.4 °C	27.1 °C	1.5 m/s	3.6
	5 August	26.5 °C	36.0 °C	31.2 °C	1.8 m/s	1.9
	10 August	26.1 °C	34.8 °C	29.4 °C	1.9 m/s	4.4
	17 August	25.1 °C	34.7 °C	29.9 °C	1.9 m/s	2.4

Meanwhile, the average spacing of the AWSs in the case study area is 1087 m, which is much shorter than other metropolises. To analyze the air temperature, statistical interpolation methods are commonly used to prepare temperature maps using point-based measurements. IDW (Inverse Distance Weighting) of Shepard [17], Kriging [18], and Spline [19] are representative statistical interpolation methods. However, although the average spacing of the AWSs is much shorter than in other cities, these methods still have limitations in that they do not effectively reflect the heterogeneity of urban spatial characteristics that include the influence of land cover and elevation on temperature. Therefore, in this study, the universal kriging interpolation method based on the GPR (Gaussian process regression) model was applied in order to consider variables such as altitude, distance to coast or river, and water space area ratio besides the distance between measurement points. The universal kriging, an unbiased linear estimator with minimum estimation variance properties, was used based upon the theory of regionalized variables [20]. The GPR model is generally constructed as follows:

$$y = F\beta + Z(X) + e \quad (1)$$

where F is the designed matrix, B is the regression coefficient, $Z(X)$ is the Gaussian stochastic process, which shows an average of 0, and $\sigma_Z^2 R(X)$ the variance–covariance matrix, and e is the normal distributed observational error that shows an average of 0 and σ_e^2 variance. Based on the GPR model, additional explanatory variables were inputted in the universal kriging interpolation method and the equation is as follows:

$$y = \beta_0 + \beta_2(elevation) + \beta_2(distance\ from\ water\ space) + \beta_3(water\ space\ area\ ratio) + Z(X) + e \quad (2)$$

The Z(X) is determined by latitude and longitude coordinates. To determine the appropriate interpolation methods, data from 220 AWSs were interpolated using universal kriging interpolation methods and they were compared with data from 26 AWSs. The results found that the root mean square predict error (RMSPE) by the universal kriging interpolation method ranged from ±0.184 °C to ±0.824 °C with a mean 0.501 °C. Among the 36 analysis time points, 10 time points that showed the relatively low RMSPE (less than 0.45) were selected to delineated air temperature (Table 2). Thus, 10 air temperature maps of 2 and 3 h after sunset were prepared, and finally, an average air temperature map was calculated from these maps.

Table 2. Ten time points to prepare air temperature analysis (RMSPE < 0.45).

		Min (°C)	Max (°C)	Mean (°C)	SD	RMSPE
2015	12 p.m., 6 June	15.330	24.021	21.890	1.320	0.390
	10 p.m., 1 July	15.124	23.133	21.569	1.034	0.439
	10 p.m., 27 July	22.330	29.242	27.897	0.921	0.428
	11 p.m., 27 July	24.356	28.327	27.258	1.021	0.435
	10 p.m., 30 July	24.745	29.756	27.235	1.243	0.325
2016	10 p.m., 5 June	16.312	25.021	22.814	1.245	0.371
	10 p.m., 8 July	16.532	25.721	23.024	1.221	0.390
	11 p.m., 10 August	29.751	29.751	28.019	1.251	0.184
	10 p.m., 17 August	31.211	31.211	29.149	1.383	0.203
	11 p.m., 17 August	30.714	30.714	27.571	1.320	0.260

2.2. Selection of Preliminary Variables

Adopting the research of Lee and Oh [3], this study classified urban spatial elements into 6 categories including topology, land use, land cover, building characteristics, human activity, and locational characteristics. The number of total preliminary variables was 22 (Table 3). Meanwhile, determining spatial resolution was important in order to identify influential variables and delineate UCZs boundaries. Considering the research of Houet and Pigeon [9] and Lee and Oh [3], this study prepared preliminary variables to classify UCZs using a 100 m grid resolution.

Table 3. The preliminary variables for the air temperature predicting model (adopted from Lee and Oh [3]).

Categories	Variables (Unit)
Topography	Slope (degree), elevation (m)
Land use	Residential, commercial, industrial, green space, water space area ratio (%)
Land cover	Impervious surface area ratio (%), albedo (0 to1), NDVI (0 to 1)
Urban form	Average width of buildings (m), average height of buildings (m), the number of buildings, building surface fraction (%), floor area ratio (%), H/W ratio (number), terrain roughness class (number)
Human activities	Population (person), number of vehicles (number)
Locational characteristics	Distance from green spaces (m), distance from water spaces (m), distance from subway stations (m)

2.3. Identification of Influential Urban Spatial Elements to Classify UCZs

To select independent variables for an air temperature prediction model, correlation analysis was conducted to investigate the interrelationship between preliminary variables and air temperature. The potential multi-collinearity among the preliminary variables were also identified. Based on correlation analysis, ordinary least squares (OLS) regression analysis was applied. In order to reduce the heteroscedastic effect of wide ranging preliminary variables, the logarithm of the dependent variable, Ln (air temperature), was used. A step-wise regression analysis method (forward selection approach) was applied to find influential variables that would affect air temperature. Since the air temperature map was delineated by the interpolation method, the spatial lag model (SLM) was next estimated to control the effects of air temperature in neighboring grids.

2.4. UCZ Classification

Using the influential urban spatial elements identified, the UCZs of the study area were classified by mean clustering analysis. Since this study had a large number of samples (N: 52,961), K-mean clustering analysis was applied due to its efficacy of ascertaining clusters within large quantities of data [21]. For the K-mean clustering analysis, the Z-scores of the influential variables identified by regression analysis were calculated. The calculated Z-scores were inputted as parameters for cluster analysis, and iterative calculations were performed until the adjustment of the centroids of the clusters did not occur after setting the centroids of the initial clusters.

On the other hand, one of the most important points in applying K-mean cluster analysis is determining K (the appropriate number of clusters). Oke [5] classified UCZs as 7 categories, and in the case of Ellefsen [8] UTZs (urban terrain zones) were classified as 9 categories. Considering such previous studies, the preliminary number of classes for K-mean clustering analysis (K) was determined from 6 to 12 (total 7 cases), and the appropriate number of K was chosen by sensitivity analysis using the ANOVA test. Thus, in the ANOVA test, the dependent variables were Ln (air temperature), and factorial variables were the cases of clusters. The *F* values of 7 ANOVA tests were investigated to determine whether the distribution of Ln (air temperature) in each cluster were statistically significant. A case with the highest *F* value among the 7 cases was chosen as the final K to classify the UCZs. Then, characteristics of each UCZ were determined based on the chosen K-mean clustering analysis results. Finally, the UCZs maps were prepared to explain the actual air temperature phenomenon.

3. Results

3.1. Air Temperature

Figure 3 presents air temperature maps of the study area. Air temperatures ranged from 24.14 °C to 30.46 °C with an average value of 27.23 °C. The maximum temperature differences were analyzed and found to be more than 6.32 °C. This confirmed that the urban heat island phenomenon was relatively severe in the study area.

3.2. Identification of Influential Urban Spatial Elements to Classify UCZs

Table 4 shows the correlation analysis results of air temperature and urban spatial elements. The most positively correlated variable was the impervious surface area ratio, whereas the elevation showed the most negative correlation. In order to create a model to predict air temperature, variables that had strong correlations were inputted for step-wise regression analysis. In order to create a model to predict air temperature, the variables that had strong correlations were inputted for the step-wise regression analysis using the statistical software (SPSS 21). The estimated model showed 0.603 of R^2 and eight variables were found to be significant at the 99% level and had signs consistent with the results of the correlation analysis. In addition, due to the multi-collinearity diagnosis, all VIFs of the dependent variables were found to be less than three, and it was confirmed that there was no multi-collinearity problem in the models.

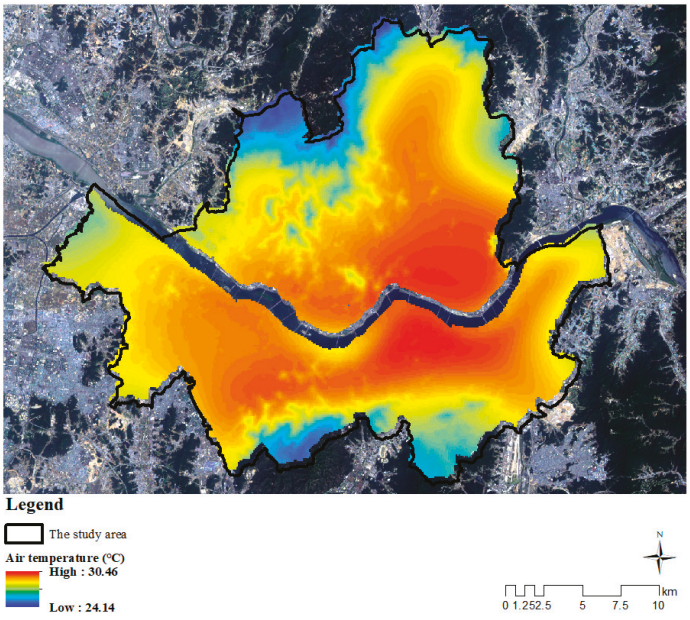

Figure 3. Air temperature in study area (Mean value of 10 air temperature maps, 2 and 3 h after sunset).

Table 4. Correlation analysis results between air temperature and urban spatial elements.

Categories	Correlation Coefficients
Topography	Elevation (−0.681 **), slope (−0.621 **)
Land use	Green space (−0.501 **), commercial (0.310 **), residential (0.284 **), industrial (0.037 **)
Land cover	Impervious surface area ratio (0.552 **), NDVI (−0.603 **), albedo (−0.461 **)
Urban form	Sky view factor (SVF) (−0.400 **), average width of buildings (0.356 **), average height of buildings (0.309 **), the number of buildings (0.331 **), building surface fraction (0.437 **), terrain roughness class (0.559 **), H/W ratio (0.187 **)
Locational characteristics	Distance from green spaces (0.411 **), distance from subway stations (−0.670 **), distance from water spaces (−0.047 **)

N: 52,961, **: $p < 0.01$.

However, as a result of the Lagrange multiplier diagnostics for spatial dependence, it was found that the OLS error terms were spatially auto-correlated. In order to reduce this spatial auto correlation, SLM was next estimated to control the effects of air temperature in neighboring grids. The results showed that R^2 of SLM increased to 0.828, and coefficients of the independent variables had the same signs as in the OLS models. In addition, eight variables were all significant at the 1% level. Therefore, eight variables, including elevation, NDVI, commercial area, average height of buildings, terrain roughness class, H/W ratio, distance from subway stations, and distance from water spaces were included as significant variables to classify UCZs (Table 5).

Table 5. Results of regression analysis (OLS and SLM).

		OLS		SLM	
		Coefficient	***t***	**Coefficient**	***z***
T	Elevation	-1.914×10^{-4} ***	−85.345	-9.936×10^{-5} ***	−58.788
LU	Commercial	4.252×10^{-7} ***	−15.332	1.775×10^{-7} ***	4.435
LC	NDVI	−0.036 ***	−15.332	−0.015 ***	−10.655
UF	TRC	0.027 ***	45.107	0.010 ***	27.525
	AHB	8.861×10^{-5} ***	8.548	3.561×10^{-7} ***	4.938
	H/W	1.982×10^{-4} ***	6.504	1.982×10^{-4} ***	4.585
LoC	DS	-1.775×10^{-5} ***	−69.509	-7.893×10^{-5} ***	−44.6821
	DW	4.204×10^{-6} ***	19.503	2.544×10^{-6} ***	17.2331
	constant	3.353 ***	3783.853	1.542	162.049
	ϱ		-	0.540	190.521
	Log-likelihood		112,643	133,591	
	R^2		0.603	0.828	

N: 52,961, ***: Statistically significant at the 1% level. (T: Topography, LU: Land Use, LC: Land Cover, UF: Urban Form, LoC: Locational Characteristics, TRC: Terrain Roughness Class, AHB: Average Height of Buildings, DS: Distance from Subway Station, DW: Distance from Water spaces).

3.3. The Results of UCZ Classification

The seven cases of ANOVA test results showed that each clustered result was in a statistically different group. In the case of the variations of F values, it was confirmed that the *F* values were the highest when the number of cluster (K) was eight. In addition, when the number of clusters was larger than nine, it was found that the *F* values decreased (Appendix A). Based on the results of this sensitivity analysis, this study found that the appropriate number of clusters for UCZs was eight. Based on the selected clustering analysis results (Table 6 and Figure 4), UCZs could be classified into mountainous areas (cluster 1), hilly areas and urban forest (cluster 4), high-rise built up areas with very a high H/W ratio (cluster 3), mid-rise built up areas with a high H/W ratio (cluster 5), mid-rise built up areas without green spaces (cluster 6), high-rise built up areas with a high H/W ratio (cluster 2), high-rise built up areas with various building heights (cluster 7), and commercial areas without green spaces (Figure 5). As a result, the classification of UCZs in this study showed similar spatial patterns with the air temperature analysis results.

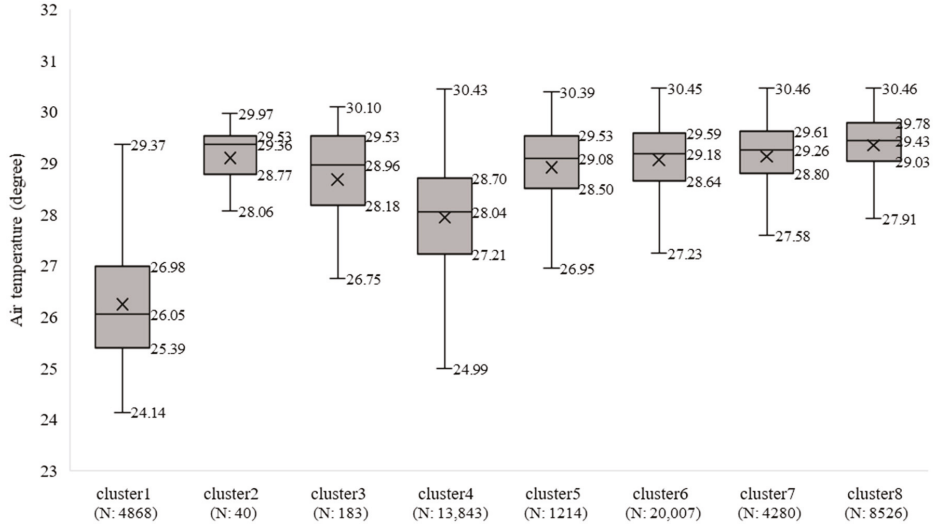

Figure 4. Air temperature distribution of UCZs.

Table 6. Classification results of UCZs.

Cluster Factor	Cluster							
	1 (N: 4868)	2 (N: 40)	3 (N: 183)	4 (N: 13,843)	5 (N: 1214)	6 (N: 20,007)	7 (N: 4280)	8 (N: 8526)
Elevation	2.583	−0.000	−0.039	0.121	−0.183	−0.390	−0.444	−0.506
DS	1.988	0.062	−0.075	0.412	−0.203	−0.400	−0.468	−0.599
TRC	−1.154	−0.187	−0.155	−1.164	0.142	0.616	0.522	0.825
DW	0.471	0.113	0.052	−0.173	0.220	0.102	−0.405	−0.058
NDVI	1.483	0.621	0.501	0.957	0.048	−0.573	−0.411	−0.870
H/W ratio	−0.491	18.211	9.461	−0.410	2.692	0.050	0.200	0.056
Commercial	−0.525	−0.528	−0.460	−0.500	−0.432	−0.284	−0.311	2.010
AHB	−0.749	3.673	2.157	−0.639	1.546	−0.066	2.415	0.125

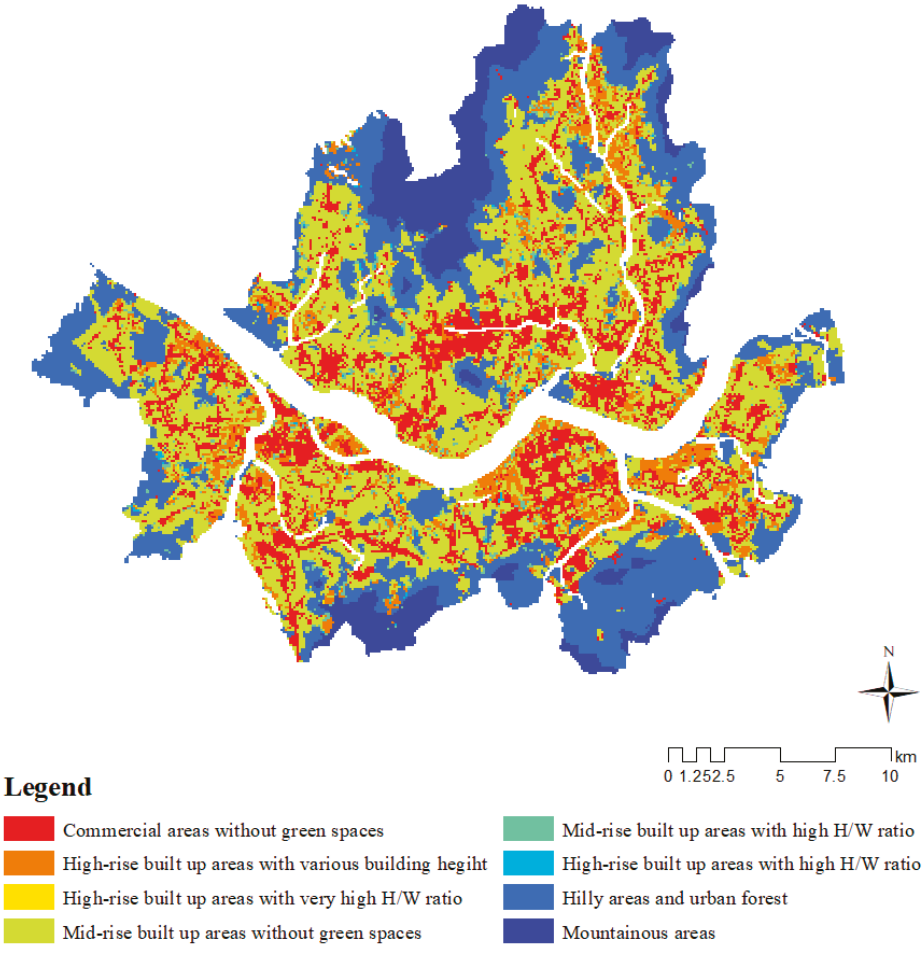

Figure 5. Classification result of UCZs.

4. Discussion and Conclusions

Through a series of statistical analyses, this study identified more detailed and clearer UCZ boundaries (100 m × 100 m) and explained statistically significant urban spatial characteristics to understand urban climate phenomena. Through spatial regression analyses, influential urban spatial

elements causing air temperature increases and their effects were concretely investigated. In addition, the potential areas where urban heat islands occur were delineated using UCZ maps.

The UCZ classification based on spatial statistical analyses conducted in this study has usefulness as follows: First, this study produced an air temperature map that shows relatively high accuracy using an interpolation method. Due to a lack of observation data, the conventional interpolation method to delineate urban air temperature was robust. As a result, it was difficult to analyze the relationship between air temperature and urban spatial characteristics. In fact, most of the previous studies used land surface temperature data in identifying the effects of urban spatial characteristics. By applying a number of AWS data, this study overcame such a limitation, and the actual sensed effects on air temperature were investigated. In addition, using a number of AWS data, applying the universal kriging interpolation method, which considers the effects of elevation and water space, more accurate air temperature maps (RMSPE: from $\pm$0.184 °C to $\pm$0.824 °C) were delineated. Such an air temperature analysis method will enhance the efficiency and accuracy of investigating climate phenomena. Since some interpolated results showed a relatively high RMSPE, there is some need for improvement of the universal kriging interpolation methods presented in this study of 100 m spatial resolution at AWS spacing of 1087 m. In order to reflect the heterogeneity of urban spaces, the spacing of AWSs still should be shortened. Recently, with advances and the dissemination of more economic smart sensing technologies, more AWSs are being installed. If such data is accumulated and obtained, accuracy and precision by universal kriging methods are expected to be further improved.

Second, by applying spatial regression analysis, influential variables that affect air temperature were identified, and their effects on air temperature were investigated. Thus, this study suggested integrated information on climate characteristics and related urban spatial elements. The outcomes of this study can provide urban planners with practical information to improve the urban thermal environment. Moreover, the results of this study will enable urban planners to determine what kind of mitigation alternatives should be employed to reduce urban heat islands.

Finally, statistical analyses allowed more concrete and accurate delineation of UCZ boundaries than previous studies regarding UCZ classification based on pre-determined urban spatial variables. Since urban spatial variables that affect air temperature can vary city by city, the usage of fixed spatial variables can cause inaccurate UCZ classifications. By considering that the distribution of influential variables has an effect on air temperature, more detailed UCZs boundaries were delineated, and the spatial characteristics of each UCZ were investigated. Through the entire process, potential urban heat islands areas and the causes of their occurrence were identified. Such results will enable urban planners to determine which areas should be preferentially managed to enhance the thermal environment.

The methods based on statistical approaches presented in this study can be effectively applied to other cities that have similar weather observation conditions. If more urban spatial characteristics, including slope, vegetation, and soil are known, more accurate air temperature analysis will be possible. Furthermore, if other spatial regression models are applied, a more concrete relationship between air temperature and urban spatial characteristics will be understood. Furthermore, if other climate factors, including wind speed and relative humidity, are considered in the classification of UCZs, more accurate and useful information can be provided for developing UHI mitigation measures in urban planning and design processes.

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

Appendix A

Table A1. The sensitivity analysis results applying ANOVA test.

The Number of Cluster (K)	Statistics	Sum of Squares	DF	Mean Square	*F*	Sig.
6	Between groups	44.909	5	8.982	7197.526	0.000
	Within groups	66.083	52,955	0.001		
	Total	110.992	52,960			
7	Between groups	44.915	6	7.486	5999.098	0.000
	Within groups	66.077	52,954	0.001		
	Total	110.992	52,960			
8	Between groups	56.294	7	8.042	7785.344	0.000
	Within groups	54.698	52,953	0.001		
	Total	110.992	52,960			
9	Between groups	56.528	8	7.066	6869.698	0.000
	Within groups	54.465	52,952	0.001		
	Total	110.992	52,960			
10	Between groups	56.575	9	6.286	6116.699	0.000
	Within groups	54.417	52,951	0.001		
	Total	110.992	52,960			
11	Between groups	56.563	10	5.656	5502.639	0.000
	Within groups	54.429	52,950	0.001		
	Total	110.992	52,960			
12	Between groups	61.069	11	5.552	5888.141	0.000
	Within groups	49.924	52,949	0.001		
	Total	110.992	52,960			

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Influence and Sustainability of the Concept of Landscape Seen in Cheonggye Stream and Suseongdong Valley Restoration Projects

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Abstract: This study considered that the pursuit of nature in a city in the restoration projects of Cheonggye Stream and Suseongdong valley was the main motive of the landscape concept premised on humanity and, furthermore, found that it originated from Korean thoughts and cultures about nature. Based on these findings, the study aimed to investigate the influence and sustainability of historical and cultural backgrounds in the planning features of nature in the two restoration projects. The concept of landscape that started from the desire to go out of a city is premised on the secular world of humans. In Korean society, the concept has been developed based on the above common premise, through cultural exchanges with China, and in its regional specificity. In particular, the Korean culture of singing and painting the beauty of landscape using the words "Gyeong (景)" and "Gok (曲)" can be found in the backgrounds and landscape architecture plans of the Cheonggye Stream and Suseongdong Valley restoration projects. Therefore, the historical and cultural thoughts that pursued natural beauty were in the work for the restoration of the two streams, and these concepts should be considered for sustainable development for harmony between the city with nature and between nature with cultures.

Keywords: Cheonggye Stream; Suseongdong Valley; restoration; concept of landscape; Korean culture

1. Introduction

Cheonggye Stream and Suseongdong Valley restoration projects are the representative examples of natural river restoration projects that have been conducted since the 2000s in cities of South Korea. This study examined the underlying motive of these two projects that pursued nature in a city from a viewpoint of landscape, a historical and cultural concept of society.

The concept of landscape that has pursued natural beauty is premised on humanity. The most important aspect of humanity is the fact that humans are the ones who live in the human world, given that Heidegger refers to humans as "being-in-the-world" [1]. Consistent with this basic idea, the French cultural geographer Augustin Bergue said that landscape is an aesthetic consciousness in which objects continue to be signified within relationships to the human world and that the social motive of landscape is the desire to go out and to get away from a secular city into the wilderness (野) or into nature [2]. That means that the consciousness of a landscape is based upon a city, which is the center of the human world. From this viewpoint, if we look into the historical intention of landscapes, we can see examples of why societies pursue natural beauty and the ways in which they realize it.

River restoration is already a global trend. In modern times, concrete banks and embankments have been built in rivers for flood prevention and water supply, but now, they are on the

"re-naturalization" of the river by dismantling the concrete bank and embankment. Typically, there is the European Rhine. In the 19th century, river management removing tributaries and straightening rivers caused more floods. To restore the old waterways since the late 1990s, re-naturalization has been promoted by reconnecting the tributaries and the mainstream and creating a wide flooding area. This change is not only a more efficient management of nature but also an ecological restoration and is culturally providing more opportunities for people to enjoy nature. Furthermore, historic value is added from the restoration of a landscape. The Florence Charter (1981) and the European Landscape Convention (2000) established criteria for the protection and management of historic gardens and landscapes, emphasizing that these are important aspects of peoples' quality of life [3,4].

Cheonggye Stream and Suseongdong Valley restoration projects lie in the flow of South Korea's river ecological restoration projects from the late 1990s to the 2000s. Although the ideas and planning of the river restoration projects at the time contained redevelopment reasonings and ecological reasonings in the contemporary city planning, these two restoration projects originally contained the common reason of a landscape concept and the local specificity that had been formed historically and culturally in the process of its realization in South Korea. Therefore, this paper will verify which traditional and cultural aspects on nature influences and sustains the planning of two restorations projects.

Concerning the process of the study, we firstly examined the discovery and evolution of the landscape concept and then investigated the evolution of the landscape concept and garden in Korea. This examination showed how the general concepts of landscape were specifically characterized in Korean society. Also, by examining the historical and cultural background of the Cheonggye Stream and Suseongdong Valley restoration projects as well as the discussions in the restoration processes, we found out what kind of meanings were given to streams and valleys in the contemporary urban planning. Finally, by examining the landscapes plans in the restoration projects and the experiences within them, we found out how the historically and culturally formed concept of landscape has been working and what kind of meaning it has had from the viewpoint of sustainability.

2. Discovery of the Concept of Landscape and of the Evolution of Garden and Korea's Landscape and Gardens

2.1. Discovery of the Concept of Landscape and Evolution of Gardens and Parks

The aesthetic consciousness of landscape is a cultural concept that has been formed historically. Landscape is a concept that has been discovered and cultivated in the human world among some social reasons. If we trace the occurrence of that historical and cultural concept, we can see why we feel an aesthetic consciousness when we look at nature and why we are creating a garden and a park for the representation of nature.

In Asia, the beginning of the landscape concept can be found in China's "hermits" during the 3rd century [2]. The urban noble men called "Seven Sages of the Bamboo Grove (竹林七賢)" revered Laozi and Zhuangzi's action in inaction (無爲) philosophy, despised the mundaneness of the city, and praised nature while hiding in the wild mountain. These poems sang personal relief by leaving the mundane world, by staying away from political power, and by taking refuge in the natural world. In addition, it was after two generations that praising a hermit life in the natural world by leaving the mundane world developed into some aesthetic consciousness by "Landscape Painting (山水書)" by Tsung Ping (宗炳, 375–443) [2]. Natural beauty was praised through poetry and landscape paintings. This aesthetic reason was materialized into gardens inside cities. So, the form of these gardens became "the forest of a mountain inside a city". That means that the outside world was represented within the inner world of the city. This is a historical moment in that the humans' aesthetic consciousness about nature dubbed as "landscape" was discovered for the first time.

In Europe, since the Renaissance, the aesthetic consciousness of landscape was discovered and widely spread. In the 15th and 16th centuries, the villas and gardens of Florence and Rome were built by aristocrats to enjoy the view of the garden and the scenery around the city beyond the gardens.

The change of landscape in the suburbs of Florence by the suburban large-scale reclamation project in Florence and the reverence of the Renaissance era for the ancient Roman culture developed into a culture of enjoying a quiet life in the countryside. Also, villas and gardens in the suburbs are used as places of relaxation and escape from busy urban life. It is well-described by Pliny the Younger (61–113), an ancient Roman scholar who was rediscovered at that time, in his writing life in villas: "a good life and a genuine one, which is happy and honorable, [is] more rewarding than any 'business' can be. You should take the first opportunity to leave the din, the futile bustle, and useless occupations of the city and devote yourself to literature or to leisure." [5]. Villas and garden cultures developed during the Renaissance era will later affect the villas and gardens of France and England.

In France, Tuileries gardens in the 16th century and Luxembourg's parks and boulevards lined with trees in the 17th century were intended to create a walkway through greenery in public places. These are the examples of pursuing natural beauty through scenery in the city. Particularly, in the 19th century, green space systems such as forests, parks, small squares, gardens, and boulevards were installed in Paris by Georges-Eugène Haussmann, which created the identity of today's Parisian road landscape [6]. The motive for the completion of the green systems in Paris in the nineteenth century was not limited to the beautification of the city through nature. Here, hygienism played an important part. The statement by Adolphe Alphand, who was the director of the "Promenade and Plantations Administration" shows that hygienic motive was very important: "In the old days, we had to walk a quite long distance or get out of Paris in order to breathe fresh air and to get sunshine; Today, Parisians have gardens near the Parisian districts." (Verne, 1985–1986) [6].

The aesthetic pursuit of nature and hygienism are the thoughts inseparably intertwined in the pursuit of nature. The development of a park was a simultaneous pursuit of natural beauty and hygiene in a city. Creating gardens and parks and planting roadside trees in the inner world city of the city is like planting a landscape symbolizing the outside world inside a complex city and providing a place for rest and relaxation. This is to feel the beauty of the outside nature inside the city without having to go out to the suburbs. The aesthetic pursuit of nature in urban history has been a major part of urban beautification. Also, hygienism, which was popular together with aesthetic motivation from the 19th century to the early 20th century, was another important motive for planting nature in a city. In the history of European cities, thoughts about the beautification of a city through nature have been accompanied by the development of landscape concept.

2.2. Evolution of the Concept of Landscape and Garden Culture in South Korea

The beginning of the concept of landscape in South Korea dates back to the Three Kingdoms period during the 5th–6th century AD, when Taoism was introduced from China. As the first record that described "Jeong (情, sentiment)" about nature, the word "Pungryu (風流)" appeared in this age. Pungryu was considered to be a profound enlightenment integrating Confucianism, Buddhism, and Taoism, and "Hwarang (Flowering Knights)", the students of the educational institute established by the Silla Dynasty, had to learn about "Pungryu". As part of their doctrines, they received physical trainings together, enjoyed themselves by singing and dancing, and traveled to famous mountains and big rivers in order to cultivate the spirit of "Pungryu." The spirit of "Pungryu" to find enlightenment in nature was to pursue spiritual communication with nature [7]. This was the beginning of the discussion about "Jeong" in connection with nature in South Korea. Afterwards, "Pungryu" was a religious custom of worshiping mountains during the Goryeo Dynasty. However, during the Joseon Dynasty, it was considered not as a unique ideological tradition or a religious custom but as an attitude toward life to get close to nature and to enjoy grace and scenic beauty [8]. This spirit of "Pungryu" is often used to refer to the origin of Korean garden culture.

When we look at Koreans' thinking about nature, their ideas about nature was greatly influenced by Confucianism and Taoism introduced from China. Nevertheless, given that Koreans had unique "Sin-Seon" (immortality) thoughts (神仙思想) similar to Taoism and the spirit of "Pungryu" that integrated Confucianism, Buddhism, and Taoism, Koreans' thoughts about nature is considered as

characteristic thoughts they accepted Confucianism and Taoism from China. First, Taoism's "what is so of itself (自然)" had a huge influence on Koreans' traditional view of nature. This thought followed the path (道, the principle of nature), referred to as "what is so of itself" and had a strong objection to something artificial. Korean gardens show a strong influence by the thought of "what is so of itself." This thought is also associated with the characteristics of a typical Korean garden that did not have artificial landscapes like Japanese stone gardens (石庭) or Chinese stone forests (石林) [7] (Figure 1). The evaluation of Korean arts and culture as "artless artifice and harmony with nature" is related to "what is so of itself". The view of nature of both Confucianism and Taoism deeply influenced Koreans' view of nature. Given that Confucianism was the national religion of the Joseon Dynasty, which was the last Korean dynasty, and that the gardens of the Joseon Dynasty was built by the scholars who studied Confucianism, Confucianism is a great ideological background for Koreans' view of nature and garden culture. Confucianism's view of nature thought of "Do (path, 道)" as the law of nature, which was Taoism's view of nature. "Do" was considered as the cosmos and interpreted as "the sky that gives birth to nature", and "Do" was linked to "In (仁, benevolence)", which is the highest virtue of Confucianism [9]. The law of nature was developed into the ethical ideal of the human world. The Confucianists enjoyed nature within nature; cultivated their virtue by following "Do", the law of nature; and practiced the virtue as their practical ethics in society. In this culture, the literary men of Joseon wrote poems to praise the beauty of nature by comparing it with the mundane world within nature, and these poems, landscape paintings, and literary painting were manifested into the gardens of Joseon.

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

Figure 1. Gardens of China, Japan, and Korea: (**a**) the Chinese stone forest (石林, Yunnan), (**b**) the Japanese stone garden (石庭, Ryoanji), and (**c**) the Korean Garden (Soswaewon).

During the Joseon Dynasty, places with scenic landscapes were named with "Gyeong (景, scenic landscape)" and "Gok (曲, valley)", as seen in the names of places such as "Dan-Yang-Pal-Gyeong (丹陽八景, Eight Scenic Views of Danyang)", "Gwan-Dong-Pal-Gyeong (關東八景, Eight Scenic Views of Gwandong)", "Jang-Dong-Pal-Gyeong (壯洞八景, Eight Scenic Views of Jangdong)", "Hwa-Yang-Gu-Gok (Nine valleys at Hwayang, 華陽九曲)", and "Go-San-Gu-Gok (高山九曲, Nine valleys at Gosan)". These expressions are the literary terms and words that have been commonly used until today to refer to scenic landscapes. Choi Gi-Soo reported that the pursuit of natural beauty which was expressed with "Gyeong (景, scenic landscape)" and "Gok (曲, valley)" seemed to be influenced by China [10]. "Gyeong" (scenic landscape) was used to refer to a place with a space smaller than a region that had outstanding and beautiful sceneries. After "So-Sang-Pal-Gyeong-Do (瀟湘八景圖, Eight Views of Xiao and Xiang Rivers)" during the North Song Dynasty of China was introduced to Korea (Goryeo Dynasty period), these places and paintings came to represent scenic landscape, and the introduction of these paintings led to a vogue of landscape paintings; the word "Gyeong" became naturalized as an expression to refer to eight scenic landscapes in South Korea (Figure 2). For instance, "Dan-Yang-Pal-Gyeong" means eight scenic landscapes in the Danyang region. People enjoyed nature in the places dubbed as "Gyeong" and praised their beauty with poems and paintings, which became a culture. The word "Gok" had two meanings; "bending" in a morphological meaning. This word was used to refer to a place that had water-streaming valleys with mystifying rocks, waterfalls, and

ponds. For instance, Song Si-Yeol, a scholar of Joseon Dynasty, named the outstandingly scenic valleys of Hwayang-dong of Mt. Sokri as "Hwa-Yang-Gu-Gok (華陽九曲, Nine Valleys of Hwayang)" and praised the beauty with his poem (Figure 3).

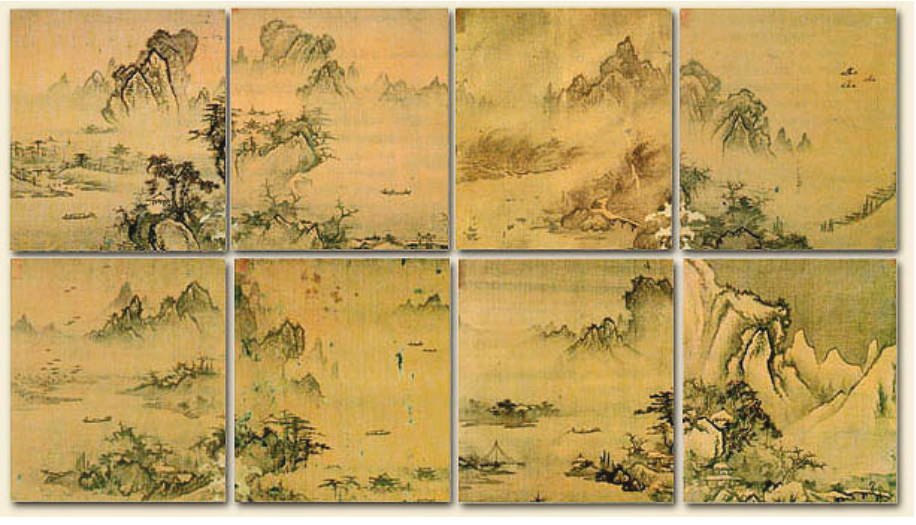
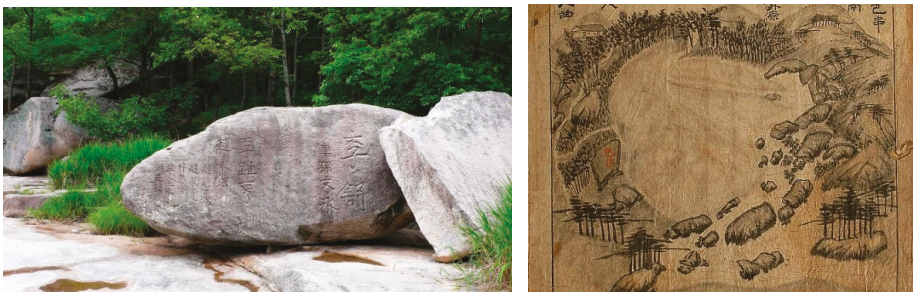


Figure 2. The Eight Views of Xiao and Xiang Rivers (瀟湘八景圖) (known to be painted by An Gyeon).



(a) **(b)**

Figure 3. Hwa-Yang-Gu-Gok (華陽九曲), (9th Valley: Pacheon): (**a**) Photography and (**b**) painting by Gwon Sin-Eung (1728–1878).

It became a culture that the beautiful scenery of nature was named with "Gyeong" and "Gok" and that the beauty of nature was pursued with poems and paintings. Together with landscape paintings depicting scenic beauty, Takjokdo (濯足圖, Feet-Washing Painting) that contrasted the human world against nature with a beautiful landscape reveals the noble class's thoughts of the world during the Joseon Dynasty (Figure 4). In the figure painting titled "Painting of Sage Washing His Feet", a scholar or sage' act of washing his feet represents his intention to get away from the chaos of the mundane world and to live by the law of nature within nature.

Figure 4. Gosa-Takjokdo (高士濯足圖, Painting of Sage Washing His Feet) by Lee Gyeong-Yoon (1545–1611).

This pursuit of natural beauty that embraces a human world develops into the "Retreat Villa Garden (別墅庭園)", a type of garden during the Joseon Dynasty. These gardens were mostly made by government officials in exile or by scholars who had given up on going into the political world, so the gardens served as quiet shelters for those who wanted to forget the world and live in nature. It can be said that the garden was made for hermits like the "Seven Sages of the Bamboo Grove" in China. The garden was built not inside a house but at a distant place with a scenic landscape, and it was a small garden with a pavilion which was surrounded by walls. The representative garden is "Soswaewon (瀟灑園)" [11]. Yang San-Bo (1503–1557), who built the Soswaewon garden, was a central government official during the Joseon Dynasty and was a nobleman who later abandoned the mundane world after the literati purges and went into seclusion there. The garden was created by walls around an existing valley and stream, by constructing pavilions inside the walls, and by creating an artificial hill near the stream (Figure 5). As seen in Soswaewon, the culture of naming the mountains and streams with scenic beauty with "Gyeong" or "Gok" and going outside to praise the natural beauty has developed into a garden culture of bringing those mountains and streams near or inside houses to admire the natural beauty.

Figure 5. The pavilion in Soswaewon: Gwangpung (光風閣, Bright Sun and Fresh Wind after Raining) Pavilion.

Also, traditionally, urban dwellers in Korea like to go out to look for nature to enjoy themselves. The genre paintings by Shin Yun-Bok (1758–1817) such as "Sang-Chun-Yha-Heung (賞春野興)" and "Dan-Ho-Pung-Jeong (端午風情)" provide a glimpse into the life of that time [12]. "Sang-Chun" means enjoying the scenery of spring. The painting depicts a story that when azaleas were in bloom in the spring, the nobles and Gisaengs (female courtesans) went to the suburbs or to the garden of a noble man to enjoy the natural beauty (Figure 6). This shows the entertainment life of the urban noble men at that time. The painting "Dan-Ho-Pung-Jeong" depicts the women washing their hair near a stream, resting under the shades, or riding a swing (Figure 6). On May 5th of the lunar calendar, when the summer heat begins, people stopped working in fields for a while, put on new clothes, and gathered together to cook and eat delicious food. On this festive day, women washed their bodies in the stream and their heads with water infused with iris and enjoyed the scenery. Likewise, the culture of enjoying nature has been an everyday culture for Koreans.

Figure 6. "Sang-Chun-Yha-Heung" and "Dan-Ho-Pung-Jeong" by Shin Yun-Bok.

3. Discourse on History and Restoration Process of Cheonggye Stream and Suseongdong Valley

3.1. Discussions on History and Restoration Process of Cheonggye Stream

The discussions on the Cheonggye Stream restoration process are related to the history of Cheonggye Stream and also to the urban development theory and ecology of the contemporary time. The project itself was one of the then Seoul mayor's election promises. Given that the planning restoration projects were determined by the political decision of the Seoul mayor, the discourses on the restoration process of Cheonggye Stream were also related to the politics. Therefore, the discussions on the restoration process of Cheonggye Stream were conducted in various aspects [13]. However, in this part, we will examine the meaning of Cheonggye Stream in terms of the relationship between nature and humans by looking into the discussions of the history and restoration process.

After Hanyang (the old Seoul) was designated as the capital city of Joseon Dynasty, the Cheonggye Stream was managed as the main river of the capital as Seoul. Originally, it was a wide creek where its tributaries coming from the surrounding valleys converged, and because of the unique climate conditions of Korea with floods in summer and little rain in winter, it had frequent floods during summer and had no flow of water during winter. As the population increased, houses were built around the stream. Flooding in the summer often led to human damages, and the stream was polluted with waste water of the city. For this reason, stone works and dredging were carried out during three periods of Joseon Dynasty: 1411, 1422–1434, and 1760–1773. If we look into the discussion on Cheonggye Stream by the king and bureaucrats in 1444, we can see how they considered Cheonggye Stream in those days. On the issue of the maintenance of Cheonggye Stream, some opinions said that the stream must be kept clean by preventing people from throwing away stinking wastes, whereas the opposing opinions said that the city could be kept clean by letting dirty and smelly things flow away

through the stream. In the end, the latter argument was adopted, and therefore, Cheonggye Stream of the Joseon Dynasty was utilized as the drainage or sewer of the city [14]. Because Cheonggye Stream was very close to the life of people, the life scenes around Cheonggye Stream are meaningful in history. Because the upper stream was relatively clean, it was a place for the lower classes to wash clothes and for children to bathe because the lower stream was dirty and unhygienic with floating wastes and trashes. Cheonggye Stream had a long strip of open space, which was used as the festival place for folk plays. On the lunar fifteenth day of the new year, many people gathered around the brides over Cheonggye Stream to fly kites and do the stepping-on-bridge play [15]. As the stone walls and stone bridges of Cheonggye Stream often appeared in poems and novels, it was a cultural space with various meanings for the life of the citizens (Figures 7 and 8).

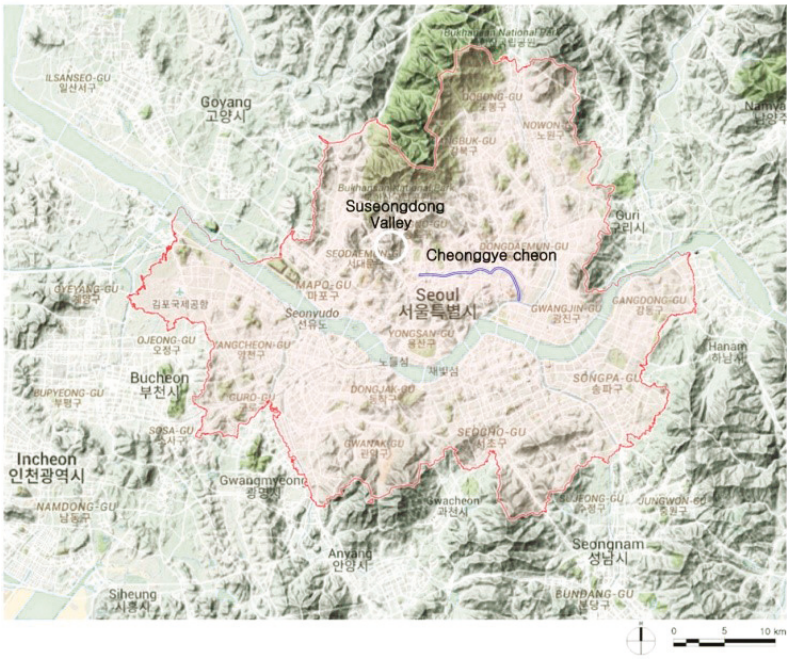
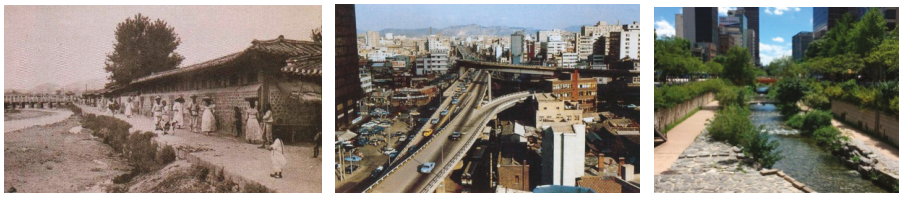


Figure 7. The location of Cheonggye Stream and Suseongdong Valley in Seoul.

Figure 8. The stepping-on-bridge play on the lunar fifteenth day of the new year.

Cheonggye Stream had the meaning as a drainage stream and became recognized as a sewer rather than a stream during the period of Japanese colonial rule and modernization. In 1937, some sections of the upper stream were covered with reinforced concrete by the Japanese colonial government, and all sections of the stream were completely covered during the period of 1955–1977 after independence and the Korean War. As South Korea underwent modernization, the population increased more and more, raising concerns about hygiene problems, safety problems, and traffic problems. For these reasons, roads were constructed by covering up Cheonggye Stream for its sole function as a sewer, and then the overpass was built on it, which became a symbol of economic development and modernization. Since then, many small factories of light industry and shops which sold electronic parts, machine tools, and clothing wholesales gathered together under the elevated rods around Cheonggye Stream to establish itself as a specialized commercial area for light industry and wholesale business. The area also had places with cultural diversity in the heart of the city (for instance, Hwanghakdong (second-hand market), but the part of the downtown area became more and more dilapidated until 2003 (Figure 9).



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

Figure 9. The waterside of Cheonggye Stream: (**a**) 1920s, (**b**) 1980s, and (**c**) 2018.

The movement to dismantle the overpasses and to remove the concrete covering Cheonggye Stream in order to restore the stream started in the 1990s and came into full swing in the early 2000s. The famous Korean novelist Park Kyung-Ri claimed for the restoration of Cheonggye Stream in an ecological direction for coexistence between nature and humans by saying "Cheonggye Stream with clean water and trees with fish in it" [16]. The environmentalist Noh Soo-Hong also insisted on the restoration of Cheonggye Stream in order to enable Seoul citizens who were far away from nature to feel the importance of environment in everyday life. In particular, people wanted to reduce the energy and time wasted on the highway, which often turned into almost a parking lot because of the heavy traffic jams of vehicles heading to seas and mountains on weekends and holidays [17]. In addition, it was designed to be reconstructed as a historic and cultural space that could show old traditional life styles and cultural plays of the past carried out around the stream by restoring historical objects such as the old bridges and stone walls of Cheonggye Stream. Instead of the development of the dilapidated downtown, they focused on the restoration of a natural environment and cultural space through the restoration of Cheonggye Stream. On the other hand, the Cheonggye Stream Promotion Headquarters, which was the core body of the Cheonggye Stream restoration project, intended to revitalize the stagnant economy of the northern part of Seoul through the regrowth of the surrounding shopping districts by creating an environmentally friendly waterfront space and, furthermore, to reinvigorate itself as an international financial and business hub. In other words, although it pursued multi-values as a historic, cultural, and environmentally friendly restoration, it focused mainly on growth [18]. In contrast, there were scholars who opposed the restoration of Cheonggye Stream. Some people opposed the idea of restoring Cheonggye Stream by pumping water from the Han River and flowing it through the stream, arguing that it was not a genuine restoration of nature but a transformation into an artificial stream and that it was focused on the development of rather than the restoration of nature.

These three different positions can be broadly divided into two kinds from the viewpoint of nature. Those who were for restoration with an emphasis either on environment and culture or on development had an urban planning viewpoint of re-gardening in downtown, while those who

opposed restoration had an idea similar to the ecological culturalism of rewilding to restore the ecological system of Cheonggye Stream as much as possible. However, either the restoration plan of Cheonggye Stream with the focus on environment or the other restoration plan to restore the watershed ecosystem as much as possible had the possibility of being abandoned because it could require a long time to change the water supply and drainage system of the whole watershed of Cheonggye Stream and the urban infrastructure system. Amid all these discussions, the Cheonggye Stream Restoration Headquarters of Seoul City decided to proceed with a restoration plan lacking environmental and historical restoration, to dismantle the overpasses within 2 years and 2 months, and to construct an artificial river (Figure 9).

The restoration project raised concerns and future problems including an excessive energy use to maintain an artificial river, a need for restoration of historical and cultural properties, and a development without the consideration of the context with the surrounding areas. It is worth noting that many people were in favor of the Cheonggye Stream restoration project despite an artificial restoration of nature and visited the stream as a resting place and historic place.

3.2. Discussions on History and Restoration Process of Suseongdong Valley

Suseongdong Valley (also known as Okryudong or Okindong) is one of the scenic spots that people have visited to enjoy beautiful landscape since the early Joseon Dynasty. Hanyang, the capital of Joseon Dynasty, was surrounded by a fortress, and the majority of people lived in a densely populated space within the fortress. Among them, Suseongdong Valley was one of the origins of Cheonggye Stream and was located at the foot of Mt. Bukhan. It was not far from Gyeongbok Palace and was located very close to the center. The name Suseongdong means a valley with a big sound of flowing water, and it was a place where the water flows with a scenic beauty of rocks and trees, which was used as the motive for the works of many writers and painters. Together with Baekundong valley, it was a place where the literary society held meetings (Figures 10–12).

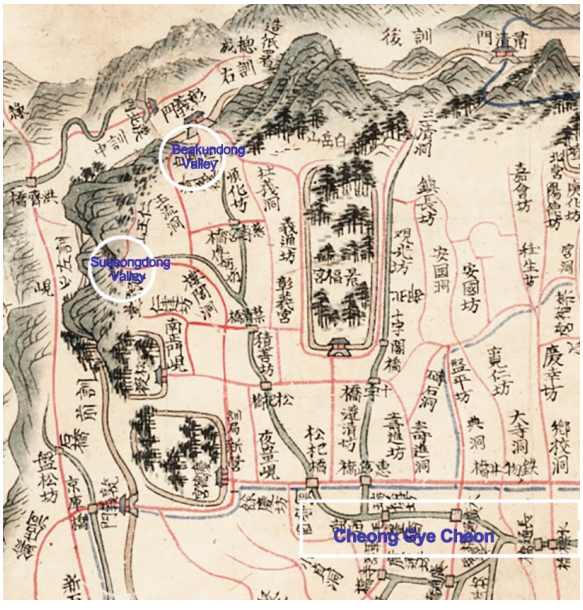


Figure 10. Suseongdong Valley and Baekundong valley on the map of Hanyang (old Seoul).

Figure 11. Landscape paintings of Suseongdong Valley and Okryudong by Jeong Seon.

Figure 12. Literary Society of the Middle Class: a picture album of the *Geumran* Group (金蘭契帖, 1857).

Suseongdong Valley was the background of one of the landscape paintings titled "8 Scenes of Jang Dong (壯洞八景)" by Jeong Seon (Gyeomjae) (Figure 11). Because the valley (Gok) with a beautiful landscape was named with "Gyeong" (scene), it was beautified by literary men and painters. Kim Jeong Hui, a famous scholar and potter during the Joseon Dynasty, praised the beauty of the landscape and lampooned the world with his poem titled "Watch waterfall at Suseongdong valley under rains" [19]:

Go just a few steps into the valley (入谷不數武)
Under the feet, the thundering sound of flowing water (吼雷殷屐下)
Mountain fog shrouding and wetting my body in blue color (濕翠似裹身)
Came in the daytime, but it felt like night (晝行復疑夜)
Neat and clean moss spread out as a bed (淨苔當舖席)
A round pine tree looking like a roof turned upside down (圓松敵覆瓦)
The cascading water sounded like the song of a bird in the old days (簷溜昔啁啾)
But today, it sounds like the song of my friend (如今聽大雅)
Feel solemn naturally in front of the upright mind of the mountain (山心正肅然)

I can't hear the birds singing anymore (鳥雀無喧者)
I wish I could let the world hear this sound (願將此聲歸)
I wish it can enlighten the unscrupulous (砭彼俗而野)
Night clouds suddenly appear in black color (夕雲忽潑墨)
It tells me to draw a paint like writing a poem to you (君詩意寫)

The poem wholly embodies Confucianism's view of nature, which has developed the principles of nature into the ethical ideal for the human world. In addition, the landscape of Suseongdong Valley was praised in Jonjae's Anthology Vol. 23 titled "Excursion to Suseongdong (遊水聲洞記)", which is the collection of the literary works of Park Yoon-Muk (with the pen name of Jonjae (存齋)), one of the great maestros of the "Literature of the Middle Class" of the latter Joseon Dynasty [19]:

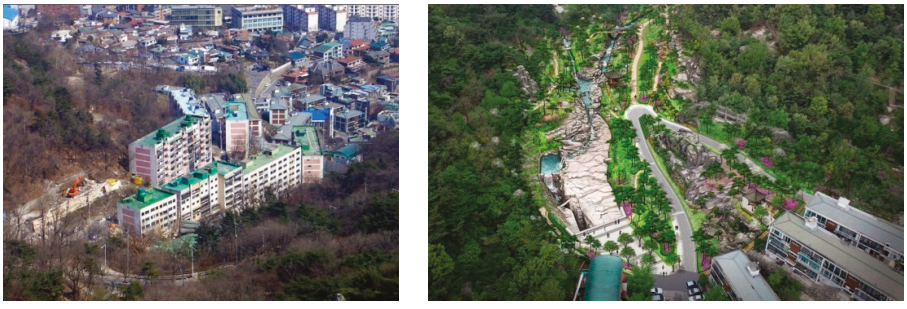
Sometimes flying water droplets are wetting clothes (時飛沫濺衣)
Cold chill cuts to the bone (意逼骨)
But my soul becomes refreshed and my mind becomes clear (魂神爽)
The mind becomes comfortable, and the will grows within (情逸意蕩)
I feel a vast-flowing spirit like the Creator (浩然如與造物者)
It seems to be playing in a good place out of this world (遊於物之外也)
Finally, drunken with alcohol, pleasure becomes greater (遂大醉樂極)
So, I untie my hair and sing a long song (散髮長歌)

The author felt being outside the world while communicating with nature. In other words, the communion with nature was recognized as another world outside of the fortress and another world outside of the human world. It shows that the concept of landscape originated from the motivation to escape out of the city center and out of the human world.

However, in 1971, when a rapid modernization and urbanization was under way, the Okin apartment was constructed across Suseongdong valley, and its stream was covered to make roads. In the dismantlement process of the old Okin apartment since 2008, the remains of Suseongdong valley came to light, which promoted the restoration of the valley. As it was designated as the Seoul Metropolitan City's Monument No. 31 in 2010, its historic value as a cultural asset was recognized. The reason for its designation as a cultural heritage is as follows:

> "It is worth preserving it as a 'traditional scenic spot' because it still retains the scenery of the past. In addition, given that this area also served as the main stage for the literary activities of the middle class during the latter Joseon Dynasty, it is also meaningful from the perspective of literature history. The stone bridge hanging below the valley also appeared in the painting by Jeong Seon (with the pen name of Gyeomjae), and it is very valuable in the viewpoint of the bridge engineering history because it is the only bridge that has remained in its original location and condition within the old fortress of the capital city and also the longest bridge made of uncut stones. Therefore, it is intended to preserve the old scenery of Suseongdong by designating the entire stream and valley including a stone bridge as one of the Monuments of the Seoul Metropolitan City." [20].

Later, the restoration project started in 2011 and was completed in 2012. The restoration of Suseongdong Valley was influenced by the ecological restoration projects of streams in cities since the 2000s. In particular, the Cheonggye Stream restoration project was recognized as a city planning project that was most successfully carried out by the citizens. This revival of nature encouraged the restoration of the Suseongdong Valley, which evolved into the revival of its cultural value as an old historic place with scenic areas (Figures 7 and 13).



(a) **(b)**

Figure 13. Suseongdong Valley: (**a**) Suseongdong Valley before its restoration (with Okin Apartments) and (**b**) a bird's-eye view of the restoration plan.

4. Influence and Sustainability of Korean concept of landscape in Cheonggye Stream and Suseongdong Valley Restoration Projects

4.1. Landscapes and Experiences in Landscape Architecture Plans of Restoration Projects

The landscape architecture of Cheonggye Stream was planned and constructed by dividing it into three sections: upstream, midstream, and downstream. The first construction section located in the city center was planned to reveal the history of the city and to create plazas in consideration of cultural activities in the city. The second construction section where small-scale commerce and industry activities were actively conducted was designed as a buffer zone for coexistence between the city and nature. The third construction section with a high concentration of low-rising multi-household houses was designed to create a natural and ecological space based on the recovery of nature. Under these three major themes, eight landscapes of Cheonggye Stream were constructed: the 1st landscape, Cheonggye Square (waterfall, eight-stone pond); the 2nd landscape, Gwangtong Bridge; the 3rd landscape, the Mural of the Royal Procession of King Jeongjo; the 4th landscape, cultural space ("Wall of Culture" and "Wall with Color Spectrum"); the 5th landscape, Washing Place; the 6th landscape, Wall of Hope; the 7th landscape, Maintained Piers and Sky Fountain); and the 8th landscape, Wetland with Willow Trees (Figures 14 and 15). These 8 landscapes can be perceived as artificial in that these natural stream landscapes were built on places where they did not exist before, under a monotonous structure of Cheoggye Stream with concrete banks running in parallel. Especially in the 1st construction section, it created an artificial landscape with various facilities of the city under the concept of providing a water-friendly space in the city center. For example, the Mural of the Royal Procession of King Jeongjo was installed on the walls next to the banks, which became not a landscape but an artificial event. However, it is important to divide the landscape of a natural stream into eight landscapes and to borrow the traditional concept of "Gyeong" to describe them. If we select two major landscapes of Cheonggye Stream from the viewpoint of "Gyeong", one landscape is created by the connection of urban installments like bridges and banks with the open space of the stream, while the other landscape is created by the connection of waterfront installments (stepping stones, steps leading to waterfront, washing places, etc.) with the waterside trails and plants. These two landscapes are the typical ones that people can enjoy in a natural stream and are also cultural and continuous spaces. Inside these two major landscapes, citizens can experience nature for resting and relaxation in the city center. Citizens can appreciate waterside landscapes from bridges or walkways on the banks lined with trees or can take a stroll. In addition, cafes and restaurants were newly moved into the waterside buildings around the promenade. Experiences at the waterfront provide important opportunities for people to enjoy nature in the Cheonggye Stream. People can appreciate the waterside landscapes by taking a stroll along the stream, crossing the stepping bridge, sitting on the steps leading to the waterside, listening to the sound of rolling water or wind, and watching the fish and birds. In particular, the scene of citizens

sitting with their feet soaked into the water is similar to the scene of the scholars of Joseon Dynasty in the "Feet-Washing Painting" (Figure 16). Like the will of the scholars of the Joseon Dynasty who left the chaotic world and tried to live in nature according to the law of nature, it can provide a time that people can experience nature in the city center where nature seems so far away from it.

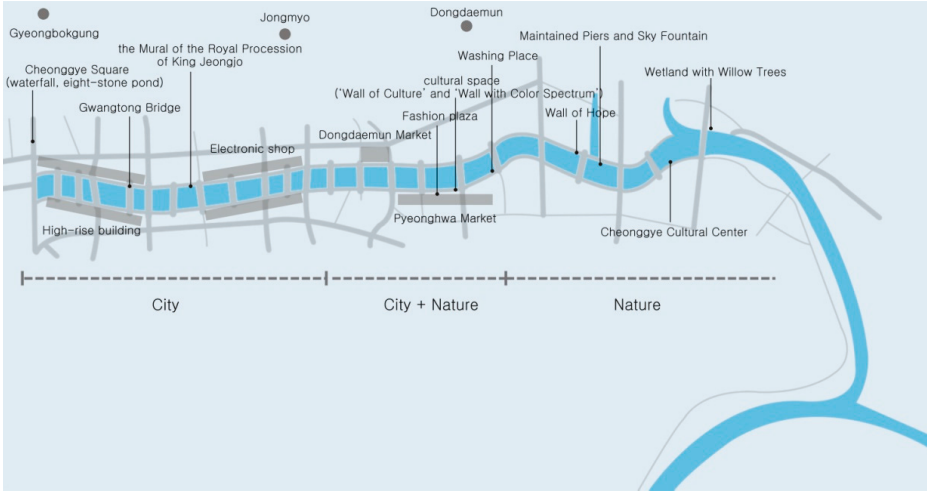


Figure 14. The restored Cheonggye Stream.

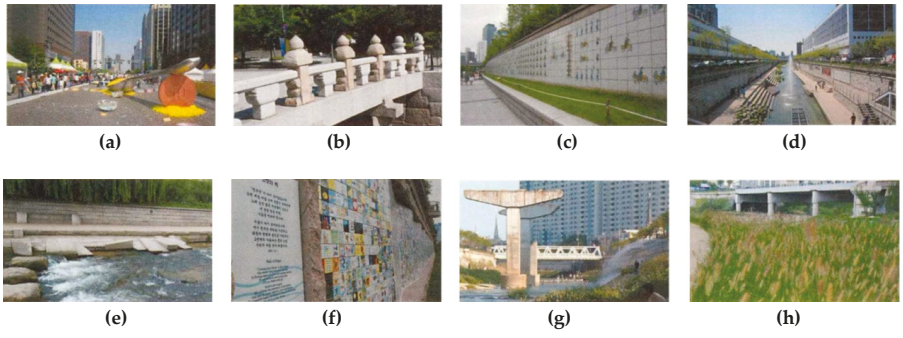


Figure 15. Eight landscapes of Cheonggye Stream: (**a**) 1st landscape, Cheonggye Square; (**b**) 2nd, Gwangtong Bridge; (**c**) 3rd, Mural of the Royal Procession of King Jeongjo; (**d**) 4th, Wall of Culture and Wall with Color Spectrum; (**e**) 5th, Washing Place; (**f**) 6th, Wall of Hope; (**g**) 7th, Maintained Piers and Sky Fountain; and (**h**) 8th, Wetland with Willow Trees.

The restoration plan of Suseongdong Valley was to restore the valley below the mountain into the original condition based on the passed-down paintings: Suseongdong Valley and Okryudong Valley among Eight Scenes of Jang Dong by Jeong Seon (Gyeomjae). It was to find out the original rock formation of the picturesque valley at the foot of Mt. Bukhan. Therefore, it exposed the rock mass in the mountain torrent area as much as possible to restore the natural beauty, and the traditional trees and landscaping plans were used to restore the traditional natural landscapes. It minimized the use of artificial installments including one pavilion built of stone and wood, a wooden bridge, and a wooden deck. In terms of trees, the acacia tree that was introduced during the modern time was removed, and pine, oak, and fir trees as well as and mountain azalea were planted instead (Figure 17).

Figure 16. The landscapes of the restored Cheonggye Stream and the citizens.

Figure 17. The planning of the restored Suseongdong Valley.

The restoration of Suseongdong Valley was to revive these traditional landscapes and the natural sensibility. Mountain trekkers walk along the path beneath a picturesque mountain watching the restored rocks and sitting on rocks or the pavilion to enjoy the nature such as mountains, valleys, water, wind, trees, flowers, birds, and insects (Figure 18). The act of composing poems and painting landscapes on a pavilion overlooking the valley while enjoying the scenic beauty was a traditional way of appreciating nature. It is close to the city center but offers an escape from the hustle and bustle of the city.

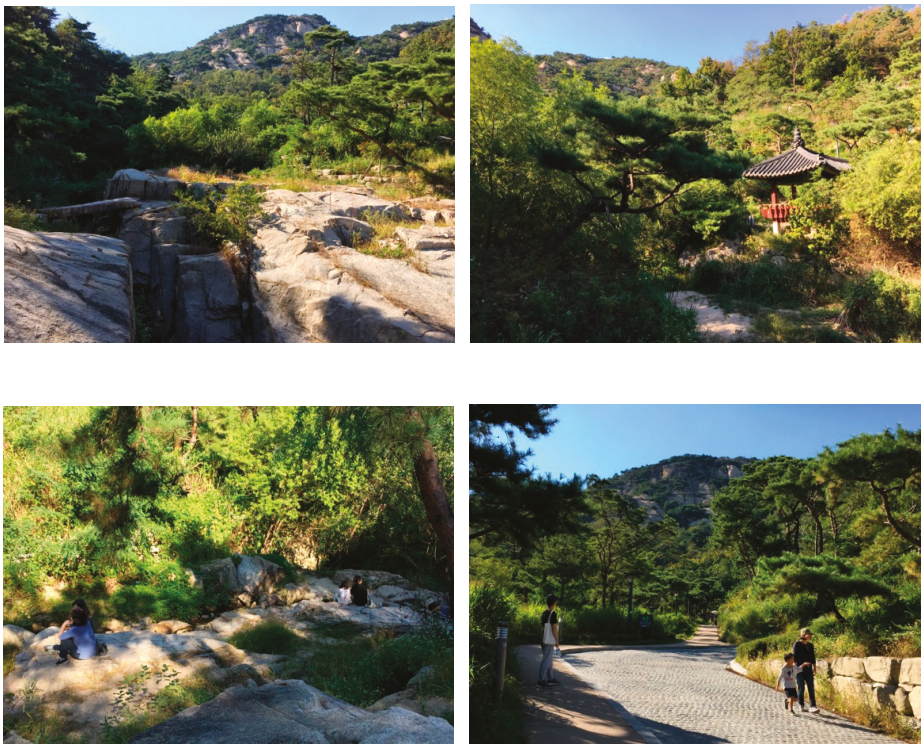


Figure 18. The landscapes of the restored Suseongdong Valley and the citizens.

4.2. Cultural Function and Sustainability of Landscape Concept in Restoration Projects

We can confirm the influence and sustainability of a historical and cultural concept of landscape through the Cheonggye Stream and Suseongdong Valley restoration projects.

First, the appreciation of natural beauty is the most fundamental motive of both projects. They restored the places where citizens could appreciate nature in the city center or in a place close to the city center. The old streams were restored into the original conditions and into the places that could improve the wellbeing of citizens. We reason that the concept of landscape, the driving force of these projects, was the citizens' desire to have a place for resting and relaxation to appreciate nature in a place with insufficient green space like the city center of Seoul. Since more than 76% of the green area of all the parks in Seoul was concentrated in the outskirts of the city, the creation of green space through the restoration of streams received much support from the citizens in the situation where the green areas were not enough within the life zone [13].

Second, both projects are the restoration of historical heritage in that they are the revitalization of the past. The discussion on the Cheonggye Stream restoration project was started by environmental scientists and novelists. Their discussion started with a nostalgia for the life of people in the waterfront landscape before being covered with concrete and overpasses. It is the restoration into a historic and cultural space such as life scenes and cultural plays around Cheonggye Stream and the restoration of a waterfront landscape as an intangible cultural heritage. The restoration projects were to plant new nature with a new landscape planning different from the past landscape projects. In the case of Suseongdong Valley, it can be said as the restoration of the cultural heritage in that it restored a place famous since the old days as a scenic spot and the landscape that has been passed down through poems and paintings. Once again, this is influenced by Korea's long-stranding Pungryu (風流), Taoism,

and Confusianism cultures to appreciate nature and by their landscapes and garden culture that has been passed down from the past.

Third, both projects have an influence on the sustainable development of the surrounding areas. The Cheonggye Stream project was originally planned to create a water-friendly space and to induce urban redevelopment in the surrounding areas within the city center. Although such a development-oriented concept can be criticized for using nature like Cheonggye Stream as a means, the surrounding areas which were dilapidated slums before the restoration are now lined with new buildings and shops, shaping up the identity as a waterfront place. However, it brings with it a challenge of striking balance with the existing area and community. The restoration of Suseongdong Valley produces synergy effects as a historical and cultural place, together with the historical and cultural heritage of Gyeongbok Palace and with the Seochon Village located between Gyeongbok Palace and Suseongdong Valley. Gyeongbokgung Palace is the biggest palace during the Joseon Dynasty and a major sightseeing spot in Seoul. As Seochon Village and its alleys are lined with small restaurants and craft shops, the whole area is a sightseeing spot. Suseongdong Valley is a starting point for trekking to Mt. Bukhan. Therefore, the restoration project of Suseongdong Valley is being considered as the sustainability of a local identity connecting history, culture, and nature.

5. Conclusions

The Cheonggye Stream and Suseongdong valley restoration projects are the representative examples of South Korea's river restoration projects carried out since the 2000s. These two streams were covered with overpasses and apartments during the 1960s and 1970s in the middle of the full-fledged urbanization and modernization of South Korea. Now they are restored into green spaces to promote natural ecosystems and to provide places for citizens to rest and relax. The Cheonggye Stream project was carried out using the concept of the re-gardening of nature. This concept considers nature as a means for urban development. Even though this project used an artificial water flowing system, it satisfied the citizens' desire to appreciate nature in the city center. Being encouraged by such a stream restoration trend, the Suseongdong Valley restoration project was carried out. This project was not only the restoration of green space but also the restoration of an old famous scenic spot as a cultural heritage. These two restoration projects are the representative examples of breaking away from the modern function-oriented mindset to use urban streams as sewers and the beginning of examples which consider nature as an ecosystem and as a historic and cultural heritage that enhances the quality of life. These projects involve human's desires to enjoy suburban nature within the city center, which has evolved with time, as well as a global and contemporary trend toward the protection and management of historic gardens and landscapes. The projects were also influenced by local ideas and culture regarding nature. From the Pungryu (風流) spirit that emphasized inspiration within nature to those old poems and paintings named with "Gyeong (景)" and "Gok (曲)" which embodied natural beauty and also to gardens, the Korean culture to enjoy nature was recreated into the landscape and waterfront facilities designed for the restoration project of Cheonggye Stream in order to provide an opportunity to enjoy nature. Furthermore, the Suseongdong Valley restoration project is the historical and cultural transmission of Korean landscape in that it was restored based on the landscape depicted in the poems and paintings by old sages. In the end, the historical and cultural concept of landscape as well as a common and specific background of a society were reflected in the restoration projects of both streams. These historical and cultural backgrounds are taken into consideration for sustainable development with harmony between cities and nature and between nature and culture.

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Do Sociodemographic Characteristics in Waste Management Matter? Case Study of Recyclable Generation in the Czech Republic

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Abstract: The generation of recyclables in the Czech Republic has long been under the European average, but the proportion from municipal waste as a whole has been growing over the past few years. Previous research in the Czech Republic mainly focused on organizational or situational factors explaining recycling performance in municipalities. This study focuses on individual characteristics that are connected, among other things, to ongoing demographic changes. Currently ongoing sociodemographic development in the Czech Republic, as well as other developed countries, influence a broad range of aspects of social life, including waste generation and its structure. This paper aims at quantifying the relation between the sociodemographic characteristics of municipality inhabitants and recyclable generation. For this purpose, 13 variables describing inhabitants, households, and housing in 4897 Czech municipalities were selected that could influence the generation of recyclables according to foreign studies. Data were analyzed using multidimensional linear regression. Even though the resulting model only explains 9%, it is statistically significant and implies that sociodemographic variables can help explain recyclable generation. From this point of view, important variables are average household size, share of tertiary educated people, share of family houses, purchasing power per person, percentage of people employed in agriculture, and sex ratio. To increase the explained variability and emphasize local differences in recyclable generation, we also used geographically weighted regression (GWR). GWR results show that, to understand waste generation (at least in the Czech Republic) on a municipal level, it is necessary to also consider spatial effects and regional specifics.

Keywords: recycling; Czech Republic; sociodemographic determinants; regression; spatial analysis

1. Introduction

The separated collection and recycling of waste fractions such as glass, paper, plastic, or metal from municipal waste represent a significant contribution to environmental protection because they save primary resources and reduce the amount of waste that has to be treated, which would otherwise mainly be landfilled. In January 2018, the European Union (EU) adopted a new set of measures as a part of a Circular Economy Package that aims to help make Europe's economy more sustainable. To implement this effort, the EU set clear targets for reducing waste generation and promoting recycling; key elements of the proposal include a common EU goal for recycling 65% of municipal waste by 2030. This target has to be implemented in Czech national legislation, but based on Eurostat data, it is quite clear that the Czech Republic is lagging behind in this matter and it could be quite difficult to reach the given target value. In 2016, the average recycling rate of municipal waste of all EU countries was 45.3%, whereas in the Czech Republic, it was more than 10% less (33.6%). With this value, the Czech Republic was ranked among the best Eastern and Central European countries, but was still far behind leaders from Western Europe [1]. To improve the situation, legislation changes would certainly be needed, but

better understanding of who recycles could also be helpful. Based on foreign studies, it seems that there are significant differences in municipal waste generation and recycling performance between households and municipalities. To explain these distinctions, the description of the sociodemographic characteristics of producers could be used. Unfortunately, for the Czech Republic, as for the most of other foreign countries, there are no available data on waste production and waste producers on a household or individual level, and that is why the most commonly analyzed units are municipalities. The municipal level is still sufficiently homogeneous to capture differences and dispose of needed data.

There is broad range of studies explaining the production of recyclables in various countries. The selection of factors used for the explanation varies according to local conditions, data availability, units that are used in the analysis, as well as according to the consideration of particular researchers. In general, factors explaining the generation of recyclables are usually divided into two categories, individual and situational variables [2]. Among situational characteristics, waste management organization, logistics, and charging policy are included (e.g., References [3–6]). On the other hand, there is also a broad range of studies dealing with individual factors, such as socioeconomic or demographic factors (e.g., References [7–10]).

Based on foreign experience, it seems that the most important sociodemographic factors influencing or explaining the production of recyclables are average household size, age, gender, and attained education level. The goal of this paper is to contribute to this literature by empirically investigating the relations between selected sociodemographic determinants and waste recycling in the Czech Republic on a municipal level. This analysis covers the biggest possible sample of Czech municipalities with available data (more than 80% of all Czech municipalities), and is built on municipal data on recycling performance and on a number of possible sociodemographic influencing factors on a municipal level. To the best of the authors' knowledge, there is no similar study for the whole Czech Republic dealing with the recycling of municipal waste and its possible sociodemographic determinants. Much greater attention was focused so far on situational (especially organizational) characteristics. This analysis was further extended with spatial aspects of this relation. Data used for this analysis have a spatial character because they are connected with concrete spatial units, in this case, municipalities. That enables us to also consider geographical differences in the relation between sociodemographic factors and recycling rate because it seems possible that these relations are not spatially stable. This approach is new in analyzing municipal waste production in the Czech Republic.

There are several reasons why mainly focusing on sociodemographic variables can be particularly interesting for municipalities. First, data on sociodemographic characteristics are available for all municipalities with a maximum of ten years periodicity in the case of information from the population census (e.g., household size, dwellings characteristics, level of education). Basic data can be obtained for every year (e.g., age or gender), and municipalities can access and use them for planning. Considering the selected variables, new indicators reflecting the specificity of the consumer's decision-making process in the Czech Republic were used, e.g., purchasing power (presenting information on inhabitants' disposable income at the level of all territorial units), or heating methods in combination with energy origins used for heating. The second mentioned variable makes it possible to study dwellings that only rely on solid fuels. These variables not only influence the amount of generated municipal waste, but also its composition and, therefore, municipal waste treatment and management costs.

Second, the results can help municipal and national authorities to better aim policies and campaigns oriented to promote environmentally responsible behavior to particular population groups or regions that recycle less, and support the recycling performance of those who already have a higher recycling rate.

Third, finding a correlation between sociodemographic and recycling performance could also be useful for planning new infrastructure. If results are connected with population projections of particular municipalities or regions (infrastructure is better served mostly for bigger regions then just one municipality), the future production of various waste streams could be predicted.

The paper consists of four sections and is structured as follows. The first chapter describes the current state of knowledge in the research dealing with sociodemographic determinants and their influence on recyclable generation in developed countries, and shortly describes the waste management system in the Czech Republic. In the second chapter, the method and data used for this research are presented. The third chapter introduces the main results. In the last chapter, the research results are concluded, and possibilities for further research are presented.

1.1. Factors Influencing Recyclable Generation

In the case of municipal waste production as a whole, it seems that the most unambiguous characteristic is average household size. The average generation of municipal waste per person drops with a growing number of household members [11–14]. However, regarding recyclables, the situation does not seem that clear. Terry [15] and Martin, Williams, and Clark [16] discovered no statistically significant relation. Abbott, Nandeibam, and O'Shea [17] only found a significant relation between average household size and biowaste recycling. Jenkins et al. [18], D'Elia [19], and Gaeta, Ghinoi, and Silvestri [20] discovered a positive connection with recycling rate that could mean that bigger households, on average, recycle more than smaller ones.

Another regularly analyzed demographic characteristic is age or age distribution of municipalities' inhabitants. A problem of result comparability regarding this indicator arises because, in some cases, age is described as mean or median age, while in other cases, the percentage of people in particular age groups is taken into account, and age-group intervals differ among studies. Sidique, Joshi, and Lupi [21], and Tabernero et al. [22] found a positive correlation between recycling rate and age. Kipperberg [5] confirmed that age significantly influences the recycling of paper, glass, and metal. The explanation is ambiguous. On the one hand, older people are probably less used to recycling. On the other hand, they have lower opportunity costs than younger people [23]. Waste recycling can be quite time-consuming, and persons with high opportunity costs especially have to decide to which activities they dedicate their time. Sterner and Bartelings [9] also concluded that if waste sorting consumes a lot of time, people are less willing to do it, and they produce more residual municipal waste. Terry [15] discovered a higher recycling rate in the 25–44 age group. Gaeta, Ghinoi, and Silvestri [20] discovered a negative correlation between average age and waste recycling, which they explained as the complexity of waste recycling making it more likely to avoid among older people compared to younger people. Negative correlation with the percentage of the population over 64 years was also observed by Saladie [24]. D'Elia [19], Hage, and Söderholm [8], and Hage et al. [25] found no relation between recycling behavior and age.

Gender is another often-analyzed indicator. However, D'Elia [19], Hage, and Söderholm [8], Tabernero et al. [22], and Pikturniené and Bäumle [26] discovered no significant correlation with recycling behavior. This was also supported by the meta-analysis results of Schultz et al. [2]. To explain recyclable production, the number of persons mostly staying at home may be more important than their gender. Usually, women stay at home. According to Bach et al. [3], municipalities with higher percentages of housewives statistically produce, on average, less waste paper. Housewives are defined as "a male or female person who does domestic work for their own family without pay" (Reference [3], p. 70). The authors did not assume any direct causality, as the percentage of household members staying at home could serve as an indicator for social structure of every particular municipality. Similarly, Sterner and Bartelings [9] found that the number of people staying at home during a part of the day has a positive effect on composting, and these households also produce less municipal waste.

The education of waste producers could also be an important indicator to explain recycling behavior. Sidique, Joshi, and Lupi [21] proved that the higher the proportion of people who studied at the university for at least four years is, the higher the municipal recycling rate is. Miller et al. [27] also supported this conclusion. If the percentage of people who are 25 years and older with a bachelor's degree or higher increases by 1%, then recyclable tons increase by 0.7%. On a household level, Jenkins et al. [18] found a weak but significant influence of a person with the highest attained education

in the household on recycling rate. If this person's level of education increases from secondary to university, the probability of recycling 95% of produced aluminous waste would rise by 0.1%. In the case of paper, it would even be 1.5%. A similar conclusion was reached by Tabernero et al. [22], and by Pikturnienė and Bäumle [26]. Hage and Söderholm [8] presented contradictory results. According to their conclusions, plastic waste recycling rate decreases with attained education level. The authors explained this relation with higher opportunity costs of households with higher education. No statistically significant influence of education on waste sorting was detected Hage et al. [25], or by Šauer, Pařízková, and Hadrabová [28] for the Czech Republic.

Another possible explanatory variable according to the literature review could be the presence of children in the household. The relation to recycling rate is ambiguous here, too. Martin, Williams, and Clark [16] came to the conclusion that young childless occupants and families with children are more likely to be nonrecyclers. No relation was found by D'Elia [19].

The influence of population density on recycling was studied by Kipperberg [5], who found that its influence on sorting of metal, plastic, and biowaste was statistically significant and negative. His results were supported by Hage and Söderholm [8] in sorting plastics in Sweden. According to them, people living in densely populated areas accumulate, on average, 530 g less plastic packaging waste per person than people living in smaller and less densely populated localities. Hage and Söderholm [8] defined a densely populated city as a municipality with at least 800 residents per km^2. No significant relation between population density and recycling rate was found by Sidique, Joshi, and Lupi [21], or by Gaeta, Ghinoi, and Silvestri [20].

Income is another broadly considered variable that has to be often omitted because of data availability. A positive but nonsignificant relation between income and recycling rate was described by Terry [15]. Jenkins et al. [18] only discovered a significant positive relation in the case of sorting waste paper, and Gaeta, Ghinoi, and Silvestri [20] observed a highly significant positive correlation. According to Sidique, Joshi, and Lupi [21], the relation is entirely opposite. They estimated that a $1000 increase in income per person and year leads to a reduction of recycling rate by 0.2%. No or rather weak influence of income on generation of recyclables was observed by Abbott, Nandeibam and O'Shea [17], Mazzanti and Zoboli [23], Hockett, Lober and Pilgrim [29], Hage et al. [25], and Saladie [24].

The relation between sociodemographic (as well as other factors) and waste recycling was analyzed by various one- and multidimensional statistical methods, e.g., correlation analysis [12], simple linear regression (among other methods, Reference [7]), time-series analysis, and input–output analysis. However, the most commonly used method is multiple-regression analysis (e.g., References [7–9,13,14]). It is quite interesting that even though most of these studies are conducted on the municipal level, their authors do not consider the data's spatial dimension. Nevertheless, sociodemographic variables may be significantly correlated with spatial factors [30], and their influence on waste generation may differ in the space [31]. For example, education may be positively correlated with municipal waste generation in a spatial unit (e.g., municipality, region, or state) and negatively in another. In this case, the data show spatial nonstationarity that can misrepresent statistical method results that do not consider this aspect (e.g., multiple-regression analysis). The number of studies dealing with spatial variation in MSW data has been rather limited so far (e.g., References [31–33]).

1.2. Waste-Management System in the Czech Republic

In the Czech Republic, the development of waste-management legislation began in 1991. Since then, Czech legislation has been adapted to meet the standards and requirements of the European Union. Currently, the basic legal document in the field of waste management is Law no. 185/2001 Coll. on Waste. It was amended in 2014 [34].

Municipalities are the producers of municipal waste and have direct responsibility for the physical waste management in their territory. Each community creates a system of collection, removal, and other waste management that is usually embedded in a municipal ordinance. Financing the waste-management system is a mandatory expenditure of municipal budgets [35].

The municipal waste includes mixed municipal waste, its separated components (paper, plastic, glass, metal, and others), large-volume waste, and hazardous waste [36]. The per capita generation of municipal waste stagnated in the period of 2009–2015; since 2015, value has been increasing (Figure 1). The mixed municipal waste category is comprised of residual (unseparated) waste produced by households and nonmanufacturing business activities [36]. Its production has been declining since 2009, which can be regarded as a positive.

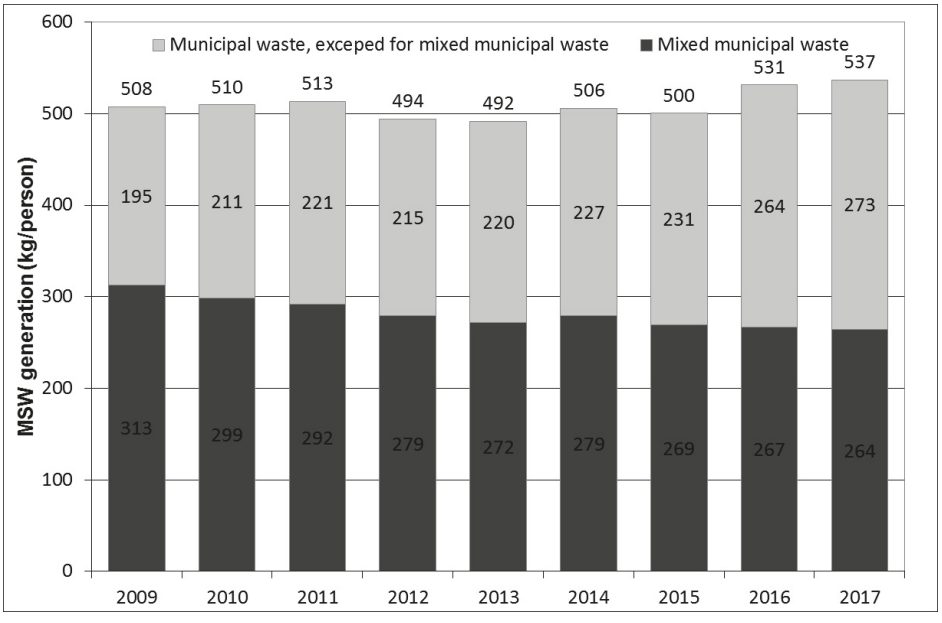

Figure 1. Production of municipal solid waste (kg per capita), Czech Republic (CR), 2009–2017. Source: ISOH (Waste Management Information System).

Czech municipalities have to separately collect hazardous waste, paper, glass, plastic, and, since 2015, metal and biowaste as well. It is up to each municipality to select a concrete collection method. It can choose between drop-off centers, large-volume containers, or curbside collection [37]. For recyclables, Czech municipalities mostly use drop-off collection [38].

To finance the waste-management system, most Czech municipalities use a local fee. The municipality is able to set a fee for individual taxpayers with regard to their waste production and the degree of sorting [35]. The law defines a maximal fee amount. Since 2013, this has been 1000 CZK per person and year (approximately €40). Before then, it was 500 CZK per person and year (approximately €20) [39]. In comparison with average monthly wages, the local fee is relatively low (see Figure 2).

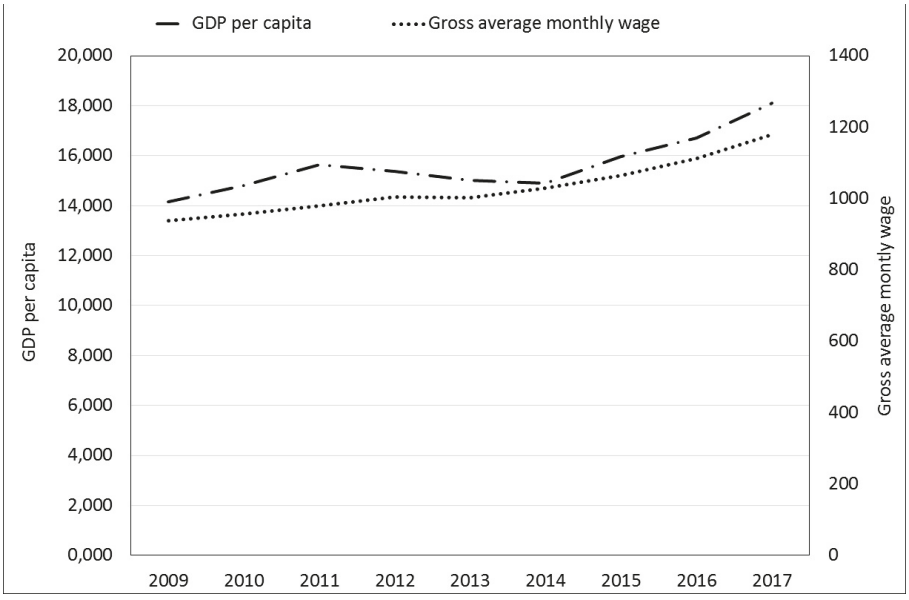

Figure 2. Gross Domestic Product (GDP) per capita and gross average monthly wage (in Euro), CR, 2009–2017. Source: Czech Statistical Office.

The most common method of municipal waste disposal in the Czech Republic is still landfilling, even though there has been a slight yearly decline in the proportion of landfilled municipal waste since 2009. Between 2009 and 2017, it fell from 64.0% to 45.5% [36]. However, this situation is still far from satisfactory. The aim of the state and the Ministry of the Environment is to decisively reduce the percentage of landfilled municipal waste and increase material and energy recovery in compliance with circular-economy principles and EU objectives [35].

2. Materials and Methods

Data preparation and analysis was done following the steps in the scheme below (Figure 3); particular working steps are further described in this section.

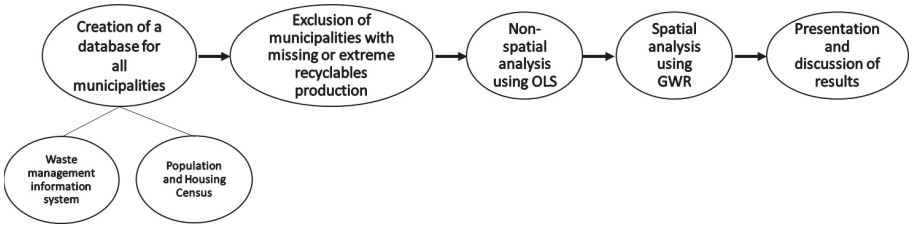

Figure 3. Working steps.

To create the needed database for analysis, two data sources were used, the Waste Management Information System, and the Population and Housing Census. We used the average production of recyclables per capita and year in kilograms as the dependent variable for nonspatial and spatial data analysis. Recyclable production was computed as the sum of separately collected paper, plastics, and glass. These three materials were selected because, in 2011, they were separately collected in all Czech municipalities, while other materials were not that widely separated, and that could lead to

higher differences in recycling rates between municipalities with and without the separated collection of other materials, which could subsequently bias the presented research results. The total production of recyclables in each municipality was divided by the number of its inhabitants to eliminate different population sizes of particular municipalities. The data used for the construction of the dependent variable were obtained from the Waste Management Information System (ISOH) database, operated by the Czech Environmental Information Agency (CENIA). Every waste producer has to report their production every year to the system if they satisfy the condition that they produce more than 100 kg hazardous or 100 tons nonhazardous waste per year [40]. This includes municipalities that are responsible for the generation of municipal waste in their territory.

After excluding municipalities with no reported data about their production or with extreme values, the sample consisted of 4897 municipalities from all Czech regions. The sample represents more than 80% of all Czech municipalities. The average production of recyclables in 2011 was 35 kg per capita (see Table 1). The table shows that the production of sorted waste streams broadly differs between municipalities. We explain these differences with sociodemographic determinants.

Table 1. Basic statistical characteristics for production of recyclables (kg per capita); CR, 2011.

	Minimum	Maximum	Mean	Std. Deviation
Recyclables	2.0	124.7	35.1	17.9

Source: ISOH.

The following map (Figure 4) shows the distribution of recyclable production on a municipal level. It is obvious that the production presents a mosaic of varying values, and it is difficult to find any pattern. In general, we can state that waste-sorting activities are more prevalent in the western half of the Czech state; in the vicinity of Brno (second-biggest Czech city, situated in the southeast), separated waste collection is lower.

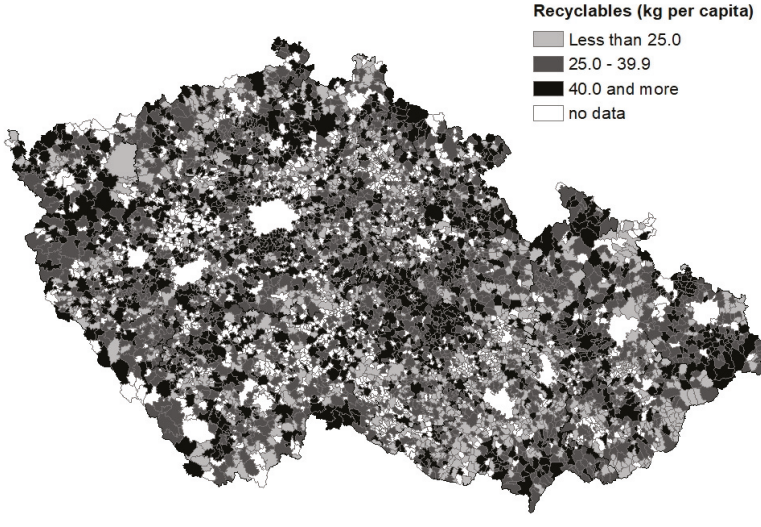

Figure 4. Production of recyclables in municipalities (kg per capita), CR, 2011. Source: ISOH.

To explain the production of recyclables, we selected 13 independent sociodemographic variables. Because some of these selected variables are not collected yearly by official statistics or any other institution, at least on the municipal level (e.g., household size or population structure according to attained level of education), we had to use the results from the Population and Housing census. In the

Czech Republic, the last census was organized by the Czech Statistical Office in 2011 [41]. That is why we could analyze the relationship between dependent and independent variables only for that year.

As explaining variables, we used the following indicators:

- average household size in the municipality (HHS),
- percentage of households with children from all households in the municipality (Child),
- percentage of population with secondary education from all inhabitants 15 years old and older in the municipality (Sec),
- percentage of population with tertiary education from all inhabitants 15 years old and older in the municipality (Ter),
- percentage of family houses in municipality from all dwellings in the municipality (Famh),
- percentage of flats with solid fuel heating system from all flats in the municipality (Heat),
- percentage of population aged 65 or more from all inhabitants in the municipality (Age65),
- median age,
- sex ratio as number of males per 100 females in the population of the municipality (IMA),
- percentage of unemployed in the 15–64-year age group in the municipality (Unempl),
- population density of the municipality (Popden),
- purchasing power per person in € in the municipality (PPP), and
- percentage of people employed in agriculture in the municipality (Agric).

Independent variables HHS, Child, Sec, Ter, Famh, Heat, Age65, IMA, and Agric were obtained from the population census carried out by the Czech Statistical Office in 2011. Unempl and Popden were added from official records, also compiled by the Czech Statistical Office. The PPP variable was obtained from company INCOMA GfK. For Czech municipalities, there are no data on average household income that could be used for analysis. The PPP indicator was used as an appropriate estimator for differences in income level among Czech municipalities [42]. Therefore, the missing data on average income should not bias the presented results. The following table (Table 2) presents basic statistical characteristics of used sociodemographic indicators.

Table 2. Basic statistical characteristics for selected sociodemographic indicators, CR, 2011.

	Minimum	Maximum	Mean	Std. Deviation
HHS	1.3	3.5	2.6	0.2
Child	0.0	54.0	28.5	5.5
Sec	38.0	85.0	68.7	4.5
Ter	0.0	35.0	8.9	4.4
Famh	0.0	100.0	83.0	17.7
Heat	0.0	100.0	43.4	26.8
Age65	2.0	43.0	15.7	3.9
Medage	30.0	56.0	40.4	2.5
IMA	52.1	781.8	101.2	17.3
Unempl	0.0	30.0	7.3	3.3
Popden	1.5	2447.4	99.6	143.3
PPP	4619.9	9154.2	6767.8	557.5
Agric	0.0	23.8	3.3	2.7

Source: Czech Statistical Office, INCOMA GfK.

2.1. Nonspatial Analysis

To analyze the influence of sociodemographic determinants on the production of recyclables in municipalities, multiple linear regression was used. This method represents the group of global methods that do not consider the spatial dimension of the analyzed data. The used model can be described with following form:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \ldots + \beta_k X_{ki} + \varepsilon_i \quad (1)$$

where Y_i are observations of dependent variables, $X_{1i}, X_{2i}, \ldots, X_{ki}$ are observations of independent variables, $\beta_0, \beta_1, \ldots, \beta_k$ are underlying regression coefficients, and ε_i are random errors. Studied data using linear regression have to fulfill assumptions of independence from random errors, identically distributed normal random variables with zero expectations, and constant variance σ^2. Stability of error variability was tested with the Glejser test, and its normality via the Kolmogorov–Smirnov test. Linearity was examined using a scatterplot between standardized predicted values and standardized residuals [14].

To estimate regression parameters, we used the standard ordinary least-squares method (OLS) that was already used by other authors in reviewed studies (e.g., References [3,8,14]). To obtain a model with only statistically significant covariates, we used stepwise regression, and backward selection with alpha for removing variables equal to 0.1 (i.e., no independent variable with p-value greater than 0.1 remained in the model [43]). The model was computed using IBM SPSS 20 program package.

2.2. Spatial Analysis

To test if the data were spatially stationary, we used Koenker's studentized Breusch–Pagan statistics. A significant result of this test indicates that there is statistically significant heteroscedasticity and/or nonstationarity in the data. Based on the results from Koenker's statistics, we computed geographically weighted regression (GWR). In the case that there was a possibility that the relation between dependent and independent variables differed over geographical space, we could use GWR to explore local relations by moving the spatial kernel through study area. Kernel functions are used to calculate weights that represent spatial dependence between observations. So, unlike OLS, GWR gives us so-called local coefficients β that are specific for each areal unit [26]. For each model calibration location, $i = 1, \ldots, n$, the GWR model is:

$$Y_i = \beta_{i0} + \Sigma \beta_{ik} X_{ik} + \varepsilon_i \quad (2)$$

where

Y_i is the dependent variable value at location i,
X_{ik} is the value of the kth covariate at location i,
β_{i0} is the intercept,
β_{ik} is the regression coefficient for the kth covariate,
p is the number of regression terms, and
ε_i is the random error at location i [44].

The GWR model was computed using the ArcGIS program.

3. Results and Discussion

3.1. Results of Nonspatial Analysis

The resulting regression model computed with OLS consists of only six from the original 13 variables (Table 3). The other seven variables do not help significantly increase the explained variability, and were therefore not included in the resulting model. These are: percentage of households with children, percentage of population with secondary education, percentage of flats with solid fuel heating system, percentage of population aged 65 or more, percentage of unemployed, and population density.

From the significant variables, five were significant on a 1% significance level: average household size, proportion of tertiary-educated inhabitants, proportion of family houses, purchasing power, and proportion of inhabitants employed in agriculture. Sex ratio was significant on a 5% level. Overall, the model is statistically significant, but only explains 9% of the intermunicipal data variability.

Table 3. Ordinary least-squares (OLS) results for production of recyclables, CR, 2011.

	Beta
Constant	46.900
HHS	−10.801 ***
TER	0.456 ***
Famh	−0.130 ***
PPP	0.004 ***
Agric	0.313 ***
IMA	−0.030 **
N	4897
R^2	0.087

, *: statistical significance at 5%, respectively, 1%. Source: own computations.

The most important variable influencing the production of recyclables is average household size. A one-person increase in household size leads to a reduction in the average production of separated waste by 11 kg. Bigger households produce, on average, less recyclable waste per person than smaller ones. This could be caused by fewer sorting activities, but this relation is also obvious regarding the production of all municipal waste (e.g., Reference [7]). Households use products regardless of size, e.g., food, newspaper, packaging, or other kinds of consumer goods [12–14]. Information on the relation between household size and recyclable production is important to municipal governments because of the management of container sizes. Over the last few decades, the average household size in the Czech Republic has been steadily decreasing, and this development will probably continue into the future. It is, therefore, justified to expect that smaller households produce more waste.

Lower production of recyclables is also connected with municipalities with a higher percentage of family houses and a higher share of men in the population. The relation between recycling performance and the proportion of family houses in the municipality is unclear because it could be assumed that in family houses, there is more space for recycling. On the other hand, it is possible that its inhabitants are able to otherwise dispose of some portion of waste (composting or waste-paper burning).

Regarding differences in recycling rates between genders, the results observed by Schultz et al. [2] supported that recycling activities are more typical in women than men. This means, in this case, that municipalities with a lower sex ratio collect higher amounts of recyclables. Proenvironmental behavior is more often connected with women.

On the contrary, a higher production of sorted waste streams is connected with a higher share of tertiary-educated inhabitants, with higher proportion of inhabitants employed in agriculture and also with higher purchasing power. Results presented here support the conclusions of Sidique, Joshi, and Lupi [21], Miller et al. [27], and Jenkins et al. [18] on the relationship between education and waste separation. A 1% increase of the proportion of tertiary-educated inhabitants in the municipality leads to an increase in recycling of 0.5 kg per person. This relationship was only confirmed for tertiary education, while secondary education has no significant impact on recycling. It could be assumed that more-educated people have better access to information, are more aware of environmental problems, and are therefore also more likely to be more concerned of the negative impact of their own behavior on the environment [45].

Purchasing power was in this case considered an estimator of household income, and the presented results therefore support the conclusions of Terry [15], Jenkins et al. [18], and Gaeta, Ghinoi, and Silvestri [20] that people with higher income recycle more. In the Czech Republic, income is also correlated with education, so the results are in agreement with the above-mentioned relationship between level of education and recycling.

In accordance with the results of studies by D'Elia [19], and Hage and Söderholm [8], age has no significant effect on waste sorting. Using the variable percentage of the population aged 65 or more and the median age, it was not possible to prove that younger people recycle more than older people or vice versa. No influence was also found in the case of household percentage with children,

even though it could be expected that children could bring home the learned behavior they obtain at school, as a lot of proenvironmental campaigns focus on schools [38].

Population density also does not influence the recycling rate, which means that, in general, there is no difference in recycling performance between bigger cities, mostly with higher population density, and smaller municipalities with lower values of this indicator. There is also no impact of unemployment that could imply that employed and unemployed people differ in their recycling activities.

The last nonsignificant characteristic was the percentage of flats with a solid fuel heating system. These results could be seen as a positive, because it could have been expected that people inhabiting flats with solid fuel heating systems could burn part of their waste (especially paper and plastics) at home, but the presented results do not show such a trend.

3.2. Results of Spatial Analysis

Further, in order to analyze if the influence of the three most important sociodemographic variables (average household size, percentage of population with tertiary education, and percentage of family houses) is spatially stable, Koenker's studentized Breusch–Pagan statistics were computed. The result of this test was statistically significant, which indicates heteroscedasticity and/or nonstationarity. Therefore, GWR application is justified.

The GWR model explains 33% of intermunicipal variation in the production of recyclables. Local R^2 distribution for the analyzed municipalities varied from 0% to 86%, as is depicted in the following map (Figure 5). Significant spatial nonstationarity regarding the influence of the three selected independent variables on waste sorting was detected. Such a result means that the relation to recyclable production spatially differs, but it is also possible to detect regions with similar patterns of sorting behavior. It is interesting that the local R^2 does not correlate with municipality population size. Demographic variables, therefore, do not better explain the situation in smaller cities than in bigger cities, or vice versa.

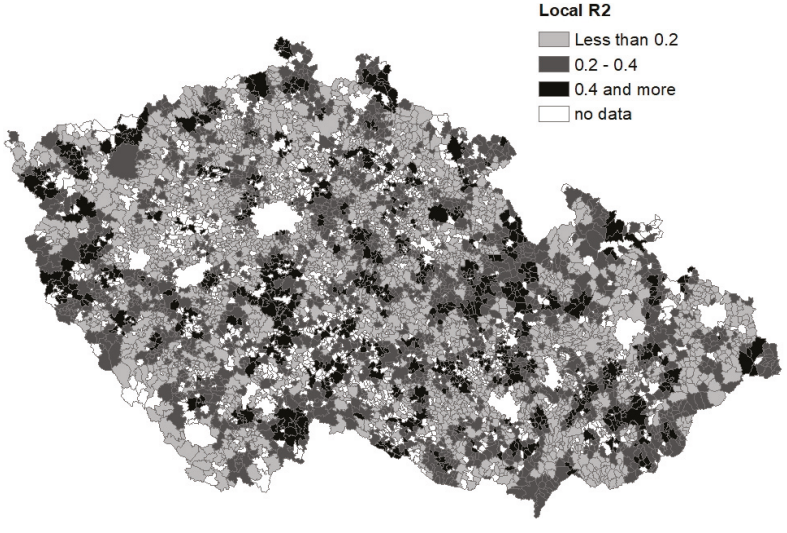

Figure 5. Local R^2 distribution for geographically weighted regression (GWR) model, CR, 2011. Source: own computations.

Regarding all three variables on the global level, the author came to the conclusion that their relation to production of recyclables is explicitly positive or negative. However, in all three cases, on the local level the relation is ambiguous. On the local level, 55% of analyzed municipalities show negative coefficient estimates for household size, on the contrary, in 45% of municipalities the

coefficient is positive. In the case of tertiary education, on the local level 65% of all coefficient estimates are positive and 35% negative. Regarding the family houses, there are 73% of municipalities with negative coefficients and 27% with positive.

4. Conclusions

The aim of this article was to evaluate the impact of sociodemographic characteristics on the production of recyclables, and what trends can be expected due to further demographic development. In the Czech Republic, there are no available data on the level of individuals or households, so analysis was carried out on the municipality level. This approach, of course, leads to some simplifications in assessing population behavior regarding environmental behavior, but in this case, it was the only option for statistical analysis, and has already been used in a number of other studies (e.g., References [7,8,14]).

Based on the reviewed studies, 13 sociodemographic variables were created that could help explain the intermunicipal variability of produced recyclables. For analysis, the multiple linear-regression method was first used. The resulting model explains less than 9% of the variability in the production of separated waste. This means that there are still other factors that have a greater influence on the production of analyzed types of waste (e.g., economic and political instruments, internal convictions). Nevertheless, it was proven that the impact of sociodemographic characteristics is statistically significant and cannot be neglected.

From the 13 selected independent variables analyzed, only six were statistically significant: average household size, proportion of tertiary educated inhabitants, proportion of family houses, purchasing power, proportion of inhabitants employed in agriculture, and sex ratio. It was not confirmed whether age has any impact on waste recycling. In accordance with foreign studies, the most important sociodemographic variable was average household size; as household size increases, the average production of recyclables decreases. Over the last few decades, it has been possible to see a decrease in average household size and an increase in the number of households in the Czech society. This trend can be expected to continue into the future. For waste management, including recyclable production, this long-term trend may mean an increase in average waste production per person, and there may be an overall increase in the volume of waste production because the Czech Republic still has a stable or even slightly growing number of inhabitants.

The presented results can help municipalities understand who recycles more, and which groups so far have mostly been nonrecyclers and should be targeted by campaigns promoting proenvironmental behavior, including municipal waste recycling.

Further, the three most important significant sociodemographic variables (average household size, percentage of population with tertiary education, and percentage of family houses) according to the linear-regression analysis results were selected, and used for analysis with geographically weighted regression. This method helped increase the explained variability, but showed that the influence of selected variables is not spatially stable, and the coefficients for a particular variable could have negative as well as positive values in different municipalities. This situation could diminish the detected variability explained by OLS and lead to neglecting the sociodemographic aspect in decision-making. This conclusion about spatial nonstationarity is important for waste-management planning as well, because it supports the application of the subsidiarity principle in the practice. Even though the objectives of waste-management policy are given at the national level, many decisions are made at the local level by local representatives who know the particular situation in their municipality or region best. The results of our study show that this approach is appropriate, and that there is no simple way of predicting municipal recycling performance based on results and experiences from other administrative units.

Even though this paper considered a broad range of sociodemographic variables, further study of the factors influencing recycling performance in the Czech Republic is needed. Several selected indicators were found significant in explaining differences between municipalities, which is why the

next step should be focusing on underlying psychological drivers, such as social norms, environmental attitudes, and other behavioral factors. To obtain such information, it is necessary to carry out research among inhabitants as waste producers and recyclers. A deeper understanding of spatial variability would also demand further research. It is possible that spatial nonstationarity is also caused by organizational factors of waste collection, but the data on this topic are also currently unavailable. It is also interesting to see the connection of the presented results with population projection. This approach would make sense for particular regions that are planning to build new waste management facilities and can estimate their future recyclable production.

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The Effect of Ideology on Attitudes toward GM Food Safety among Chinese Internet Users

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Abstract: This study explores the causal relationship between Internet users' ideologies and their corresponding attitudes to genetically modified (GM) food safety. Using the 2015 Chinese Internet User Survey data (N = 3780) as a representative sample of Internet users from China, the study investigates factors influencing people's attitudes to GM food safety. Multinomial Logistic Regression Models are applied to examine the effects of demographic features (gender, age, education, family annual income, location, CPC membership, and occupation) and ideological factors (general ideology, political ideology, economic ideology, and cultural ideology) on attitudes to GM food safety. The results demonstrate that the percentage of people whose attitude is that "GM food is risky" (35.1%) surpasses those who think "GM food is safe" (20.4%). The young generation respondents think that GM food is safe, while those with higher levels of income and education are more inclined to view GM food as risky. In addition, public sector employees tend to think that GM food is risky. Respondents characterized with right-wing ideology in general tend to regard GM food as safe, compared to left-wing ideologists. However, their attitude varies in different ideological dimensions of politics, economics, and culture. This paper contributes new insights into understanding ideological influences on science development and sustainability.

Keywords: food safety; GM food; ideology; politics; economics; culture

1. Introduction

Genetic engineering is one of the most powerful 21st century technologies. In 1985, the genes from Bt (Bacillus thuringiensis) were inserted into the genetic sequences of tobacco plants, in order to make the plants insect-tolerant [1]. Gradually, several Bt genes were engineered and subsequently approved for use in crops like cotton, corn, mustard, and rice. These crops were then labelled as genetically modified (GM) foods [2,3].

The world's population is predicted to reach 10 billion by 2050. Therefore, increased yields will be needed to feed the increasing population, if a sustainable world is to be achieved. The goal of increased yields was considered to be the prime application when GM technology was first introduced [1,3–5]. It is estimated that, on average, between 15% and 20% of crop yield could be lost to animal pests worldwide. However, the actual losses caused by these pests were reduced to approximately 10%, because of the introduction of pest control measures [6]. However, in developing countries, the adverse effects of synthetic insecticides (particularly to human health) are still quite common, due to the use of older forms of chemistries, as well as laxity in the preparation, application, storage, and disposal of chemicals [7]. Today, GM technology enables crops to produce insecticidal proteins, which offers a means to control insects without the potential harmful effects caused by the misuse of synthetic insecticides [8]. Furthermore, GM technology can directly improve crop yields by accelerating growth rates, or increasing the size of the crop plant [1].

However, GM technology is also the subject of heated debate in relation to its effects on the environment and public health [2]. Some insist that GM technology could help address some of

the major challenges to agriculture-based economies created by climate change, relieve the starving population, reduce energy and chemical inputs, and deliver more profits to farmers, which in turn, would contribute to the sustainable development of the human world [3,8–11]. Others, however, worry that GM technology could contaminate the environment, destroy ecological balances, exert side-effects on human health, and ultimately jeopardize the sustainable development of humanity [9,12,13].

The GM debate among consumers has been consistently presented as being contentious [14], and further characterised as being polarised into two main groups—those who are pro-GM and those who are anti-GM [15]. Consumer surveys regarding the acceptance of GM foods have been conducted in the EU and the U.S. since the early 1990s. The 2005 Eurobarometer survey shows that "GM food is widely seen as not being useful, as morally unacceptable and as a risk to society" [16]. In 2018, the International Food Information Council Foundation (IFIC) surveys found that nearly half of U.S. consumers avoid GM foods. A large majority of Americans say they oppose GM foods primarily because they are concerned about the human health impacts [17]. In Italy, Harrison et al. [18] reported that approximately half of Italian people do not consider GM foods to be ethically acceptable. The study found that Italian consumers are more sensitive to the potential risks that GM food may pose to human health and the environment, even compared to U.S. consumers. In China, researchers have conducted surveys to gauge the level of public awareness and acceptance of GM foods. For instance, Lv and Ma [19] conducted a series of surveys entitled "Chinese Public and Biotechnology"; the surveys were conducted in 2003, 2006, and 2009. The level of public awareness of GM foods was low in 2003 (16%), moderate in 2006 (57%), and high in 2009 (90%). Huang et al. [20] verified that two-thirds of urban residents have heard of GM foods. Huang and Peng [21] reports that the percentage of consumers who perceived GM food as unsafe for consumption increased by more than 30% in the 2002–2012 period. They explained that consumers' attitudes were changing because of the increasing influence of negative media reports in recent years regarding GM technology.

Having the largest population (but a relatively limited quantity of arable land), China intends to use GM technology to improve agricultural productivity [22]. China has developed effective plant genetic transformation systems and established several national centres for plant genome research and GM crop testing [22]. In 2008, in addition to several national and provincial investments in agricultural biotechnology research projects (such as the "863" program and "973" program), a much larger government program was launched. This project aims to commercialize Chinese genetically engineered crops and livestock species and has a budget of CNY24 billion (US$3.8 billion) over 12 years [10]. In 2009, China became the first country in the world to approve insect-resistant rice and high-phytase maize as safe for consumption and production [10,22].

However, in late 2008, in China, milk suppliers were discovered adding melamine to artificially boost the milk's protein readings. This practice resulted in nearly 300,000 infants becoming sick, and six died, dramatically arousing the public's awareness of food safety issues [23]. China's decision to commercialize GM products even after the milk-tampering scandal may have induced an increase in opposition to GM-related activities [21]. Those opposing GM foods launched a series of anti-GM initiatives in the public media, and especially on the Internet, starting in early-2010 [21]. Further, GM food safety became one of the top 10 concerns in the Chinese consumer sector in 2013, and was listed among the top 10 keywords during the NPC (National People's Congress) & CPPCC (Chinese People's Political Consultative Conference) in 2014 [24]. In addition, in September 2013, a sensational debate—held on the Internet—over GM food safety was ignited. The main participants in the debate were Fang Zhouzi, who is an Internet celebrity and who supports GM food, and Cui Yongyuan, who is a well-known former CCTV (China Central Television) host who opposes GM food [25]. Subsequently, thousands of millions of bloggers, blog followers, and other Internet users participated in the GM food debate.

As of December 2017, the number of Internet users in China had reached 772 million [26], meaning that 55.8% of the Chinese population were Internet users. Meanwhile, in 2017, the number of Chinese E-commerce customers reached 533 million, generating a total online transaction of CNY29.16 trillion

(US$4.23 trillion) [27]. E-supermarket is one of the flagship stores of E-commerce giants (i.e., JD, Taobao, and Suning), and, on each single day, thousands of millions of food and drink items are listed for sale. Internet users including E-commerce customers, therefore, are the primary debaters, arguing online about the safety of GM foods in China.

Research into consumer attitudes to GM food has demonstrated that consumer acceptance is driven not only by perceptions of potential personal benefits and health effects [21], but also by concerns and beliefs, such as ethical, moral, and political considerations [10,28,29]. As it is the overall responsibility of the government to ensure food safety, their behaviour is very important to the development of public opinion about the GM food safety network. Many studies have pointed out that government policies [10,22], official behaviours [10], and administrative statements [24] could trigger intense discussion on GM food safety. For instance, in China, the massive amount of money being invested in the commercialization of GM products clearly indicates that the Chinese government is pro-GM food. In spite of this, the spike in the Internet activities of those who oppose GM foods is inconceivable when one considers the ideological administration in China.

In China, administrative politics are guided by socialist ideology, venerating Marxism-Leninism. (It is written in the very beginning of the Constitution of the Communist Party of China, which states that "The Communist Party of China uses Marxism–Leninism, Mao Zedong Thought, Deng Xiaoping Theory, the Theory of Three Represents, the Scientific Outlook on Development, and Xi Jinping Thought on Socialism with Chinese Characteristics for a New Era as its guides to action".) [30]. According to socio-psychological theories, ideology is one of the most important factors that reflect people's values and perceptions of policy and politics [31]. In political science, ideology is traditionally divided dichotomously; that is, into two groups, usually called "left vs. right", or "conservative vs. liberal" [32,33]. Although certain distinct, well-acknowledged core aspects of left-right distinctions have been identified [33–35], in different societies, "left" and "right" carry meanings that vary in political, economic, and cultural conditions [36]. For example, Carney et al. [37] reviewed many studies on ideology and found that, in personal traits, left-wing ideologists in Western countries are usually open-minded, creative, desirous of novelty, uncontrolled, and imaginative. In contrast, right-wing ideologists tend to be nationalist, and in favour of a strong state.

In China, the debate between left and right ideologies was historically a sensitive core issue of political life, and in reality, Chinese administrative politics are generally considered to be left-wing ideology in nature [38]. In recent years, social science researchers have applied methods of multidisciplinary studies, such as literature reviews or questionnaire surveys, to analyse the status quo of left-right ideology in contemporary China [39,40]. For example, based on a national online survey, Pan and Xu [41] categorized Chinese ideologies into three dimensions, namely political, socio-economic, and nationalistic ideologies. Similarly, Le and Yang [42] categorized Chinese ideologies into three dimensions according to their Internet survey findings, which are political, cultural, and economic ideologies. These researchers found that there are clear left-right ideological preferences among Chinese Internet users.

As is well acknowledged by the Chinese government and academic scholars, online opinions are the source, hub and leading guide of public opinion for the whole of society [43,44]. A large volume of research has proved that online public opinion can exert significant influence over legislation, law enforcement, public administration, medical treatment, and environmental conservation [45–47]. If we look back in history, all too often we find that scientific progress and innovation have been blocked by ideologies [48].

Accordingly, with the extremely large number of Internet users who are willing to express their attitude towards GM food safety, public opinion could certainly be swayed, particularly with general regard to GM food safety in China. In the present study, we apply previous findings of left-right ideologies and define the left ideology in China as indicating people who support "state power in politics, more government involvement in economics, and traditional Chinese culture"; while conversely, the right ideology in China prefers "individual rights and freedom, less government

involvement in economics, and western culture". This study aims to examine if there are cause-effect relationships (in terms of Internet users) between ideologies and attitudes towards GM food safety in China. Specifically, three dimensions of ideology (political, economic, and cultural ideologies) are applied to investigate such relationships.

2. Materials and Methods

2.1. Data Collection

We used an open database, the "2015 Chinese Internet User Survey" data to examine the cause-effect relationship between Internet users' ideology and their attitude towards GM food safety. The database is part of the Chinese National Survey Data Archive, and is released by the Chinese General Social Survey Organization. Survey questionnaires were designed in Chinese [49,50]. In 2015, the survey was distributed through "Wen-juan" web (www.wenjuan.com) and Sina Weibo from July to August, 2015. Wen-juan web is a professional website for distributing academic and empirical surveys. Sina Weibo is the most popular microblog platform and online public opinion battlefield in China. People who access these two websites are considered to be active opinion givers on the Internet [50]. The reliability of answers to the survey was controlled by the following measures: (1) each IP address could only submit the questionnaire once; (2) the time taken to answer each questionnaire was calculated, and answers that took less than eight minutes were disregarded; (3) determining the truthfulness of answers was done by asking "How truthful were you when filling out the questionnaire?". Ultimately, 3780 valid responses were collected. The reported truthfulness of answers was measured using ten categories, from 1 (low) to 10 (high). In this case, 69.0% of respondents reported a score of "10", 26.2% reported "9" or "8", and the remaining 2.5% reported scores of "7 to 1". The respondents come from 32 out of 34 provincial regions in China (no responses were received from Tibet and Macao). In addition, 0.8% of the responses came from overseas (see Appendix A).

2.2. Measurements

2.2.1. Dependent Variable

Attitude to GM food safety was used as the dependent variable. In the survey, the question was asked as "regarding GM food, some people think it is risky, yet others believe it is safe. What is your opinion?". The question had three possible answers: risky, safe, and don't know (hereafter, 'DK').

2.2.2. Explanatory Variables

Previous studies have shown that demographic features are related to attitude towards GM food safety [9,21]. In the present study, demographic features were used as explanatory variables. For gender, male was coded as "1", and female was "0". For CPC membership, CPC member was coded as "1", and non-CPC member was "0". Age was a continuous variable ranging from 13 to 87 years old. The variable of education was measured by eight categories, ranging from less than primary school to graduate school. We recoded the education variable in five categories, with "1" representing less than primary school, "2" representing primary or secondary school, "3" as high school, "4" as undergraduate school, and "5" as graduate school. The variable of family annual income was measured by 12 categories, ranging from 0 to above two million CNY. We recoded it into five categories according to the 2015 real GDP per capita, which was CNY50,251 (US$8211) [51], with "1" representing 0 to 40,000, "2" representing 40,000 above to 100,000, "3" as 100,000 above to 200,000, "4" as 200,000 above to 500,000, and "5" as above 500,000.

The variable of occupation is measured by 21 detailed items. According to the traditional division standard of the employment market in China, we recoded those 21 types of occupations into two categories: occupations in the public sector, and those in the non-public sector. Occupations in the public sector include bureaucrats, soldiers, state-owned enterprise employees, teachers, researchers,

students, public hospital doctors, staff in CPC branch organizations (such as the Women's Federation, the Youth League, etc.) and journalists [52]. (Schools, research institutes, public hospitals, and the press (all traditional media and their news media branch) are owned by the government in China. Salaries of employees in these sectors are financed by national or provincial governments. Appointment of leaders in these sectors is also controlled by the governments.) Accordingly, occupations in the non-public sector include farmers, five types of private entrepreneurs and employees, lawyers, entertainment industry workers, NGO staff members, freelancers, the unemployed, and others. The variable of location was divided into six categories, i.e., village, town, small city, medium-sized city, large city, and overseas.

For variables of ideology, the present study uses a series of questions in the survey concerning the fundamental issues of politics, economics, and culture in contemporary China. Political ideology was investigated via 17 questions (P1–P17). Specifically, people who prefer social equality, sovereignty, nationalism, authoritarianism, Marxism-Leninism and socialism, and Maoists were identified as having a left-wing ideology. Economic ideology was investigated using four questions (E1–E4). People who prefer government involvement in markets, state ownership and control over property and other vital economic domains were identified as having a left-wing ideology. Cultural ideology was investigated via four questions (C1–C4). People who prefer traditional Chinese culture, while opposing premarital sex and homosexuality, were identified as having a left-wing ideology. General ideology was investigated by the results of these three dimensions of ideology. Answers to those three dimensions of ideology and the general ideology were assigned as the average value of answers to the related questions. For example, answer values with regard to political ideology were the average value of answers to those 17 questions (P1–P17).

The method of a five-point Likert scale was applied to measure respondents' opinions toward questions of ideology, from "strongly agree" (coded as "1") to "strongly disagree" (coded as "5). The code of "6" represents "don't know" answers and was recorded as a missing value. Accordingly, the total number of respondents in the descriptive analysis was less than 3780. In the process of regression analysis, to reduce the loss of respondents' information, we applied the method of "linear trend at the point" to substitute missing values, and thus, the number of respondents was 3780. We conducted the test of reliability of attitude towards GM food safety and three ideological dimensions. The Cronbach's α value was 0.636 (N = 3780), indicating an acceptable model fit.

2.3. Data Analysis Strategy

Logistic regression models were applied to analyse the cause-effect relationships between attitudes towards GM food safety and ideology. Tests of model assumptions were conducted using the Multinomial Logistic Regression Model. The analysis was processed by IBM SPSS 23.

3. Results

A total of 3780 respondents were used for analysis. Results of the descriptive analysis and regression analysis are presented in this section.

3.1. Descriptive Analysis

3.1.1. Demographic Features

Descriptive analyses of respondents' demographic characteristics and ideology are presented in Table 1. Out of all 3780 respondents, 35.1% thought GM food was risky, 20.4% thought GM food was safe, and 44.5% answered "DK". The age of respondents ranged from 13 to 87 years old (M = 34.15, SD = 10.84). For gender distribution, 2643 (69.9%) were male, and 1137 (30.1%) were female. Regarding CPC membership, 972 respondents (25.7%) were CPC members, compared to 2808 (74.3%) non-CPC members. In terms of annual family income, 812 families (21.5%) earned no more than CNY40,000; 1118 families (29.6%) earned CNY40,000 to 100,000; 1052 families (27.8%) earned CNY100,000 to

200,000; 586 families (15.5%) earned CNY200,000 to 500,000, and 212 families (5.6%) earned more than CNY500,000. For the variable of occupation, 1531 respondents (40.5%) were public sector employees, and 2249 (59.5%) of them were non-public sector employees. Regarding location, almost half of the respondents were living in large cities (48.8%), compared to 6.7% who lived in a town or village. Regarding education, only 3.0% of respondents were below the level of secondary school, while the majority (67.8%) had undergraduate diplomas.

Table 1. Descriptive analysis of attitudes to GM food safety and ideology.

	Frequency (*N*)			**Percent (%)**	
Attitude towards GM Food Safety					
Risk	1325			35.1	
Safe	772			20.4	
DK	1683			44.5	
Gender					
Male	2643			69.9	
Female	1137			30.1	
CPC Membership					
Yes	972			25.7	
No	2808			74.3	
Annul Family Income (CNY)					
<40,000	812			21.5	
40,000 to 100,000	1118			29.6	
100,000 to 200,000	1052			27.8	
200,000 to 500,000	586			15.5	
>500,000	212			5.6	
Occupation					
Public sector	1531			40.5	
Non-public sector	2249			59.5	
Location					
Village	117			3.1	
Town	135			3.6	
Small city	667			17.6	
Medium-sized city	987			26.1	
Large city	1843			48.8	
Overseas	31			0.8	
Education					
Less than primary school	5			0.1	
Primary or secondary school	111			2.9	
High school	346			9.2	
Undergraduate school	2562			67.8	
Graduate school	756			20	
	N	***Mean***	***SD***	***Min.***	***Max.***
Age	3780	34.15	10.84	13	87
Political Ideology	3780	3.42	0.91	1.12	5
P1 Individual's benefit must subordinate to the state's.	3743	3.28	1.34	1	5
P2 Territorial and trade conflicts are provoked by other countries.	3595	3.18	1.16	1	5
P3 The central government should get Taiwan back by force if necessary.	3729	3.64	1.37	1	5
P4 Patriots must boycott Japanese goods.	3761	3.92	1.22	1	5

Table 1. *Cont.*

P5 Hostile forces abroad, which account for most of China's troubles, want to subvert China.	3703	3.47	1.39	1	5
P6 China should be tough on territorial disputes.	3681	2.86	1.2	1	5
P7 No criticism of China by teachers should be allowed in class.	3753	3.81	1.24	1	5
P8 Free speech, association and demonstration should be controlled.	3764	4.18	0.94	1	5
P9 Press censorship is necessary.	3759	3.48	1.35	1	5
P10 We should narrow the gap of wealth and build a society of equal rights for everyone.	3761	1.92	0.98	1	5
P11 I feel solemn when the national flag is raised.	3683	2.48	1.18	1	5
P12 Sovereignty outweighs human rights.	3727	3.85	1.11	1	5
P13 Mao's great contribution overshadows his errors.	3727	3.64	1.32	1	5
P14 There is no such thing as universal values such as freedom, democracy and human rights.	3708	3.72	1.26	1	5
P15 China should not implement electoral democracy, because it's a fake democracy.	3715	3.9	1.09	1	5
P16 China should adhere to Maoism and socialism.	3693	3.35	1.39	1	5
P17 We should harshly punish those who challenge authority.	3742	3.4	1.34	1	5
Economic Ideology	3780	3.18	0.63	1	5
E1 Land-related property rights should be owned by the state or collectives, not individuals.	3679	3.81	1.09	1	5
E2 Businesses related to national security and any other vital economic domains must be run by a state-owned company.	3719	3.39	1.23	1	5
E3 It's much better for the government to intervene more in the market.	3733	3.7	1.04	1	5
E4 The government should guarantee basic living standards for low-income citizens.	3761	1.83	0.83	1	5
Cultural Ideology	3780	3.39	0.62	1	5
C1 We should respect Confucian culture and Chinese conventions.	3750	2.71	1.09	1	5
C2 Homosexual marriage should not be protected by law in the same way as heterosexual marriage.	3731	3.65	1.08	1	5
C3 No premarital sex should be allowed.	3748	3.45	1.12	1	5
C4 I trust the Eight Diagrams & Feng-shui.	3697	3.75	1.01	1	5
General Ideology	3780	3.33	0.59	1.58	5

Notes: *SD* = Standard Deviation.

3.1.2. Characteristics of Ideology

Variables of general ideology, political, economic, and cultural ideologies are continuous variables. As displayed in Table 1, the general ideology variable has a mean value of 3.33 (*SD* = 0.59), indicating that respondents had moderately right-wing ideology. The political ideology has a mean value of *M* = 3.42 (*SD* = 0.91), the economic ideology has a mean of 3.18 (*SD* = 0.63), and the cultural ideology has a mean of 3.39 (*SD* = 0.62). Specifically, radical right-wing ideology was seen in opinions relating to the political issues of "Free speech, association and demonstration should be controlled" (*M* = 4.18, *SD* = 0.94). Radical left-wing ideology was seen on opinions about political issues of "We should narrow the gap of wealth and build a society of equal rights for everyone" (*M* = 1.92, *SD* = 0.98), and opinions about economic issues of "The government should guarantee basic living standards for low incomes" (*M* = 1.83, *SD* = 0.83).

3.2. Relationship between Attitudes to GM Food Safety and Ideology

Two types of logistic regression models were constructed to explore cause-effect relationships between attitudes to GM food safety and ideology. The first model is made up of a total of nine variables,

including attitudes to GM food safety, general ideology, and demographic variables. The second model is made up of a total of four variables, namely attitudes to GM food safety, political ideology, economic ideology, and cultural ideology. Regarding the first model, model fitting information shows that the Chi-square is 320.194 ($p = 0.000$). Goodness-of-fit shows that the Chi-square is 7530.816 ($p = 0.411$). For the second model, model fitting information shows that the Chi-square is 242.661 ($p = 0.000$). Goodness-of-fit shows that the Chi-square is 4966.445 ($p = 0.318$). These results indicate that those two models demonstrate a good model fit [53]. Results of these two logistic regressions are presented in Tables 2 and 3.

Table 2 shows that, although CPC membership and location do not have a significant effect, other variables (age, gender, family annual income, occupation, education, political ideology, economic ideology, cultural ideology, and general ideology) have a significant influence on Internet users' attitudes to GM food safety.

Table 3 shows the results of parameter estimates of the two logistic regression models when both models took answers of "GM food is safe" as a reference category. Regarding the age variable, with a one-year increase in age, there is a 1.04 times stronger tendency for respondents to believe that GM food is risky ($p < 0.001$), and 1.02 times stronger tendency for respondents to answer DK ($p < 0.001$). For gender, females are inclined to answer DK ($p < 0.05$). Regarding family annual income, people whose family earns CNY40,000 to 100,000 a year have the strongest tendency to believe that GM food is risky ($p < 0.001$), while people whose family earn no more than CNY40,000 a year have the strongest tendency to answer DK ($p < 0.001$). For occupation, people who work in the public sector have a stronger tendency to believe that GM food is risky ($p < 0.001$), and are also inclined to answer DK ($p < 0.05$). Regarding education, people who only finished primary or secondary school have the strongest tendency to believe that GM food is risky ($p < 0.001$), and are also inclined to answer DK ($p < 0.01$).

Regarding ideological variables, respondents who have left-wing ideology in general tend to believe that GM food is risky ($p < 0.001$), and also tend to answer DK ($p < 0.01$). Specifically, respondents with left-wing ideology in political issues show a strong tendency to answer safe ($p < 0.001$). However, respondents with a right-wing ideology in terms of economic issues are more likely to believe that GM food is risky ($p < 0.001$). Respondents who have a left-wing ideology in terms of cultural issues are prone to regard GM food as risky ($p < 0.001$) and are also inclined to answer DK ($p < 0.001$). An illustration of the relationships between attitudes to GM food safety and ideologies can be seen in Appendix B.

Table 2. Likelihood ratio tests between attitude to GM food safety and variables ($N = 3780$).

	Chi-Square	df	Sig.
Age	79.279	2	0.000 ***
Gender	6.476	2	0.039 *
CPC membership	1.258	2	0.533
Family annual income	28.126	8	0.000 ***
Occupation	25.067	2	0.000 ***
Location	15.231	10	0.124
Education	44.276	8	0.000 ***
Political ideology	52.649	2	0.000 ***
Economic ideology	42.859	2	0.000 ***
Cultural ideology	148.241	2	0.000 ***
General ideology	87.278	2	0.000 ***

Notes: * $p < 0.05$, *** $p < 0.001$.

Table 3. Parameter estimates of logistic regression (N = 3780).

	B	*SE*	Wald	Exp (*B*)
Risky (Safe as Reference)				
Age	0.042	0.005	73.169	1.043 ***
Gender (Female as reference)				
Male	−0.187	0.109	2.942	0.829
CPC membership (Non-CPC member as reference)				
CPC member	−0.096	0.114	0.722	0.908
Family annual income (CNY) (Above 500,000 as reference)				
0–40,000	0.752	0.220	11.722	2.121 ***
40,000–100,000	0.816	0.212	14.811	2.262 ***
100,000–200,000	0.456	0.207	4.842	1.578 *
200,000–500,000	0.437	0.217	4.064	1.549 *
Occupation (Occupation in non-public sector as reference)				
Occupation in public sector	0.497	0.104	23.045	1.644 ***
Living area (Overseas as reference)				
Village	−0.005	0.641	0.000	0.995
Town	−0.294	0.621	0.225	0.745
Small city	0.263	0.579	0.207	1.301
Medium-sized city	−0.099	0.571	0.030	0.906
Large city	−0.139	0.567	0.060	0.870
Education (Graduate school as reference)				
Less than primary school	0.940	1.249	0.566	2.560
Primary or secondary school	2.181	0.543	16.120	8.856 ***
High school	0.584	0.212	7.591	1.793 **
Undergraduate school	0.295	0.130	5.186	1.343 *
Political ideology	−0.137	0.075	3.332	0.872
Economic ideology	0.428	0.102	17.487	1.534 ***
Cultural ideology	−1.053	0.089	139.612	0.349 ***
General ideology	−0.727	0.086	71.602	0.484 ***
DK (Safe as Reference)				
Age	0.023	0.005	24.233	1.023 ***
Gender (Female as reference)				
Male	−0.259	0.102	6.393	0.772 *
CPC membership (Non-CPC member as reference)				
CPC member	−0.118	0.106	1.236	0.889
Family annual income (CNY) (Above 500,000 as reference)				
0–40,000	0.692	0.200	11.981	1.997 ***
40,000–100,000	0.668	0.193	11.966	1.950 ***
100,000–200,000	0.515	0.187	7.601	1.674 **
200,000–500,000	0.269	0.197	1.857	1.308
Occupation (Occupation in non-public sector as reference)				
Occupation in public sector	0.199	0.096	4.248	1.220 *
Living area (Overseas as reference)				
Village	−0.156	0.543	0.082	0.856
Town	−0.328	0.521	0.396	0.721
Small city	−0.027	0.479	0.003	0.974
Medium-sized city	−0.467	0.471	0.985	0.627
Large city	−0.386	0.466	0.687	0.680
Education (Graduate school as reference)				
Less than primary school	−0.173	1.240	0.019	0.841
Primary or Secondary school	1.481	0.537	7.605	4.397 **
High school	−0.069	0.199	0.121	0.933
Undergraduate school	−0.184	0.114	2.622	0.832
Political ideology	0.288	0.073	15.645	1.334 ***
Economic ideology	−0.101	0.096	1.122	0.904
Cultural ideology	−0.666	0.083	64.979	0.514 ***
General ideology	−0.234	0.080	8.504	0.792 **

Notes: "GM food is safe" was used as reference category of the dependent variable; *B*, estimated multinomial logistic regression coefficients for the models; *SE*, standard errors; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4. Discussion

A total of 3780 respondents were used in the analysis. The study found that 35.1% of respondents think that GM food is risky, which is more than those who believe that GM food is safe (20.4%). This result is consistent with previous studies. With data comparison among several surveys on attitude to GM food safety in China, Huang and Peng [21] found that the percentage of consumers who perceived GM food as risky increased by more than 30% in the 2002–2012 period. Major shifts occurred after 2010, when the percentage of "GM food is risky" surpassed that of "GM food is safe". These changes might be due to the increasing influence of negative media reports on GM technology. It was also noted that the 2010–2013 period was a sensitive time for the Chinese administration, and therefore, scientists and bureaucrats did not challenge media attacks on GM food [10].

Frewer et al. [54] found that, in studies aimed at understanding consumers' attitudes to GM food safety, demographic information is frequently reported in terms of sample characteristics, but is rarely used as an explanatory variable. In the present study, we construct the first model to explore the effect of demographic features on attitudes to GM food safety. For the age variable, young people tend to view GM food as safe, which is in line with previous study findings [55]. This might be explained by the fact that, compared to older people, young people are more often risk-takers and keen for new technologies [56]. For the variable of occupation, respondents who work in the public sector are inclined to think that GM food is risky. This might be because, in Chinese society in general, the majority of employees in the public sector have a high level of education and left-wing ideology. As left-wingers are conservative in respect to novelty [42], public sector employees are inclined to think GM food is risky.

Regarding the variable of family annual income, we found that, compared to people whose family earns more than CNY500,000, people all tend to think GM food is risky if their family's annual income is near the top of the income range (CNY0–40,000; 40,000–100,000; 100,000–200,000; 200,000–500,000). One explanation for this finding might be that a higher level of income may translate into a search for health food and, in general, GM food does not correspond to this perception [55]. Specifically, people whose family earns CNY40,000 to 100,000 have the strongest tendency to believe GM food is risky, compared to people from families of other income ranges. When considering the income standard of 2015 in real GDP per capita (CNY50,251), families earning CNY40,000 to 100,000 could be categorized as middle-class families. This speculation is supported by results of cross-tables of family annual income and education (see Appendix C). We found that the number of respondents who have an undergraduate diploma was the highest in families with annual earnings of CNY40,000 to 100,000. In addition, for people whose family earn CNY40,000 to 100,000, the number of respondents who have diplomas of primary, secondary, and high school ranked in the second place in those five income ranges. Thus, the effect of the family's annual income on attitude towards GM food safety might be largely influenced by respondents' education levels.

Regarding the variable of education, we found that, in contrast to people who have less than a primary school education, people who received formal education diplomas all tended to think GM food is risky. However, people who received higher education, such as undergraduate school, have a weaker tendency to regard GM food as risky, compared to those with lower levels of education. Similar findings have been pointed out by Hester and Gerda [57], and Rodríguez-Entrena, Salazar-Ordóñez and Sayadi [55], who reported that more knowledge of GM technology leads to more tolerance of GM food consumption. People who had a diploma from primary or secondary school showed the strongest tendency to believe GM food is risky, and also tended to answer DK. The explanation might be that, on one hand, primary or secondary school education cannot provide enough information on GM food; on the other hand, people with such education can be easily influenced by the opinions of entertainment stars (e.g., Cui Yongyuan), rather than scientific evidence.

Regarding ideology, results of descriptive analysis of ideology show that, generally, respondents have a moderately right-wing ideology ($M = 3.33$). This finding is in accordance with what Pan and Xu [41] found about the ideological positions of Chinese Internet users. The regression analysis results

show that both general ideology and the three ideological dimensions have a significant influence on attitudes to GM food safety. These results are in line with previous studies, which state that scientific problems are not solely about science, but are entangled with ideological issues [58,59]. Our findings show that respondents characterized as having a right-wing ideology, in general, tended to regard GM food as safe, compared with those with a left-wing ideology. Similarly, respondents who had a right-wing ideology in the cultural dimension think GM food is safe. This can be explained by the fact that right-wingers in China are usually people who are open-minded, creative, curious, and novelty-seeking [37]; they are not overly restricted by the traditional culture, like Confucianism. As GM food is produced using advanced genetic engineering technologies, right-wingers might have gained more knowledge about GM food, and thus show a friendly and welcoming attitude towards it, compared with left-wingers. In contrast, respondents with a left-wing ideology are more likely to consider GM food as risky. Left-wingers in China are represented by people who oppose capitalism, resist western modern values, yet acknowledge the great contribution of Mao Zedong to China, and support strong and powerful authoritarianism [60]. Thus, our findings can be explained by left-wingers resisting the products of Western technologies, so they regard GM food as risky.

Nevertheless, respondents with right-wing ideology in political issues showed a strong tendency to answer DK. This can be explained from a political perspective. It is a fact that China approved insect-resistant rice and high-phytase maize as safe for consumption and production, but the government did not make a public announcement [10,22]. Right-wingers in China prefer individual rights and freedom, and less government involvement in economics. Low political involvement on the part of right-wingers might be the reason why right-wingers in political issues showed a strong tendency to answer DK. What's more, we found that respondents with right-wing ideology in economic issues are more likely to believe that GM food is risky. This is easy to understand because people who have a higher family annual income also showed a strong tendency to regard GM food as risky.

Another possible explanation can be made from the perspective of media influence. Media researchers suggest and have proved in different ways that people selectively expose themselves to certain media contents according to their inherent preference and interests; for example, those searching for political information prefer to watch news, while those searching for social interaction are more in favour of using social media [61–63]. In addition, it has been proved that trust in the media positively affects people's attitudes toward new technologies, genetic engineering and other social issues [64]. Therefore, it is plain to understand why left-wingers in political and economic issues feel safe about GM food. Left is the official ideology of the CCP and certainly the "tongue of CCP"—mainstream media, whether traditional or new social media, are promulgating the official point of view. The Chinese government and mainstream media, like People's Daily and CCTV, once strongly promoted GM food [65] and, after the hot debates between Fang and Cui, which revealed more negative influences of GM food, the mainstream media still hold a relatively neutral or even moderately 'pro' position on GM food. Left-wing Internet users who are involved in political issues, those who trust the national voice, are unsurprisingly inclined to regard GM foods as safe.

As discussed above, we found that the effect of ideology on attitude towards GM food safety was not consistent, but varied in different ideological dimensions. Take right-wingers for example, we found that right-wingers in the cultural dimension view GM food as safe; right-wingers in the economic dimension view GM food as risky; those with a right-wing ideology in the political dimension tend to answer DK. This is a heuristic finding, which indicates that the effect of ideology on GM food safety should be examined from different aspects of ideology. This conclusion reflects the fact that attitudes toward GM food safety should be investigated from multidimensional perspectives.

The limitation of this study is in the research design. Since we use secondary data, which means that data were collected by other scholars, and since GM food safety was only one part of the data collection efforts, some issues of GM food safety, like GM food consumption, were not included. Future studies with specific designs for GM food safety and ideology could remedy this. Further discussion

is also needed on cause-effect relationships between ideology and attitude to GM food in concrete political, economic and cultural contexts.

5. Conclusions

This paper contributes to the current understanding of attitudes toward GM food safety in China in three important ways. First, we extend understanding beyond the existing literature, which usually treats demographic features as sample characteristics. Our study shows that the individual features of age, gender, family annual income, occupation, and education have significant effects on attitudes to GM food safety. Secondly, we provide new insights into the underlying determinants of attitudes to GM food safety by differentiating ideological dimensions. We examine the three ideological dimensions of politics, economics, and culture. We find that individuals who hold right-wing ideologies, in general, tend to view GM food as safe, while those right-wingers' attitudes to GM food safety vary in different ideological dimensions. Thirdly, this study advances the present knowledge regarding the impact of ideology on scientific development among contemporary Internet users in China. Up to now, very few studies have paid attention to the effect of ideology on attitudes to GM food safety. This study makes a pioneering challenge and provides empirical evidence for this important topic. These findings can help researchers and policy-makers to shed more light on the ideological influences on scientific development and the sustainability of the human world, rather than simply being restricted to discussions in the scientific domain.

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Appendix A

Table A1. Distribution of Places of Respondents' Residence (N = 3780).

	Frequency	Percent (%)
Beijing	440	11.6
Tianjin	111	2.9
Shanghai	387	10.2
Chongqing	82	2.2
Hebei	110	2.9
Shanxi	75	2.0
Liaoning	123	3.3
Jilin	43	1.1
Henan	141	3.7
Jiangsu	290	7.7
Zhejiang	249	6.6
Anhui	104	2.8
Fujian	83	2.2
Jiangxi	58	1.5
Shandong	248	6.6
Heilongjiang	47	1.2
Hunan	93	2.5
Hubei	144	3.8
Guangdong	455	12.0
Hainan	15	0.4
Sichuan	159	4.2
Guizhou	17	0.4
Yunnan	42	1.1
Shaanxi	95	2.5

Table A1. *Cont.*

	Frequency	Percent (%)
Gansu	22	0.6
Qinghai	4	0.1
Inner Mongolia	28	0.7
Guangxi	46	1.2
Ningxia	9	0.2
Xinjiang	21	0.6
Taiwan	2	0.1
Hong Kong	6	0.2
Overseas	31	0.8
Total	3780	100.0

Appendix B

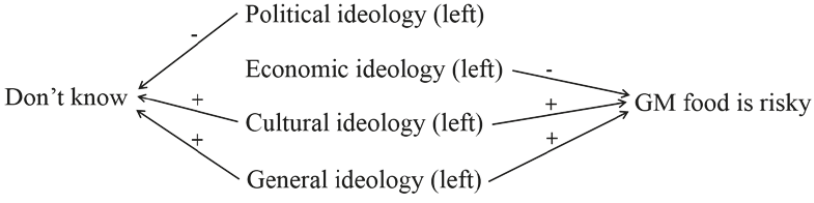

Figure A1. Illustration of Relationships between Attitudes to GM Food Safety and Ideologies.

Appendix C

Table A2. Cross Table of Education and Family Annual Income (N = 3780).

		0–40,000	40,000–100,000	100,000–200,000	200,000–500,000	Above 500,000	Total
Less than primary school	Count	3	1	0	1	0	5
	% of Total	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
Primary or secondary school	Count	52	36	16	5	2	111
	% of Total	1.4%	1.0%	0.4%	0.1%	0.1%	2.9%
High school	Count	136	125	53	23	9	346
	% of Total	3.6%	3.3%	1.4%	0.6%	0.2%	9.2%
Undergraduate school	Count	493	797	747	397	128	2562
	% of Total	13.0%	21.1%	19.8%	10.5%	3.4%	67.8%
Graduate school	Count	128	159	236	160	73	756
	% of Total	3.4%	4.2%	6.2%	4.2%	1.9%	20.0%
Total	Count	812	1118	1052	586	212	3780
	% of Total	21.5%	29.6%	27.8%	15.5%	5.6%	100.0%

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sustainability

MDPI

Essay

Designing Urban Green Blue Infrastructure for Mental Health and Elderly Wellbeing

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Abstract: The main objective of this essay is to illustrate the state-of-the-art on 'mental health-sensitive' open space design in the built environment. Urban Green Blue Infrastructure can contribute to urbanites' mental health and wellbeing as well as healthy aging, while providing co-benefits balancing the negative impacts of climate change, through the provision of integrated ecosystem services. There are a number of ways that exposure to and affiliation with Nature have shown to support mental health, but we are still missing the necessary evidence of the actual benefits achieved, as well as the key performance indicators and metrics to monitor and adapt our open space to the growing urban challenges. After introducing the key concepts of degenerative mental disorders as they are growing in the urban environment, and the emerging green blue infrastructure design approach, the authors present international case studies describing how evidence-based design and Nature-based Solutions have been found to be beneficial, especially to those diagnosed with mental disorders. Subsequently, in a comparative critical analysis, the authors look closer at a number of design solutions capable, at different scales, to support healthy aging through exposure to, and affiliation with, biodiversity.

Keywords: healthy public space design; healing gardens; dementia-friendly cities; Alzheimer; elderly people; evidence-based design; age-sensitive landscape design

1. Introduction

The United Nations Sustainable Development Goal 3 (2015) states that "ensuring healthy lives and promoting the well-being at all ages is essential to sustainable development" [1,2].

Achieving *health* requires striving for complete physical and mental health, the latter being "a state in which a person is most fulfilled, can make sense of the surroundings, feel in control, can cope with every day demands, and has purpose in life" [3] (p. 27).

The urban built environment particularly influences social health and wellbeing, especially of the elderly [3]. Worldwide, the total number of people over 60 is set to double by 2050, rising from 1 billion to 2 billion, with 80% living in low- and middle-income countries [4].

According to the World Health Organization (WHO) '*Healthy Ageing*' is the "process of developing and maintaining the functional ability that enables wellbeing in older age" [5] (p. 28). Healthy ageing represents, therefore, the continuous interaction between people and the environment in which they live [6].

There is growing recognition that the leading causes of disease and death, including heart disease, cancer, cerebrovascular disease, chronic lower respiratory disease and injury, can be exacerbated by elements within the built environment which contribute to sedentary lifestyles and unhealthy

environments [7,8]. Moreover, climate change is determining a host of mental health challenges, and the public health threats people are experiencing are considered among the most urgent of the 21st century [9]. Thermal stress negatively affects the functioning and health of people. When the temperature is extreme, vulnerable groups (e.g., groups with mental health conditions or with substance abuse problems, the poor, the children, the elderly) have a higher risk of worsened mood or behavioral disorders, violence, aggression or suicide [10]. Elderly people are particularly susceptible and are likely to suffer from moderate heat stress even under prevailing conditions. During periods of heat waves, however, the risks to vulnerable urban residents increase—with increased mortality rates having been recorded for many countries, including France, US, Korea, Russia and the Netherlands [11–14].

Another serious health risk increasingly connected with the ageing population is dementia, currently affecting approximately 5% of the world's elderly population [15]. Dementia is one of the most expensive diseases to manage, and is the fifth-biggest cause of death in high-income countries [16]. The worldwide figure of people living with dementia more than doubled up from 1990 to 2016, mainly due to increases in population ageing and growth [17].

The connection between the built environment and health has been extensively examined in working-age populations, but we can count on comparatively fewer studies concentrating on the elderly and mentally impaired urbanites [18].

The World Health Organization's goal of the Global Action Plan on the Public Health Response to Dementia 2017–2025 is to improve the lives and careers of people with dementia and the lives of their relatives, while reducing the impact of dementia on them and on communities and nations [19]. It is considered equally important to understand how to efficiently promote healthy aging and prevent dementia-like neurodegenerative diseases, such as Parkinson's, Alzheimer's, and Huntington's disease [15].

Nowadays, we can rely on many decades of environmental psychology and environmental behavior research examining the mentally restorative potential of exposure to the natural environment, as well as to the natural elements and systems in our urban built environment. With the sociocultural environment influencing the degree of psychological and restorative benefits that we may be genetically predisposed to receive [20].

Urban design can play a primary role in the healthy ageing process, helping adults stay socially active as they age, and thus supporting their general health and wellbeing [20–22]. There is substantial evidence demonstrating that urban design and landscape architecture are powerful tools to improve the human condition and health [23–26]. We can also already count on several bottom-up initiatives, i.e., age-friendly towns, districts and communities—such as Manchester's "Older People's Forums", Hong Kong's "Elder Academy", Ottawa's "Better Strength Better Balance"—which are promoting healthy and active ageing, assisting elderly people to stay autonomous for as long as possible, and providing care and security when required, while respecting the autonomy and dignity of elderly people [5].

International research confirms in principle the need for better knowledge of specific landscape aspects and design strategies, as well as of blue and green features able to promote healthy ageing and mental health and wellbeing in increasingly critical urban scenarios [22,27]. For example, in a recent European project conducted across 17 cities in Austria, Germany, Norway, Poland, Romania and Slovenia, Artmann et al. (2017) [28] reported that more types of age-sensitive facilities should be considered in urban green areas, particularly in support of physical activity for elderly and mentally impaired people [28].

So far, studies mostly revealed only general associations between greater exposure to the natural environment and improved mental health, and this limit has created a much-needed evidence basis on which to address and solve existing boundaries to conclude clear cause and effect. Case studies and critical appraisal of current and on-going projects represent in this respect a sound methodology to acknowledge and progress mental health-sensitive open space design, as well as encouraging awareness and stewardship.

The purpose of this critical essay is to better explore the relationships between Urban Green Blue Infrastructure, mental health and healthy ageing, and to provide useful insights aimed at progressing informed age-sensitive design and planning for the built environment.

2. Urban Green Blue Infrastructure for Healthy Ageing and Mental Health

Green Blue Infrastructure is strongly linked to the concept of '**G**reen **I**nfrastructure' (GI). GI is an approach related to landscape planning and design linked to Nature-based strategies and solutions, such as greenways and ecological networks [29,30]. GI had originally been defined as "a strategically planned network of natural and semi-natural areas, with other environmental features designed and managed to deliver a wide range of ecosystem services" [31], and more recently as "the elements of biodiversity and the organized systems that can be traced back to the Natural Capital, of any urban area, valuable or degraded, including the individual technological devices that rely on biodiversity and are integrated in the built environment, such as green roofs and vegetation walls, permeable paving, rain gardens and other systems for the collection and management of rainwater, which promote, through the provision of ecosystem services, environmental protection, economic feasibility, health and well-being, equity and social inclusion" [32].

GI is present in rural, urban and peri-urban environments, at different scales [31,33]. In urban areas, Urban Green Blue Infrastructure (UGBI) is normally a hybrid infrastructure of green spaces, or blue spaces if aquatic ecosystem are included, and built systems [31,33,34]. Examples of UGBI are urban forests, parks, domestic gardens, green roofs and walls, community orchards, parklets and sidewalk gardens, while blue components are aquatic ecosystems, such as wetlands, rivers, canals, ponds, creeks, etc. (Figure 1).

Figure 1. Urban Green Infrastructure: (**a**) Green roof in Antwerp, Belgium, (**b**) green wall in Oxford, UK, (**c**) urban park in Padua, Italy, (**d**) urban–park in St. Petersburg, Russia, (**e**) "green" tramway in Paris, France, (**f**) community garden in Freiburg, Germany. **Urban Blue Infrastructure**: (**g**) Canal in London, UK, (**h**) canal in Amsterdam, Netherlands, (**i**) pocket garden with water feature in New York City, USA, (**l**) canal in Dublin, Ireland, (**m**) urban wetland in Suining, China, (**n**) pond in Moscow, Russia. Credits: Alessio Russo (**a**–**e**, **g**, **h**, **l**, **m**) and Maria Beatrice Andreucci (**f**, **i**, **n**).

The mismatch between what human beings need and what urban built environments often fail to provide—exposure to nature—has proven detrimental to mental health [35]. Conversely, other

studies have reported that human exposure to UGBI increase physical activity [36,37], improve mental health [38–44], and decrease crime, violence and aggression [45–48], as well as morbidity in multiple disease categories [49–51].

UGBI is essential to support the basic ecosystem services on which human survival depends [52]. UGBI regulates water quantity and quality, controls surface runoffs, protects biodiversity, filters pollutants, improves air quality, and is vital to the food chain leveraging on nutrient cycling and pollination [53,54].

De Keijzer et al.'s research [27] revealed that proximity to natural green and blue areas is associated with a slower decrease in walking speed and grip strength among respondents between the ages of 50 and 74. Wang et al. (2017) [55] studied the contributions of neighboring green space to mortality among Chinese males and females 65 years of age and elderly living in Hong Kong. Results showed that a 10% increase in green space coverage was correlated with a decrease in all-cause mortality [55].

Lewis and Booth (1994) [56] found that people living in built-up areas with access to gardens and other greenspaces had a lower prevalence of psychiatric morbidity as compared to people in built-up areas with no such access.

Other studies have recently supported the connection of socio-economic and socio-demographic factors in elderly people as possible confounding variables with respect to the relationship between health and UGBI [57].

There are a number of ways that exposure to, and affiliation with, UGBI have shown to support mental health. These include nature's ability to reduce stress, create positive affective states, and improve cognitive functioning [39,58,59] (Table 1).

Table 1. The health benefits of green and blue infrastructure for elderly people.

Benefits	References
Lower mortality	[55,60,61] ¢
Slower decline in walking speed	[27]
Lower risk of cardiovascular disease	[62,63] **
Slower cognitive decline	[64] **
Stress reduction	[65] **
Decreased inflammation	[66] ⊖
Social connectedness improvement	[66] ⊖

** Passive recreation (e.g., exposure), ⊖ horticultural therapy, ¢ coverage of green space.

Exposure to the natural environment can take many forms that range from simply viewing images of nature, to actively accessing UGBI, to receiving treatments in institutional settings.

Landscape architects design therapeutic or healing gardens at different scales [67,68]. Healing gardens are outdoor spaces designed to support health and well-being and provide comfort for people suffering from illness [68].

In countries like the United States and Singapore, some healing gardens focus on the design of sensory stimulation and accommodation of horticultural activities [66,69]. Therapeutic gardens influence the quality of life of aged care residents with dementia [70].

The beneficial effects of outdoor activities in people with dementia have also been well documented [70,71]. Nature-based walks, as compared to urban walks, have been found to be beneficial to those diagnosed with mental disorders [40].

At the same time, other studies [72,73] confirm that general mental health improvements may also be attributed to the restoration gained by passive exposure to greenness, independent of exposure gained by actively accessing it for physical activity, and also independent of the mental benefits of the social interaction that can take place in it.

Worldwide, Edible City projects have demonstrated that edible green spaces (e.g., allotment gardens, edible forest gardens, edible urban forests) can improve social cohesion, healthy aging and wellbeing [74–77]. Research in Spain has shown that urban gardens could be promoted as a

nature-based solution in urban planning to facilitate elderly social integration [78]. A study conducted in the UK by Wood et al. 2016 demonstrated that as little as 30 minutes of allotment gardening can produce significant health gains [79].

The experience of visiting allotment gardens positively influences the quality of the elderly participants' daily lives, including restorative experiences, peacefulness, inspiration, joy, and positive emotion [80].

Although UGBI has been found to be associated with physiological benefits for humans in several studies, it should not be forgotten that increasing biodiversity in the built environment may also support ecosystem disservices, i.e., nuisances and losses produced by ecosystem functions [67,81,82], or even the introduction and survival of vectors or host organisms for infectious pathogens, with the resulting spread of a variety of diseases [67,83]. Ecological, social and technological changes determined by planning and design will affect both what kind of disservices will emerge and how they will be experienced and managed [81].

3. Dementia-Friendly Cities and Biophilic Design for Healthy Communities

Therapeutic design of the built environment is widely recognized as a major aid for people with Alzheimer's disease [22].

Growing evidence suggests an interrelationship between dementia on one side and lifestyle-related risk factors on the other [84,85]. These risk factors include physical inactivity and obesity, together with unbalanced diets, tobacco use, harmful use of alcohol, diabetes mellitus and mid-life hypertension [86,87]. In addition, other potentially modifiable risk factors are more specific to dementia and include social isolation, low educational attainment, cognitive inactivity and mid-life depression [88,89]. Reducing the level of exposure of elderly populations, and individuals in general, to these potentially modifiable risk factors can strengthen the capacity of urbanites to make healthier choices and follow lifestyle patterns that foster good mental health and wellbeing.

There is growing consensus that integrated and multiscale nature in the city is protective and can reduce the risk of cognitive decline and dementia: increasing physical activity, preventing and reducing obesity, promoting balanced and healthy diets, discouraging the harmful use of tobacco and alcohol, promoting social engagement, cognitively stimulating activities and learning, as well as preventing and healing depression [85,90].

The biophilic cities concept builds on much of the work of biophilia [91] and biophilic design that have both been experienced more on the building scale [92]. Sets of biophilic design principles have also been generated [93,94] providing reflections and guidance about design qualities and natural conditions people appreciate the most in the urban built environment—biodiversity, light, water, and natural sounds, among others [92,95].

There are numerous case studies of Dementia-Friendly Communities worldwide [96].

As an example, a supportive community specifically for people with dementia has recently been established in Canada [97]. This project, called The Village, includes six single-story cottage-style homes and a community center surrounded by a lush garden [97,98]. The main focus of The Village is to encourage and enable people with dementia to live their lives as they would normally do [97,98]. The development of the Village was influenced by the world's first dementia village, Hogeweyk, in the Netherlands. Hogeweyk is designed to accommodate 152 people suffering from dementia [99]. The design layout includes 23 houses with a variety of parks and gardens designed by the Dutch landscape architect Niek Roozen [99].

In the UK there are several examples of dementia friendly parks. For example, the oldest Royal Park in Scotland was transformed into a dementia-friendly park in 2018 [100]. The aim of this project was to make green spaces more accessible and inclusive for people with dementia through the provision of additional benches, the installation of a handrail and dementia friendly toilet signage [100]. Another good example is the dementia friendly garden at Springhead Park in Rothwell, Leeds [101]. The garden has been built to support people with dementia and to "demonstrate the principles of

a dementia-friendly garden to inspire families, care home managers and other local authorities to develop their own" [101] (p. 2).

In Oslo, Norway (Figure 2), the horticultural therapy project Loseter Garden of Senses is another example of how bringing fertile soil into our built environment can transform a barren area into a thriving green and dementia-friendly meeting place, where all people can comfortably learn about and experiment with food production.

Figure 2. Horticultural therapy project Loseter Garden of Senses in Oslo, Norway. Credits: Maria Beatrice Andreucci.

Sprouting Oslo—to which the Loseter project belongs—is an outstanding example of the 2019 Green Capital's commitment to inclusive urban landscapes.

4. Healing Garden Design and Mental Health Institutional Setting

The psychophysiological or psycho-evolutionary stress recovery theory [58] postulates that our innate connection with the natural environment results in a fairly rapid reduction in stress when viewing natural elements or pleasing natural landscapes. Ulrich's study into the therapeutic properties of nature views revealed that hospital patients convalescing from surgery had shorter hospital stays, lower intake of narcotic pain drugs, and more favorable evaluations by nurses if their hospital room windows allowed views of trees rather than views of a brick wall [102].

There are few places where the power of landscape architecture is more needed than in institutional settings where patients and relatives react to mental illness.

Along the life course continuum, exposure to the natural environment appears to benefit affective states of older persons in institutional settings with degenerative mental disorders [103,104].

The risk of developing dementia in institutional settings has also been found to be dramatically reduced with exposure to, and affiliation with, nature achieved with regular gardening [105].

In health care settings, a patient's ability to process information and instruction given by health care providers is critical to enhancing care and health outcomes.

Among those with late stage dementia in nursing homes, natural sounds and pictures have been found to reduce agitation, if not aggression [106,107].

Healing gardens are defined as "green spaces designed to promote and improve health and well-being for people suffering from illness" [68] (p. 43). There has been a growing interest in healing gardens around the world and many of these gardens have been designed in several countries [108].

Design features such as street layouts, building forms, signage and other details influence the orientation and wayfinding abilities of older people with dementia [109].

For example, in Ferrara, Italy, the Garden of Happiness (Figure 3), has been specifically designed for the benefit of almost two hundred elderly patients, their guests and family, as well as the healthcare providers. The space can be set up for community use, and it includes specific design elements that work to maximize accessibility, safety and orientation. The planting design stimulates all senses, while the tree planted areas provide comfort for both informal and spiritual gatherings. The site also provides physical access to a vegetable garden and an orchard suitable for a variety of therapies. There is also equipment and specially-designed furniture, which can also be enjoyed by patients in a wheelchair.

Figure 3. Example of a healing garden in Italy, the Garden of Happiness in Ferrara. Credits: Monica Botta.

On a different scale, in Singapore, there is an ongoing initiative aimed at creating the Therapeutic Gardens Network and Social and Therapeutic Horticulture Programmes, meeting the needs of elderly people, including those affected by dementia [110]. The first, prototype garden was completed in May 2016 by the National Parks Board with design inputs from the Psychological Health Department of the National University of Singapore and the Alzheimer Disease Association. The design principles included: safety, security and privacy, accessibility, physical and emotional comfort, positive distraction, engagement with nature, maintenance and sustainability (Figure 4). It is located within the North Park area in West Singapore. The Therapeutic Garden is located close to a building equipped with comfortable washing areas, toilets, and drinking water sources. It provides deep shade under large tree canopies and comfortable wooden benches (equipped with full support for the back and armrests). The layout is simple and clear without confusing dead ends. The garden is fully accessible for wheelchairs, also through the furniture for horticultural therapy sessions: Planting racks and work benches in which the height and design has been adjusted for both standing participants and those seated in wheelchairs.

Figure 4. Examples of Therapeutic Gardens and Social and Therapeutic Horticulture Programmes in Singapore. Credits: A. Olszewska-Guizzo (**a**–**c**) and NParks (**d**).

Since 2016, three more Therapeutic Gardens have been built in different areas of Singapore, and more are to be implemented in the network, as a response to the ageing population and increasing levels of dementia.

5. Evaluating Design Quality and Potential Benefits of Therapeutic Green and Blue Open Spaces

As the Therapeutic Garden Network in Singapore in expanding, the National Parks Board, through its Research Centre for Urban Greenery and Ecology (CUGE), is keen on collaborating with academics and doctors to test their designs and functions using scientific methods. Several collaborative research studies have been conducted in the Singapore Therapeutic Gardens to evaluate their potential contributions to the elderly and inform the policies for a dementia-friendly urban agenda. For example, a study completed in 2016 assessed the effects of horticultural therapy on the mental health and immune functioning of the 69 elderly participants, using the randomized control-trial design [66]. Recently, the data collection for a follow-up study on the effects of the horticultural therapy on people with dementia has been concluded. Another large cohort study has tested the influence of certain physical activity protocols performed in parks on the health and wellbeing of Singaporeans, including the elderly [111]. Currently, the research on the effects on brain activity of passive exposure to the Therapeutic Gardens' landscape is being conducted with sample representative of the Singaporean population. This study specifically targets individuals diagnosed with depression, including the elderly [112].

In 2012 the WHO released an assessment tool for the quality of physical attributes and functions of mental healthcare facilities, including homes for elderly people and Alzheimer institutions [113]. However, the "WHO Quality Rights Tool Kit" [113] does not provide any recognition concerning the issue of accessibility of green space to patients of such institutions.

In 2007 Clare Cooper Marcus developed a tool for landscape architects and other designers that evaluates the quality of outdoor space for those with Alzheimer's disease [114]. The Alzheimer's Garden Audit Tool (AGAT) includes a checklist divided into seven sections, e.g., moving from Location and Entry to the Garden, to Layout and Pathways, Planting, Seating, Overall Design and Details, to Maintenance and Amenities [114]. This tool has been tested by thirteen participants attending a multi-disciplinary symposium on healing landscapes in Portland in 2005 [114]; however, the tool has not been exposed to psychometric testing and targets environments for advanced dementia [115].

Recently, Paraskevopoulos and Kamperi (2018) have examined the evidence-based design of healing gardens [116]. The study showed that the design of healing gardens must be adapted to the needs of each type of patient [116]. The review of the literature also reported a limited number of evidence-based design strategies and post-occupancy evaluations for the healing of hospital gardens [116].

6. Conclusions

While UGBI is supporting mental health, it is simultaneously providing an array of other health benefits, some of which are essential to sustaining life, others to enhancing it. However, it is not solely the volume of co-benefits of GI that pervade life and support health that should be considered, rather the intrinsic design qualities of the open space, favoring maximization and interconnection between these co-benefits [117].

The opportunity of the contact with nature or the use of more biodiverse environments certainly represent an important aspect of healthy ageing and dementia-friendly environments [118]. The case studies presented have identified and highlighted the relevant design qualities and characteristics of dementia-friendly cities, healing gardens, and mental health institutional settings.

The complex dimensions of urban nature cannot be easily synthesized, considering the many interconnected features, and the many variables that come into place at different levels when dealing with associated programs, activities, and other mediators. There are in fact many different ways to experience and interact at different scales with nature in cities. Both physical and visual connections

matter, as the design of the case studies in Italy, UK, Canada, Norway, the Netherlands, and Singapore demonstrates.

Progress in post-occupancy evaluation of therapeutic green and blue open spaces already indicates that elderly people seem to have prevalent preferences for natural, esthetic, and varied landscape design characteristics, with easily accessible and well-maintained infrastructure and amenities.

Notwithstanding the positive findings, the actual benefits of designed garden spaces for people with dementia are still not fully supported by meta-analyses and remain mostly unexplored [119].

The barriers facing people living with dementia in accessing the natural environment particularly need to be investigated further through large scale studies providing both qualitative and quantitative insights [120].

More research is necessary about the negative influence of climate on human health and enjoyment in the open space environment, as scientists at the National University of Singapore have recently highlighted [121].

Context, informed decision making and inclusive governance represent important factors when selecting and implementing integrated, multiscale actions targeting the elderly's mental health and wellbeing. Financial incentives, public education, applied research and dissemination are to be considered critical for a balanced and sound welfare development.

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sustainability

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Concept Paper

Interior Architectural Design for Adaptive Reuse in Application of Environmental Sustainability Principles

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Abstract: The paper discusses an interior architectural design model to enable the accomplishment of sustainable design strategy of efficient resources/waste management. The proposed design concept, referred to as interior architectural design for adaptive reuse, is based on the reintroduction of reclaimed or salvaged building construction materials and products acquired from demolished or refurbished building structural portions, into the structure of interior components. The presented design approach puts circular design methods and techniques in interior design practice at the core of environmentally responsible architectural design. To achieve its objectives, the implementation of resources efficiency strategy into the interior design scheme should remain a decisive interior design quality criterion. Meanwhile, the issues related to the environmental contextualization of interior spaces and their constitutive components, in fulfilment of sustainable design requirements for the conservation of natural resources, are neither sufficiently recognized by interior designers, nor appropriately highlighted in the current design practice. The main purpose of this concept paper is to develop a theoretical scheme for systemic inclusion of interior architectural design for adaptive reuse into the environmentally sustainable interior architectural design framework. This study provides interior designers with the concept of interior components design for the fulfilment of resources efficiency and waste management effectiveness.

Keywords: sustainable architectural design; sustainable interior design; interior components; adaptive reuse; environmental contextualization

1. Introduction

The reuse of reclaimed building construction materials and products should be treated as the supporting method for the reduction of construction and demolition waste [1] produced as the result of cyclical building activities associated with forming the built environment, and thus responding to the environmental ethical questions that are to be addressed by architects, as well as interior designers. The design practice towards the accomplishment of a closed loop concept, as postulated by McDonough and Braungart [2], can be maintained by consequently applying an adaptive reuse model into the building internal environment components design. This model meets the environmentally sustainable demand for minimization of building construction waste.

The issues related to the extension of the lifespan of a building, as well as its structural components, are still insufficiently recognized [3] by interior designers. Meanwhile, the repeated processes of construction, refurbishment, and especially demolition, understood as an undifferentiated process of taking apart and compressing building components for their final disposal at a landfill [4], remain the primary source of wasted resources [5,6].

The sustainable design approaches, from design for waste prevention, to design for recycling, as presented in the waste hierarchy model of the efficient resources' management strategy, enable

control over the negative impacts of these destructive procedures on the natural environment. Design methods for effective waste management are situated between preventing construction and demolition waste production as the most favored and effective method, and the disposal of waste in landfills which is destructive to the natural environment. The objective of their application is the reuse of potential building waste "by extracting from them an extra (i.e., additional or new value) while generating a minimal amount of refuse" [7] (p. 94). The list of possible methods for products' technical life extension include the following: design for repair, remake and replacement; design for reclaim understood as a process of reintroducing building materials without reprocessing or cleaning, and with limited repairing processes [5]; and design for adaptive reuse. This design concept of retaining the reclaimed or salvaged building materials and products, acquired from refurbished or dismantled objects in new architectural designs, is supposed to be the best design practice to preserve building materials [6] and lengthen the building product's life cycle. Consideration of the entire lifespan of a building's products, imperative for sustainable architectural design, is an incentive for changes in interior architectural design. The environmental context of a building and its internal spaces influences the design decision-making process with regard to the consequences of potential repetitive remodeling processes of building structural components or the interior environment. These procedures related to refurbishment, modification or adaptation due to the changing of functional or formal requirements, leads to deconstructed, dismantled, removed or demolished components. They are becoming the vast reservoir of building materials and products, differing in quality, value, and physical parameters, that offer new areas of re-introduction into built structures, thus stimulating a search for innovative design methods.

There is a need for developing a thorough system on the application of building material adaptive reuse involving vendors, deconstruction contractors, developers, facility managers, and interior designers, to provide an effective reintegration of deconstruction or demolition waste with interior components. "Building Material Reuse Consulting Process Workflow" [6] (p. 2) adopted for sustainable interior architectural design, is to develop a multi-disciplinary online platform enabling the exchange of essential information on the availability of reclaimed components, complemented by guidelines providing modes of their successfully exercised reintroduction. The goal is to transform the design process, stakeholders' involvement, and knowledge on the principles of sustainable design for the built environment. These combine with life cycle assessment, and equally ensure the minimum amount of embodied energy, regarding the specification of building materials and products to form interior components, is retained. Equally formulated exigencies are to be applied to the process of creation of a sustainable interior and are understood as the second building block of the built environment or near environment [8].

Stuart Walker's view that "sustainable product design explores reuse of materials" [9] (p. 81), and that production of artefacts should be based on "cyclic resource use" [9] (p. 93) can be confirmed through the adjusted interior architectural design methodology. The presented Interior Architectural Design for Adaptive Reuse (IADfAR) concept, to be implemented by environmentally responsible designers realizing "integrated, comprehensive, anticipatory design" [10] (p.268), can be assessed as an attempt to achieve resources efficiency, as well as an alternative solution to the waste of valuable building materials.

The objective of this study is to present a conceptual model of interior architectural design for adaptive reuse defined as the process of acquisition of reclaimed building materials and products from refurbished or demolished buildings, and their incorporation into new spatial and functional contexts of the indoor environment. Conversion of waste building materials from demolished or refurbished building portions into valuable resources to complete interior components, accomplishes eco-effectiveness through the resources' recirculation and redistribution. The presented design method of forming new or refurbished interior components with reused parts identifies the design discipline contribution to assure the extension of building materials lifespan. An innovative approach from designers to form interior components is required for this method to be successfully applied, and the

development of modified design criteria focuses on the limited use of new resources in order to "cause minimal detriment to the environment" [9] (p. 191).

The structure of the article is as follows: the first part addresses sustainable interior architectural design strategy for resources efficiency, then the adaptive reuse design concept is presented as a method of its accomplishment. The next section concerns the interior components assessment model, with emphasis on its environmental contextualization. Then, the interior architectural design for adaptive reuse concept is clarified, with regard to implications, strategies, and determinants of its effectiveness in shaping interior constitutive components.

2. Sustainable Strategies in Interior Architectural Design

To prove its ecological effectiveness, interior architectural design identified as environmentally sustainable should be based on a holistic approach, as the building interior forming the near environment directly mediates with its occupants and remains a relevant part of the built environment. It is necessary to make predictions of possible impacts of the interior setting on the natural environment, with which the inner spaces remain another indirect form of mediation. Interior architectural design is to respect this interrelationship and reduce the environmental costs of interior settings completion. Walker claims that sustainability in design, involves "resourcefulness and restraint" [11] (p. 81), and exploration of the reuse and remanufacturing of materials as environmental indicators. Interior architectural design sustainable strategies for resources efficiency and effective waste management, "based on the principles and strategies common for the built-environment" [12] (p. 180), are therefore essential for establishing the role of interior design discipline in fulfilment of environmental responsibility.

2.1. Resources Efficiency

Buildings can be considered resources in the long-term perspective [13]. The concept of retaining and reusing existing buildings realized in architectural design and addressed as "a significant priority of sustainability" [14] (p. 222), can be identified as an example of creative approach within interior architectural design as well. Therefore, as Winchip claims [14], reusing buildings and providing the preservation, restoration or reconstruction of a building's substance to retain the quantity of valuable materials and products is becoming the preferred method for the creation of a sustainable interior environment.

The design methods of adaptive reuse of existing buildings comprise the alterations and conversions of the building structure itself, as well as the functions it accommodates. The important position in this design concept is assigned to the adaptive re-use as intervention adjusted to the scale of the interior environment [15,16]. Among other terms accompanying the adaptive re-use design model and interchangeably investigated, are adaptation, reworking, and rehabilitation [15], which address most adequately this complex issue. All these notions emphasize the benefits of retaining architectural heritage, employed with the implementation of an adaptive re-use design concept into the architectural design framework. Brooker and Stone [17] consider the adaptive reuse of existing buildings from the interior architecture perspective and address the transformation and remodeling of existing buildings to assign them new functions, and to present different approaches to establishing a relationship between new functions and existing building substance. They identify the design strategies toward the accomplishment of this concept as insertion, intervention or installation.

Adaptive reuse and conversion of existing buildings, as a task within the architectural discipline, as well as interior architectural design, complies with sustainability resources efficiency principle, through the minimal physical interventions, efficient management of existing building substance, and environmentally conscious design of interior components. An example of this approach is the dematerialization scheme [18] which outlines the components of interior spaces, and purposefully reduces the amount of used materials permitted to perform their basic functions without deterioration of their quality [19]. This ultimate design concept strengthens sustainability awareness in the effective management of building materials and products by minimizing resource consumption. The rationally

introduced dematerialization concept, assuring the expected quality performance of internal spaces and their components, becomes an innovative design method to shape stylistically and ethically defined sustainable interiors [20]. The fulfilment of the objectives of resources efficiency in interior components creation facilitates other design methods, including design for reclaim [21] which is associated with design for deconstruction [18,19]. According to Kibert [22], the deconstruction process in relation to buildings is becoming an architectural design strategy, which offers opportunities for the reintroduction of recovered and valuable components in new locations through the partial or whole dismantling of existing structures. Design for deconstruction or selective dismantling concept [18], based on the carefully previsioned management of available resources, enables the optimization of products' performance, responding to ethical questions regarding cost-effectiveness and ecological-efficiency of design methods applied for the building's completion. The latter can be described as the basic model for multiple usage of interior components enabling the extension of the components and products' lifespan, and completion of the circular building materials flow scheme within the built environment.

2.2. Waste Management

Although an increasing body of knowledge on resources management and methods of waste diversion from construction sites already exists, the substantial role of designers in reducing the amount of waste is not precisely defined [6]. As indicated by Osmani, Glass, and Price [23], very few attempts have been made to address the effect of design practices on the generation of waste.

The production of solid waste during construction or demolition phases, inevitably associated with the built environment [24], can be assessed in different scales. The maintenance and refurbishment of internal spaces are in fact the beginning of waste producing, due to those partial demolition processes [3]. Constant transformations of the indoor environment cause massive waste production exceeding the amount of waste coming from simple demolition. It is, then, justified to broadly employ waste management as a sustainable design strategy. Frequently executed refurbishments of interior environments, especially commercial ones, characterized by a relatively short lifespan is a cyclical process of making new structures simultaneously accompanied by waste production. Consideration of the constant alterations and refurbishments of interior spaces in the context of building waste production, is to define the latter as an important stage in the continuous cycle of use, decay and regeneration [24] of building substances. Establishing a new approach to reinvent the reclaimed building materials and products in a new surrounding is conditioned by the decline in understanding construction and demolition waste as worthless materials. According to Lyle [25], it is necessary to revise the assumption that building materials, acquired from refurbishment or demolition, cannot exist in any form other than their originally presumed function. Van der Ryn and Cowan [26] and Yeang [27] emphasized the significance of restorative closed cycles of materials in the creation of ecologically efficient architectural design assuring the minimization of impact on natural surroundings through the implementation of reuse or recycling design methods. As Thomsen, Schultmann and Kohler indicate "waste is increasingly considered as another form of resource" [3] (p. 328) in the currently developed theoretic scheme of architectural design. This statement endorses the cradle-to-cradle theory on the cyclic character of building products technical life and highlights the reuse design method as mostly efficient in extending this perspective. The sustainable design of an interior space and its components with regard to the environmental effects of the constant flow of used substances, acknowledges the concern that "the design of a product exists within a wider system of production, consumption and disposal" [9] (p. 813). Interior architectural design must contribute to significant improvements in this procedure, in order to diminish the building waste production; this is possible by achieving the principle of using "what is available and use limited resources in creative new ways" [13] (p. 36). Superuse Studios achieved such a concept of reusing discarded construction material with objects of different scales and functions [28].

3. Interior Components in Sustainable Interior Architectural Design

The inclusion of environmental criteria to the process of interior components creation, assures the accomplishment of environmentally sustainable design imperatives, while requiring the employment of different design methods and techniques. These comprise interior design and its components for multi-functionality, design for adaptability, followed by design for flexibility. The above-mentioned design approaches allow for the rational outline and environmentally-responsible arrangement of internal spaces, as well as forming of their components through efficient resources/waste management. The design principles assuring the creation of an environmentally responsible indoor environment comprise the following: (1) reduction in energy and resources as required to produce new building materials and products; (2) reduction in the construction, refurbishment and demolition waste flow due to resources efficiency; (3) preservation of the embodied energy present within the existing and in-use structures from dissipation due to the demolition stage; (4) extension of the lifespan of building materials and products accomplished with the comprehensive implementation of an adaptive reuse model into interior components substance. Adjustments in the conventional interior components design methodology are a condition for the avoidance of the high environmental impact of indoor spaces. In the following sections, the interior components typology is presented, then the constitutive interior components identified by the author as interior responsive constructs, are analyzed within an environmental context.

3.1. Interior Components Typology

Classification of interior environment components, proposed by the author, corresponds with the scheme developed by McClure and Bartuska, where the content of seven built environment connected layers or "levels of varying scales" [8] (p. 7), as well as their spatial contexts are exposed as fundamental factors. The indoor environment as part of this developed set of interrelated components comprises products, understood as basic elements to enable performance of different activities, and interiors described as "arranged grouping of products and generally enclosed within a structure" [8] (p. 6) to enhance activities and mediate external circumstances.

The proposed interior components typology respects the concept of building introduced by Duffy and formally articulated by DEGW — architectural and design practice co-founded by Duffy, Ely, Giffone and Worthington, in the early 1970s [4]. It recognizes the building as several layers of longevity of built components to be designed with regard to their different change rates that influence the whole built environment performance. These interconnected and interdependent parts of the building should be conceived within the spatial, structural and temporal contexts. This approach, further developed by Brand [29], enables consideration of these parts' adaptation to new functional or spatial requirements, with control over the material and products consumption, as well as energy usage. The model of the built environment presented by Duffy addresses the time-based approach in interior design and distinguishes relatively long-term architectural elements from those responding instantly to shifting demands regarding technological or organizational issues [4]. This scheme of shearing layers comprises of a shell, services, scenery combining space layout along with walls, suspended ceilings, raised floors, and settings. Duffy claims that these elements of different lifespans should be designed to remain independent from each other, so as to enable "intervention and replacement" [4] (p. 45) cycles within the built environment. The model presented by Brand distinguishes, respectively, structure, skin, services, space plan and stuff comprising furniture, recognized as separate parts of the built environment. In Brand's concept the interrelationship of layers, and the temporal context of changes are essential. As Meagher notices, the diagram developed by Brand suggests "rates of change as a primary organizing principle for building components" [30] (p. 161). This involves sustainable designs for adaptability, flexibility or deconstruction applied to the forming of interior components, as methods to conform to the resource's efficiency principle.

The typology proposed by the author classifies the interior components within the environmental context, referring to them as constructs that can assimilate the reclaimed or salvaged building materials

and products from building structural portions of refurbished or demolished buildings. The first group comprises components described as constitutive or structural, that establish the group of "non-shell portions" of building as assigned by Yudelson [31] (p. 188). In the proposed classification to discuss design methods to accomplish sustainable strategies in forming interior components, the author proposes inclusion of the following: (1) external walls and remaining structural building elements, determined as enclosures separating the inner space from the natural environment that remains physically developed and accompanied on the inner side by various technical devices or biological finishing [20]; (2) partitions and space dividers of various dimensions and configurations and multifunctional structures; (3) raised floors and (4) integrated, as well as suspended ceilings. The second group, described as supplementing or completing, comprises finishes of partitions or space dividers. The third one includes furniture, furnishings, fixtures and equipment, which remain of lower significance for the fulfilment of the sustainability requirement for waste management, realized with the further discussed adaptive reuse concept.

3.2. Interior Components Environmental Contextualization and Evaluation

The evaluation of man-made settings and its components, concentrated exclusively on the assessment of the degree to which a designed setting supports occupants' demands or affects human behavior, is incomplete. The post-occupancy evaluation mode offering the human-centered approach, and the analysis of "transactions of people and the built environment" [32] (p. 5), in sustainable design is to be expanded upon as well. It should extend the proximate environmental context (i.e., location of the space characterized by local climate conditions, air quality or transportation) on the valuation of the designed setting and its physical elements, and change the perspective assigned to the evaluation process. Comprehensive design assessment is to consider the consequences of creation of the designed environment on the integrity of the natural environment, while underlining both settings interdependency. Woolley, Kimmins, Harrison and Harrison claim that "each design decision [. . .] has environmental implications" [33] (p. 5) demonstrates this complex approach to the design concerns. Their statement can be assigned to the creation of interior components, evaluated in terms of their impact on the health of the natural setting, as well as the occupants of the built environment.

The environmentally sustainable interior architectural design scheme emphasizes the role of these components in moderating the interrelationship between designed and natural environments, based on predicting the consequences of mutual interconnectedness. Application of the interior components multifaceted environmental contextualization [34] proposed by the author, facilitates identifying and interpreting this interrelationship. The adjusted interior architectural design model integrates demands for interior components functional compliance, formal integrity and aesthetic identity, considered priorities within the conventional design framework, with the components' environmental contextualization, which is becoming the sustainable interior architectural design principle, and a driver of the process of integrative design (Figure 1). The design scheme of interior components comprises: (1) development of interior components in conformity with integrative architectural design objectives; (2) employment of comprehensive design criteria with emphasis on the temporal context; (3) inclusion of the interior components' environmental sustainability-oriented assessment to the design procedure.

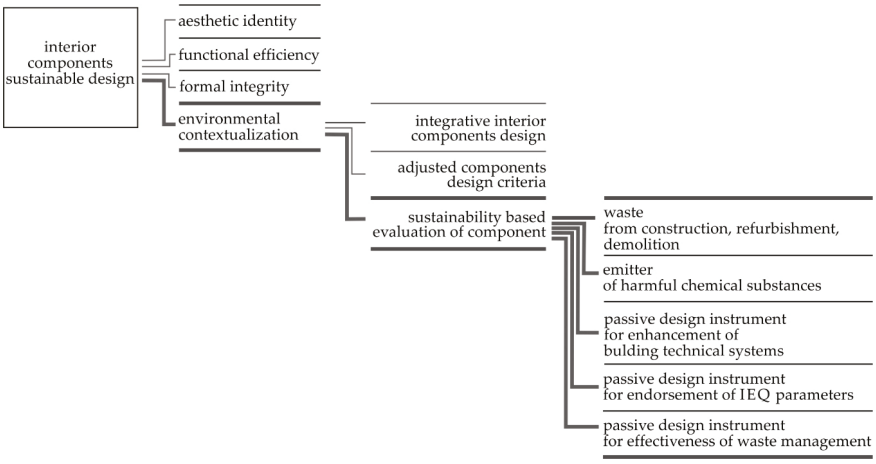

Figure 1. Interior components assessment based on their environmental contextualization. Source: author's drawing.

Application of interior components sustainability-based assessment (Figure 1) with regard to their spatial configuration, developed technical solutions and specification of used building materials, enables their recognition as: (1) waste coming from the cyclical processes of construction, refurbishment or demolition; (2) emitters of potentially harmful chemical substances influencing occupants health and wellbeing due to off-gassing process; (3) passive design instruments to employ passive mode design approach in the creation of the indoor environment.

Interior components, considered as passive interior architectural design instruments, and being environmentally activated [34,35], integrate the following multidimensional functions:

- Enhancement of building systems' performance through the reduction in energy consumption (e.g., suspended ceilings with light reflective finishing materials and inner light shelves supplementing external passive solar optical systems, to endorse building lighting systems with increased transmission and distribution of daylight in underlit areas of closed spaces, thermally activated suspended ceilings to enhance cooling and ventilating systems, partitions and space dividers' dimensions permitting cross ventilation and unobstructed air flow to reduce the usage of mechanical ventilation systems).
- Endorsement of indoor environment quality parameters including inner air parameters, relative humidity, thermic and acoustic comfort (e.g., vertical biological space dividers to assure appropriate level of relative humidity and temperature of inner air, and to provide occupants with acoustic comfort).
- Effectiveness in resources/waste management achieved with the reuse of reclaimed, recovered, and salvaged building materials and products initially forming other dismantled or refurbished interior or building components (e.g., ceramic bricks reclaimed from structural building portions, and reused as partitions finishes).

The statement indicating that "closing materials loops in construction remains the most challenging of all green building efforts" [36] (p. 390), can be applied to the design process of building interior spaces. The same requirements assigned to the complexity of building materials and products' manufacturing, transportation, installation, use, and maintenance processes, are to be met while creating the components of an indoor environment. The phases of completion and exploitation process followed by components dismantling and recovery to enable the remanufacturing procedure, remain in accordance with the close-loop concept [37]. The life-cycle approach to the creation of inner space,

as required from the environmentally responsible interior designers [38], and applied to the interior components shaping, is to decrease the negative environmental impact of building products, due to the execution of their "integrated life cycle management" [39] (p. 11). With the assigned substantial role in diminishing building waste production, interior components can be recognized as responsive parts of the built environment in reducing its negative effect on natural settings due to the reintroduction of building waste into interior space as valuable resources.

4. Interior Architectural Design for Adaptive Reuse

The design concept based on the process of reintroducing reclaimed materials or products into the building setting, requires adjustments of planning procedures and design solutions according to what becomes available, as Baker-Brown from the Superuse Studios indicates [28]. This approach to the architectural design process combines the comprehensive framework of adjustment existing building substance to new functional requirements, along with the cost-effective process of deconstruction, reclaiming and adaptive reuse of building materials and products. The interior components made with reused parts without significant reshaping or reprocessing, and placed in a different functional and spatial context, are becoming developed products of a high environmental profile. Prevention of the negative environmental impact of building products through their conversion as deconstruction or demolition waste to valuable indoor environment components, is therefore a complementing design method for the adaptive reuse of existing buildings.

The design approach of remanufacturing building waste into high performance, valuable interior components, indirectly leads to changes in users' consumption-related attitudes. With the modifications of design intervention focused on design for the sustainable use of products [40], these components become drivers for changes in consumers' perception of environmentally responsible design methods and build up reflections on the reduction of the negative impact on natural settings accomplished through the resources' efficiency strategy. Therefore, this interior architectural design approach, emphasizing the environmental context in interior components development, is to become a part of Design for Sustainable Behaviour. As the "environmental performance of a product during its use phase is directly affected by user's behavior" [41] (p. 426), it is justified to make assumptions that the performance of the product made by a sustainable interior architectural design method of inter-setting adaptive reuse, as detailed in the following section, can influence occupants' environmental attitudes and habits.

4.1. Inter-Setting Adaptive Reuse in Application of Waste Management Scheme

The proposed interior design intervention situated between reuse and recycle architectural design approaches, and oriented towards controlling the consumption of building materials and products, is appropriate for sustainable interior components creation (Figure 2). Interconnectedness of natural and built environments allows us to recognize adaptive reuse as an integrative interior architectural design model, as well as essential for a designers' environmental-responsibility indicator of an interior and its components. It is, thus, reasonable to apply a similar scheme regarding the indoor environment constitutive components creation process, and design methods in search for the means of resources management optimization and extension of building materials' lifespan. The most effective and technically affordable methods of fulfilment of reuse demand, combine the design for selective demolition, design for direct reuse, as well as design for adaptive reuse of reclaimed or salvaged building construction materials and products. The latter refers to the employment of acquired objects in another, differently defined application mode, while preserving their usefulness and performance. Components designed with the proposed adaptive reuse method can be identified as complex "instrumented products" [41] (p. 430) that are structured with acquired parts and then situated in different environmental, functional and formal contexts.

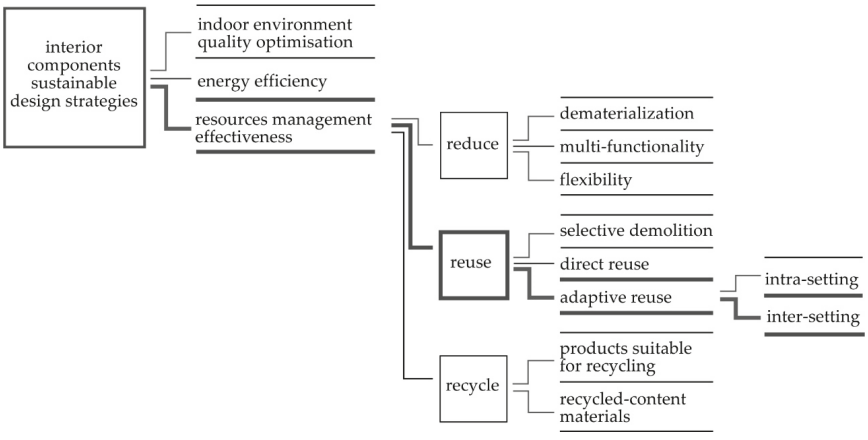

Figure 2. Inter-setting adaptive reuse in application of efficient resources management strategy into interior components design. Source: author's drawing.

Interior architectural design for adaptive reuse, respects semiotic connotations of adaptive reuse, meaning to reuse in order to fit [42]. The term is identified for the purposes of this study, as a design method based on the reintroduction of reclaimed building materials and products from refurbished or demolished buildings into the indoor environment in order to: equip them with new functions, add new formal value, and provide them with a new spatial context resulting from their transfer and conversion from building waste to resources enabling the completion of new interior components. Through their placement in different functional and environmental contexts, the value of building materials and products is maintained, and usefulness extended. Interior architectural design for adaptive reuse concept can be analyzed from different perspectives and in multi-dimensional aspects. Building materials or products recovered from a dismantled or deconstructed building structural portions and re-introduced in a new context of internal spaces on the basis of the inter-setting adaptive reuse scheme, are becoming quality resources for the completion of refurbished or newly conceived interior space components.

4.2. Implications of Interior Architectural Design for Adaptive Reuse

The scope of possible environment-oriented implications, due to the employment of this design method, is described in the Figure 3. The consequences identified by the author include the following: (1) multiple transfer of reclaimed or salvaged building materials or products and their reintroduction into structures of interior components; (2) multi-faceted implementation of reclaimed or recovered building materials or products as multifunctional structural parts of interior components; (3) structural reconfiguration of interior components achieved with partial replacement of their originally conceived parts; (4) expand-circuit distribution as more environmentally friendly then the unfavorable open-circuit linear process and achieved by drawing back building materials from refurbished or demolished building structural portions, and incorporating them into the indoor environment as interior components construction or finishing; (5) extending building products' lifespan through the reintroduction of reclaimed building materials and products, with limited treatment procedures and generated post-construction waste, into the indoor environment as a quality part of developed interior components.

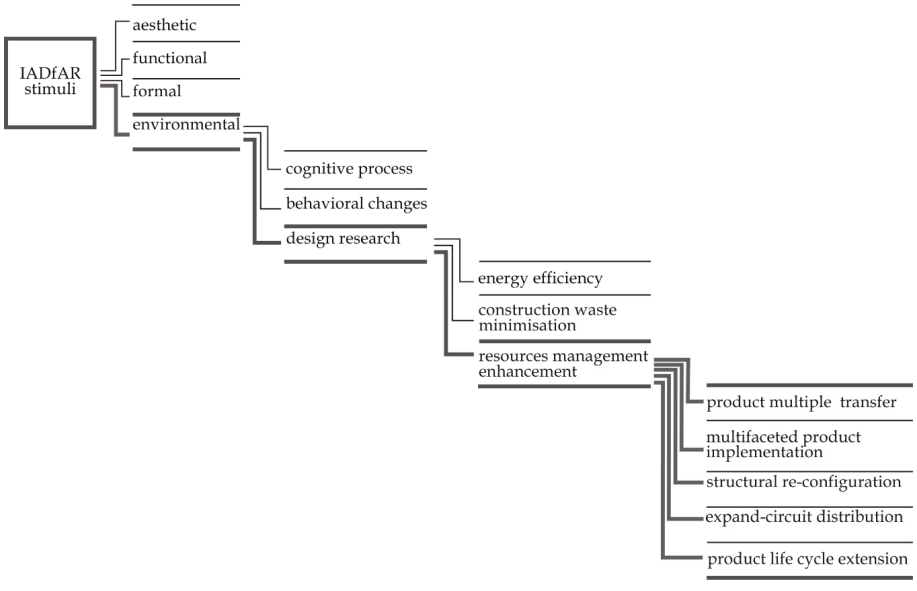

Figure 3. Environmental implications of Interior Architectural Design for Adaptive Reuse (IADfAR). Source: author's drawing.

The proposed conceptual model of interior architectural design for adaptive re-use, generates new design strategies and methods for the shaping of interior components. Functional and formal assimilation of reclaimed or salvaged building materials and products with interior components is an alternative to the production of their equivalent substitutes containing recycled materials. This adaptive reuse design model assures a closed-circuit model identified by Kibert [22], as being in the opposition to the once-through or open-circuit design patterns.

4.3. Strategies and Methods of Interior Architectural Design for Adaptive Reuse

The effectiveness of the presented design model requires design intervention strategies to emphasize the inventive character of design based on the reintroduction of construction waste, namely reused parts of building portions, into the interior space components substance and techniques of integration from the building product's former appearance with their new image. The framework of interior architectural design for adaptive reuse corresponds to the design strategies defined by Brooker and Stone [17]. The IADfAR conceptual model identifies following possible design strategies:

- Inversion, meaning the broad acquisition of available reclaimed building products from refurbished or demolished buildings to their reintroduction into the indoor environment and adaptive reuse as valuable building materials, understood as the superior design principle aimed at building products reversal from costly reprocessing, recycling or final disposal in a landfill.
- Inclusion, meaning fragmentary inclusion of salvaged building materials or products, and their link with other parts of interior components, as means of an exercised flow of resources between the indoor environment and natural surroundings.
- Integrity, understood as established unity of building components and interior spaces constituting components, to enable multi-functional interpretation and exploration of their potential.

The design methods and the execution modes to complete the inter-setting adaptive reuse design concept are to assist consumers in understanding sustainability principles, accept pro-ecological design proposals focused on the conscious resources' management, as well as stimulate their pro-ecological

behavioral schemes. Building up a relationship based on recognition of environment-responsibility associations with appearance of an interior component can be realized through the exemplary design methods: (1) design for display to attract users' attention through the appearance of reused building materials; (2) design for interaction to build up knowledge on the impact of interior components on the natural environment; (3) design for connection to provide users with evidence on their contribution to environmental integration due to interior components selection based on adaptive reuse models.

The objectives of the above-mentioned design methods, supplemented with the exemplary execution modes to enable their application, are presented in Figure 4.

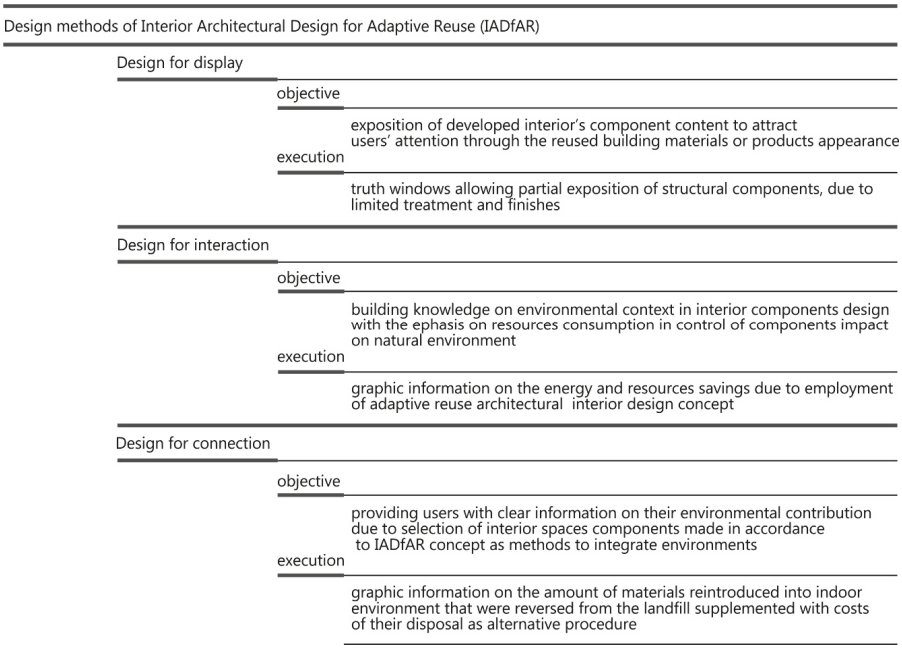

Figure 4. Design methods for application of Interior Architectural Design for Adaptive Reuse (IADfAR). Source: author's drawing.

4.4. Interior Architectural Design for Adaptive Reuse Determinants

The successful application of this sustainable strategy of resource consciousness requires an innovative approach from designers in forming interior components, and developing modified design criteria focused on the limited use of new resources in order to "cause minimal detriment to the environment" [9] (p. 191). To investigate determinants for successful acquisition and recirculation of reclaimed building materials and products from structural building components in the indoor environment, the analysis of multiple data is required. Data assembled as a the result of conducted studies to facilitate the application of sustainability-oriented proposals into environmentally responsible interior design comprise: (1) feasibility studies on availability of material supply from refurbished or demolished buildings to create a distribution model, and assess the technical aspects related to method's application; (2) assessment of designers' knowledge and commitment to apply adaptive reuse design model to accomplish sustainability principles; (3) assessment of users' environmental habits, and their approach toward the implementation of reclaimed building materials or products into interior components substance.

Feasibility concerns regarding the inter-setting adaptive reuse design conceptual model address the following questions:

- Availability of building materials and products reclaimed from structural portions of refurbished or demolished buildings that are suitable for reintroduction into indoor environment, costs of their acquisition, transportation and distribution;
- Access to the online detail inventory of waste materials from demolition or refurbishment processes to be reintroduced into interior components substance;
- Access to the systems to connect building materials to reuse vendors and deconstruction contractors with architects or interior designers in order to provide them with the information about the undertaken "just-in-time building demolition" [43] (p. 391) activities;
- Assessment of physical parameters of reclaimed products, including the content of potentially harmful chemical substances used in the production and assembly processes employed initially;
- Specification of necessary restoration works or treatment procedures as preceding reintroduction of acquired building materials or products, to assure their high performance;
- Specification of treatment of materials or products to conform the current building code requirements (e.g., thermal insulation, acoustical conditions, fire safety rules);
- Accessibility of accredited green building consultants and professionals to provide expertise on the process of reintroducing reclaimed products into the interior environment;
- Accessibility of professionals skilled in performing the restoration of reclaimed building products to be reintroduced.

Reintroduction of the reused artefacts into an indoor environment involves other practical problems that address different technical and technological aspects to investigate. These refer to the evaluation of the structural obsolescence and poor durability of acquired products, as a consequence of originally employed faulty techniques and assessment of the exploitation and maintenance procedures implemented in the previous technical life phases of the objects, due to low performance standards of reclaimed building products as a result of outdated manufacturing methods and poor material quality.

The commitment of interior designers to the consequent execution of innovative design strategies focused on rationalization of resources' consumption requires complex decision support systems, as well as the support of end users assured with the incorporation of social-cultural dimensions within the environmentally responsible interior design model. Application of IADfAR moderates adjustments in occupants' behavioral attitudes towards the assignment of environmental perspective to design decisions, as "designing a product means designing a user experience with the product" [40] (p. 429). Indication of the potential benefits of reintroduction of reclaimed materials and products made by designers on the basis of the identification of these artefacts' aesthetic and experience values [16], is a condition of users' acceptance of proposed pro-ecological solution. The behavioral effects of reintroduction of reclaimed products into the indoor environment combines occupants' engagement in the environmentally-conscious creation of the near environment, as well as their involvement in the employment of sustainable practices in other forms of activities. Thus, establishment of users' reconnection to reclaimed building materials or products, remains another positive aspect of this innovative method in interior architectural design.

As indicated Kollmuss and Agyeman [44], an investigation to undertake prior to the project is to comprise internal factors assigned to the personal experience, (i.e., personal attitudes, individual priorities influencing the awareness of environmental impact of buildings internal surroundings) as well as external factors comprising normative influences (i.e., traditional socio-cultural models as exercised in a close circle or family customs being traditionally repeated). The Model of Responsible Environmental Behavior [44,45] forms another substantial tool for the relevant research. It emphasizes the knowledge of issues and situational factors (e.g., social pressures, opportunities to choose different actions) as important and scientifically proven variables associated with the ability of taking pro-environmental actions. All these factors can influence the users' pro-environmental behavioral schemes, and affect their acceptance of sustainable interior design decisions, including the discussed adaptive reuse concept.

The predesign research on the socio-behavioral context of the interior design process is to provide designers with valuable outcomes on the respondents' approach toward the indoor environment, and to determine the reasons of probable rejection of IADfAR in shaping indoor environments by consumers. The exemplary factors to be identified and measured in the predesign phase are as follows:

- Recognition of the value of the environmental context applied into the interior architectural design;
- Assessment of the influence of the visual obsolescence of acquired building materials and products, as a probable source of unsatisfactory aesthetical sentiments or negative emotional responses;
- Assessment of the social obsolescence of acquired reclaimed building products, as source of confusing semantic connotations;
- Assessment of the scale of attachment to the aesthetical preferences established on the traditional socio-cultural schemes.

This research measures occupants' abilities to discover the main benefits of the reintroduction of reclaimed or salvaged building construction materials and products into interior spaces. These comprise preservation and adaptation of cultural and heritage values expressed in the valuable reclaimed components, exposure of multi-functional values of selected reclaimed components, continuity in the cultural proficiency coming from the reused building parts, expression of the identity of local building tradition, craftsman's workshop, and development of new knowledge related to technical methods of forming building components. The identification of these possible effects on values associated with human activities is to increase the users' interest in exploring the environmental context in the interior components' creation, through the application of the adaptive reuse concept. The complex introduction of this design method is to build knowledge on sustainability issues that stimulate users' sustainable behavior and encourage them to make environmentally responsible choices focused on efficient resources management.

5. Conclusion and Future Research

The waste that results from building deconstruction, refurbishment, or demolition is recognized as one of the leading problems by architecture critics and the design profession. The design methods and techniques toward the conservation of natural resources, minimization of energy consumption and waste production, have to be supplemented with the adaptive reuse of reclaimed or salvaged products. Regenerative and restorative objectives of environmentally-oriented interior design could be endorsed and achieved with the consequent application of the adaptive reuse of reclaimed or salvaged building materials and products in the interior design concept. This model assures resource efficiency in the interior's completion in a more then alternatively considered manufacturing or recycling processes.

The multi-faceted introduction of recovered products or their parts as proposed by the author, assuring their superuse [27] within the indoor environment can be identified as an important environmentally responsible interior design method. The reclaimed building materials and their specification in the project's documentation, can become a decisive factor in the shaping of "deep ecological aesthetic" [46] (p. 165). This notion, originally used in the context of architectural design to explore the influence of environmental factors on buildings spatial modeling, can be assigned to the interior architectural design process that includes the comprehensive management of materials, products or internal components, available on site or acquired from buildings under deconstruction or demolition.

Interior architectural adaptive reuse design model can be identified as an incentive for innovative searches for aesthetical identity, functional conformity or formal integrity of inner spaces and their components, as considered in conventional design processes. The proposed interior architectural design concept stimulates the accomplishment of environmental sustainability, endorses cognitive transformations and evolutions in the interior spaces of users' behavioral schemes and drives an interior architectural design research toward pro-ecological design solutions, assuring control over construction waste production, as well as the enhancement of resources management. This demand

is achieved with the implementation of interior architectural design for adaptive reuse, particularly through its inter-setting procedure.

This conceptual paper points out some new approaches for the sustainable interior components design and provides a starting point for further discussions on the comprehensive inclusion of adaptive reuse into the interior design methodology, highlighting the importance of the waste management criterion as for the object's ecological effectiveness. Inclusion of this concept into the decision-making process, as well as its further development is to defeat uncertainties or misunderstandings over the position of discipline in the reduction of the negative impact on the natural environment, and to build up the informed interior architectural design.

There is necessity for the complementing studies on the designers' perception of this innovative design model in order to build a framework for integrative building materials and products adaptive reuse concept within a traditionally structured linear design process. Further studies should provide empirical findings on effects of this new design method on the measurement of the designers' ability to: (1) identify the main benefits of reimplementation of reclaimed or salvaged building materials and products from structural building components into interior components; (2) explore the architectural implications of forming internal spaces components in accordance with the interior architectural design adaptive reuse model; (3) develop design techniques to shape interior components as responsive multifunctional structures within the indoor environment.

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