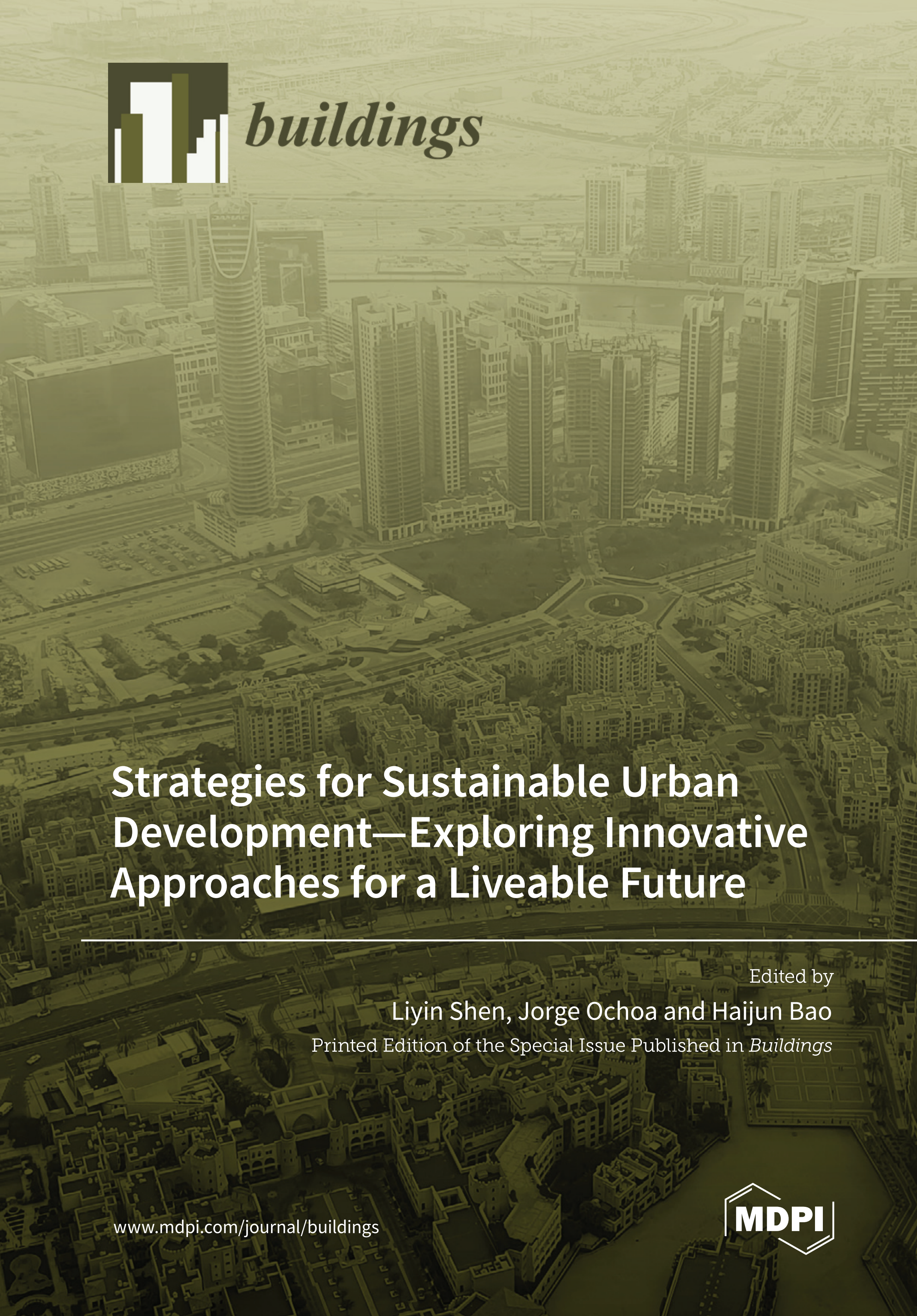

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Strategies for Sustainable Urban Development—Exploring Innovative Approaches for a Liveable Future

Edited by
Liyin Shen, Jorge Ochoa and Haijun Bao

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Prof. Liyin Shen is a Qiantang Distinguished Professor and the Chief Scientist at the Research Institute for Planning and Sustainability at Hangzhou City University. He is also the Director of the International Research Centre for Sustainable Built Environments at Chongqing University. Professor Shen's research is currently focused on sustainable built environments, with a specific interest in the low carbon city, the urban carrying capacity and the experience of mining for sustainable urban development. He is on the list of internationally Highly Cited Researchers, published by Clarivate, on that of The Most Cited Chinese Research Scholars, published by Elsevier, and on that of The World's Top 2% Scientists (Career and Singler), published by Stanford University. Professor Shen was the Founding President of the Chinese Research Institute of Construction Management (CRIOCM) and the Founding Editor-in-Chief of the International Journal of Construction Management (IJCM). He holds a number of external appointments as an Honorary Professor and a Visiting Professor, internationally.

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Dr. Jorge Ochoa is a Senior at the University of South Australia. He is a leading scholar in the field of the sustainable transformation of built environments. His research is focused on developing systems and decision support tools that leverage cutting-edge technologies, such as big data analytics, artificial intelligence, and visualisations, in order to address challenges in the built environment. Dr Ochoa collaborates closely with industry partners and end-users to develop innovative solutions with real-world impact beyond the academic sphere. As a result, his work has been widely recognised and adopted by prestigious organisations, including the United Nations Human Settlements Programme (UN-Habitat), the European Commission DG Environment, the United Nations World Water Assessment Programme, and the New York City Panel on Climate Change. Dr Ochoa's contributions to the field have also earned him numerous external appointments as a Visiting Professor, and he has been invited to deliver keynote addresses at prominent industry and academic forums, such as Rio+20 and the World Urban Forum.

Haijun Bao

Prof. Haijun Bao is a Professor and the Head of School of Spatial Planning and Design at Hangzhou City University; he is also the Director of the Research Institute of Planning and Sustainability at the University. He obtained his PhD degree and Postdoctoral training in the College of Environmental and Resources Sciences at Zhejiang University. Professor Bao's research interests include spatial planning and urban and rural governance. Recently, he has focused on the issues of new urbanisation and rural revitalisation, land space governance and common prosperity. He is the Director of the Special Committee on Quality of Urban Green and Low Carbon Development in the China Association of Building Energy Efficiency (CABEE). In the capacity of Principal Investigator, Professor Bao has obtained four national-level projects from the National Natural Science Foundation of China and the National Social Science Foundation of China, and ten provincial and ministerial-level projects. He has published more than forty academic papers in top journals internationally, including Land Use Policy, Cities, the Journal of Rural Studies, and Habitat International. Impressively, he has received both the 20th Outstanding Achievement Award of Philosophy and Social Sciences of Zhejiang Province and the 19th Outstanding Achievement Award

of Philosophy and Social Sciences of Zhejiang Province.

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Editorial

Strategies for Sustainable Urban Development—Exploring Innovative Approaches for a Liveable Future

Liyin Shen [1], J. Jorge Ochoa [2,*] and Haijun Bao [1]

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Cities are the engines of economic growth, but they are also the source of many environmental and social challenges. The increasing urbanisation trend and the associated rise in energy consumption, greenhouse gas emissions, waste generation, and social inequality have raised the urgency to develop sustainable urban strategies. Sustainable urban development is not only concerned with reducing environmental impacts but also creating liveable, healthy, and inclusive cities that enhance the well-being of their residents.

This Special Issue presents a diverse set of topics that address various aspects of sustainable urbanisation. It covers different dimensions of green buildings, rail transportation, land-use efficiency, energy consumption, innovation management, heritage preservation, digital technologies, and behaviour change. These topics are relevant to the current urban sustainability discourse and have the potential to contribute to the development of practical and effective strategies for sustainable urban development.

The works presented in this Special Issue are intended to provide researchers, practitioners, policymakers, and students with a comprehensive and up-to-date perspective on sustainable urban development. A total of ten original research studies were published, offering empirical evidence, theoretical insights, and practical recommendations that can inform and inspire sustainable urban strategies. The Special Issue's interdisciplinary and international scope reflects the complexity and diversity of urban sustainability challenges and opportunities.

Fu et al. [1] examined the impact of green building schemes on the well-being of occupants, an important yet underexplored dimension of urban sustainability. Despite the growing popularity of green buildings, existing studies tend to focus on technical aspects rather than the impact on occupants. The authors conducted a systematic review of current research to develop a conceptual framework that links green building features with six dimensions of occupant well-being, including both subjective and objective aspects. The study demonstrated that green features can positively affect occupant well-being in various ways, such as improving indoor air quality and reducing noise pollution. The authors recommended that future green building development and empirical research take a more occupant-oriented perspective to maximise the potential benefits of green buildings. This paper contributed to the emerging discourse on sustainable urban development by providing a new perspective on the role of green buildings in promoting occupant well-being.

Tordai and Munkácsy [2] studied the relationship between real estate prices and distance from metro or commuter railway stations. Previous studies on this topic were limited due to the heterogeneity of real estate. In this study, the researchers analysed data on panel flats in Budapest, which were built with uniform technology between the 1960s and 1990s, and therefore represent a highly homogeneous real estate type. Using linear regression, the study reported a statistically significant relationship between real estate prices and distance to the nearest station, with a 1% decrease in prices for every additional

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five minutes of travel time to the nearest station. These findings have potential implications for value capture policies aimed at increasing the viability of urban railway projects.

Chen et al. [3] investigated green land-use efficiency (GLUE) in the Yellow River Basin (YRB), an ecologically fragile area and an important ecological functional area, using the super-efficiency SBM model and Tobit regression model to analyse influencing factors. The results revealed a spatial pattern of "high in the west and low in the east" for GLUE, and an overall annual increase in efficiency values, although differences exist among various areas and types of resource-based cities. Economic development and population growth significantly impact GLUE, highlighting the importance of improving social and public services to ensure regional green and low-carbon transformation and development. The study concluded that improving the efficiency of low-efficiency regions or cities is crucial for enhancing regional GLUE.

Xie et al. [4] presented a new method for identifying and classifying urban functional areas using a multimodal deep learning approach with an attention mechanism. Urban functional areas are essential spatial units for urban planning and management. The complexity of urban land use makes it challenging to identify these areas using only remote sensing images. This study proposed a method that combines remote sensing data and social perception data to identify functional areas. The remote sensing images, points of interest, and building footprint data were divided into block-based target units, and a two-branch convolutional network was used to extract remote sensing image features and social perception data features. Features were then sequentially extracted along two separate dimensions to generate an attention weight map for the identification and classification mapping of urban functional areas. The method was tested on the Ningbo dataset, and the results showed that the proposed method outperforms traditional methods, with an accuracy above 93%. This study provided a reference for the classification of urban land use and data support for urban planning and management.

Jo and Kim [5] aimed to identify the factors affecting electrical energy consumption in urban buildings and to analyse their influence at both global and local scales in Seoul, Korea. Multiscale geographically weighted regression (MGWR) was employed to explore the impacts of urban characteristics such as population and household characteristics, outdoor temperature, green and water areas, building area according to usage, and construction age. The findings indicated that these factors significantly affect the energy consumption of buildings, and their effects vary spatially and regionally. The study provided important insights into the spatial distribution and patterns of urban characteristics and their influence on energy consumption reduction in buildings. This research has significant implications for policy-makers and urban planners seeking to promote eco-friendly policies and sustainable energy practices in cities.

Yin et al. [6] studied the significance of digital green innovation management for sustainable urban development, with a particular emphasis on the prefabricated construction enterprises (PCEs). The authors proposed a conceptual partner selection framework for the digital green innovation management of PCEs towards urban building 5.0. The framework system was built based on the integration of symbiosis theory and six analysis methods, resulting in a 3W1H-P framework. The dual combination weighting method was used to avoid any subjective or objective deviation in attribute weight and time weight. Empirical research was conducted to verify the reliability and practicability of the framework system and selection model. The study concluded that the proposed framework system and selection model can assist PCEs in selecting joint investment partners for digital green innovation projects, contributing to sustainable urban development.

Konbul and Yanalak [7] discussed the importance of preserving culturally and historically significant buildings, while also acknowledging the economic losses that landowners may face due to restrictions on development rights. The lack of compensation for these losses can result in social injustice and can even lead to the destruction of unlisted historic buildings for redevelopment. Traditional methods of compensation, such as expropriation and property exchange, have not been successful in addressing this issue. The article suggested that transfer of development rights (TDR) could be a viable option in Turkey, and outlines a step-by-step methodology for implementing a TDR program from a land management perspective. The methodology was tested and validated through interviews with 18 professionals from related sectors, and the results have the potential to benefit both property owners and preservation efforts in the country.

Zhang and Zhou [8] explored the impact of digital policies and technologies on in-situ urbanisation patterns in China, which is a topic that has been largely overlooked in the existing literature. The study adopted a law and policy research approach to conduct the phenomenon presentation, institutional analysis, and limitation interpretation. The authors of the study argued that the digitalisation of the countryside has drastically changed the traditional in situ urbanisation process, which is termed as in situ urbanisation 2.0. The study identified three reasons why rural digitalisation reform has triggered in situ urbanisation 2.0, namely historical legitimacy, performance legitimacy, and socially sustainable reproduction. However, the study highlighted the double dilemma of overreliance on technological change in the in situ urbanisation 2.0 process, which requires legislative and policy adjustments. The study concluded by proposing four recommendations for action to address these dilemmas, thereby contributing to the literature on sustainable urban planning and rural digitalisation reform.

Li et al. [9] investigated the ways in which the global hospitality industry faces the challenge of managing energy and reducing carbon intensity due to growing environmental concerns and significant energy consumption in hotel buildings. One potential strategy to achieve sustainable hotel operation and maintenance is by activating guests' energy-conservation behaviours. However, the psychological mechanism of hotel building energy-conservation intention and the roles of personality traits remain inadequately investigated. This study used a modified theory of planned behaviour (TPB) to examine the impact of guests' extraversion levels on their hotel building energy-conservation behavioural intention. The study reported that extraversion negatively affects perceived behavioural control but positively impacts personal norms, both of which significantly contribute to guest energy-saving intention. Past behaviour positively moderates the effects of extraversion on subjective norms and personal norms. The research contributed to the hospitality and tourism management literature by shedding light on the influence of guests' personality characteristics on their pro-environment intentions during their stays in hotel buildings. The findings can drive the hotel building energy management forward through actionable and effective energy-conservation interventions and enhanced guest satisfaction.

The academic study by Xu et al. [10] investigated the impact of city–county consolidation on enterprises' earnings management through the theoretical transmission mechanism of intensified competition in the enterprise market. Using a difference-in-differences method on data from 1999 to 2006 of industrial enterprises, the authors determined that city–county consolidation promotes the use of earnings management and intensifies downward earnings management behaviour. Additionally, non-state-owned enterprises are more motivated to implement earnings management than state-owned enterprises. However, the impact of city–county consolidation on earnings management is only significant for enterprises affiliated with counties, not for those affiliated with central, provincial, or municipal governments. These findings provided important empirical evidence for optimising administrative divisions to improve national governance capacity in urbanisation development.

In conclusion, this Special Issue provides valuable and multifaceted insights into the complexities and diversities of sustainable urban development. The diverse range of topics covered in this Issue yields valuable insights into the opportunities and challenges presented by sustainable urbanisation. The collection of articles underscores the importance of sustainable urban strategies that consider not only environmental issues, but also social, economic, and health factors. This highlights the need for a holistic and integrated approach to sustainable urban development.

The editors would like to sincerely thank all the authors who contributed their work to this Special Issue. Their expertise and knowledge have made this publication a comprehensive and insightful reference for researchers, practitioners, policymakers, and students contributing to sustainable urban development. We express our special appreciation to the peer reviewers for their valuable contribution in providing constructive feedback and enhancing the quality of the presented works.

The editors hope this Special Issue will contribute to a better understanding of sustainable urban development and inspire practical and effective strategies for creating liveable, healthy, and inclusive cities for all.

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

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Article

New Dimension to Green Buildings: Turning Green into Occupant Well-Being

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Abstract: A series of international conferences and initiatives, such as the Habitat III New Urban Agenda and UN Sustainable Development Goals, have urged industry, scholars, and policymakers to create an inclusive and sustainable built environment for all in the coming era of cities. Green building schemes, which have been gaining momentum over recent decades, are one of the most influential measures that have been taken to promote urban sustainability. However, due to disciplinary characteristics, most current studies share a techno-engineering focus. Seldom do they answer the question: will green buildings make a difference to the occupants? This paper explains how, and to what extent, green features and design contribute to different dimensions of occupant well-being by conducting a systematic and comprehensive review of current journal articles and industrial reports. It provides an alternative, occupant-oriented perspective to the conventional discourse. A conceptual framework is developed, revealing that green building aspects are linked to six dimensions (three subjective and three objective) of occupant well-being. It further shows how different green features are linked with these dimensions through a detailed examination of the literature. Finally, suggestions are provided based on the research findings for the direction of future green building development and empirical research.

Keywords: green buildings; occupant well-being; healthy buildings; occupant-orientation; indoor environment conditions

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1. Introduction

Urban sustainability on multiple frontiers has been promoted in recent years, with the human-centered perspective receiving unprecedented attention and more stress on the utility, performance, and effectiveness of sustainable measures. These themes occur regularly, most recently in a series of international conferences and initiatives. The Habitat III New Urban Agenda is probably the most important, as it constitutes a more specific and feasible agenda for urban sustainability and highlights the importance of building an urban environment that contributes to the well-being of all residents. Occupant well-being has always been one of the issues in built environment sustainability, yet it has never become the focus of academic debate. However, in a new urban epoch where the built environment is playing an unprecedented crucial role in people's lives, this question needs to be examined more thoroughly and systematically.

Nevertheless, attempting to maximize the utility of the environment and contribute to the well-being of human beings is not a contemporary theme. Its seeds are buried in our civilization even at the earliest stage, thousands of years ago. The pursuit has never halted. For example, dating back to the warring state period (around the beginning of Anno

Domini) in China, the integration of human behaviors and spirit with the environment was considered the top priority of human well-being, which is the cornerstone of the popular Confucius and Taoist doctrines [1,2]. This view has not diminished in the process of rapid urbanization. Rather, it has mutated and adapted itself to the era of cities, arguing that the built environment now surpasses the natural environment and exerts an ever-increasing influence on the well-being of city dwellers [3,4].

This trend echoes with multiple global development consensuses and initiatives. For instance, the 11th Sustainable Development Goals (SDG) of the UN 2030 Agenda for Sustainable Development clearly states that city residents need to be provided with an "inclusive, safe, resilient and sustainable" built environment and to improve the well-being of the general citizens [5]. The Gallup poll in 2016 also indicates that the built environment is highly relevant to the overall well-being of occupants worldwide [6]. In effect, efforts have been maneuvered globally to enhance the well-being of occupants by encouraging more sustainable/greener design and construction technologies, leading to the flourishing of various green building schemes with little difference in regional characteristics. Green building certification, as one of the most universally adopted approaches to promote the sustainability of the built environment, therefore, needs to be revisited to see how, and to what extent, green buildings have contributed to the well-being of occupants. As a result, a group of academic researchers and professional practitioners at the cusp of the interface of social, environmental, and engineering studies has begun to investigate the influences of the built environment on people [7].

However, it should be noted that current research is still scattered, and there is remains a gap to fill. First, current research is mostly from a techno-engineering perspective and seldom from an occupant-oriented perspective. Second, occupant well-being is a very broad concept, with many different dimensions, covering a wide range of disciplines from engineering to sociobiology. Thus, current studies are mostly fragmented and isolated. Often, they simply deal with only one or some dimensions of occupant well-being and fail to evaluate the issue in a comprehensive and systematic manner. Most relevant research targets cases in a certain region or country, so the results may be less representative on a global scale. Third, as a multi-faceted concept, some dimensions of well-being are more subjective. To date, current research on such aspects is still lacking. Moreover, the benefits involved change over time, which is also an often-neglected area of study.

This paper provides a panoramic view of how green buildings contribute to different dimensions of occupant well-being by reviewing current journal papers and interdisciplinary industry reports. As shown in Figure 1, the renowned tripartite structure of sustainability is one of the most popular concepts in research into sustainable urbanization. Nonetheless, previous research into green buildings, although also addressing issues in these three aspects, is mostly drawn from impersonal perspectives. This paper aims to summarize the current research from a human-oriented perspective to investigate how and to what extent green buildings will contribute to occupant well-being. It is, therefore, meaningful to evaluate whether the steps taken to promote urban sustainability have really made a difference to the public in general. The second part introduces the method of this paper, explaining how the current literature is reviewed and reorganized in a more comprehensive and systematic manner. Section 3 examines the dimensions of well-being and reveals how different green building aspects are connected to the dimensions of well-being. Section 4 illuminates the way forward for green building development in the future by offering some practical suggestions. It also discusses possible prospects for future research into green buildings. Conclusions are made in the final section.

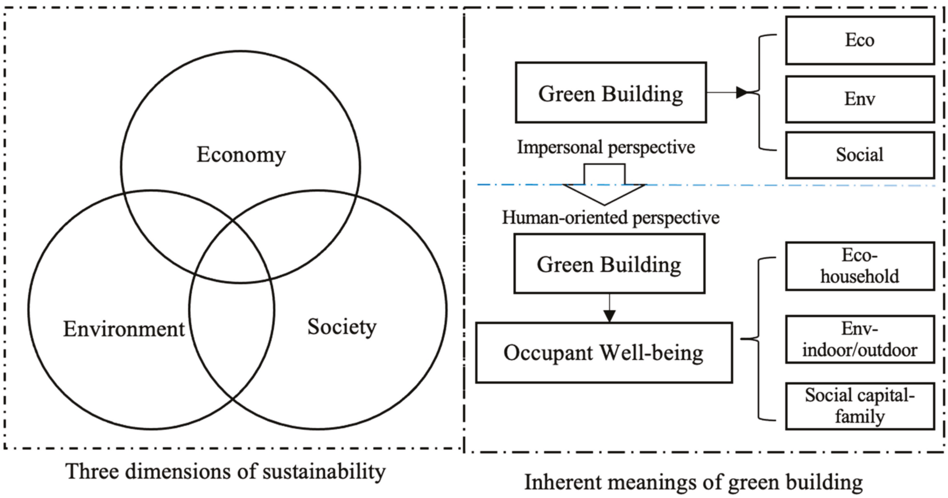

Figure 1. Inherent meanings shift from "Turning green into gold" to "Enabling green for well-being".

2. Methods

The arguments in this paper are based on a systematic review of the current literature concerning green buildings and occupant well-being, including both academic journals and industrial reports. It needs to be highlighted that occupant well-being is a broad concept that covers various dimensions. However, green buildings are relevant to aspects of occupant well-being. Figure 2 reveals the roadmap of the research. To specify the conjunction of these two concepts, we need first to review the literature relating to the dimensions of well-being and see how they are connected to green buildings. In Section 3, a summary of the definitions and dimensions of well-being is followed by a review of general well-being relating to green buildings. The Web of ScienceTM is the primary source of the review. However, as articles on the overall impact of occupant well-being are rare (around a dozen in number), complementary reports from industry are also included to define the dimensions of well-being most relevant to green design and features. As a result, it is concluded that the conjunction of green buildings and overall occupant well-being (i.e., green features and design) will directly or indirectly affect the dimensions of well-being. These comprise reducing household expenditure (bill saving) on energy and water, physical health, indoor environment, mental health, occupant comfort, satisfaction, and way of life. It should be noted that the former three are objective dimensions while the latter three are more subjective.

Upon defining the six dimensions, journal articles in the Web of ScienceTM were searched using the keywords (and synonyms) of each dimension together with "green building". Figure 3 shows the number of publications between 2005 and 2016 relating to each dimension. Publications prior to 2005 are not illustrated, as such themes are very limited. Some articles also simultaneously measure the mental and physical health of green building occupants, so the two types are combined together as "health", yet as they belong separately to objective and subjective realms, a detailed discussion of the two dimensions is still made in two groups in the upcoming sections. However, research into how green buildings have changed the way of life and enhanced the social capital of the community is lacking. Though they are not illustrated in the figure, they are discussed as a distinct category in the following sections. It is clear that bill saving, which includes energy saving and water saving, attracts the most attention, but peaked in 2013. Although still the leading research topic in these dimensions, it is quickly being overtaken by research into other dimensions.

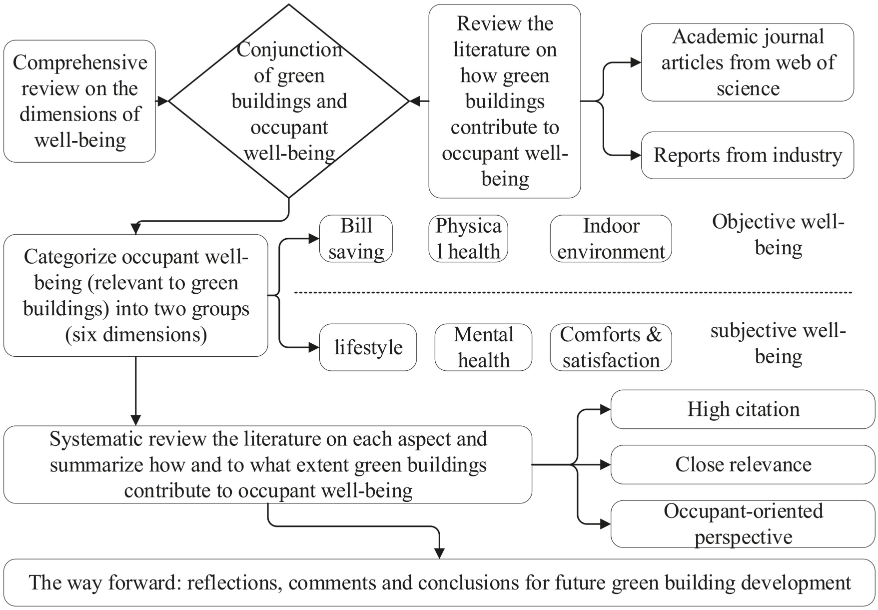

Figure 2. Process of the research design.

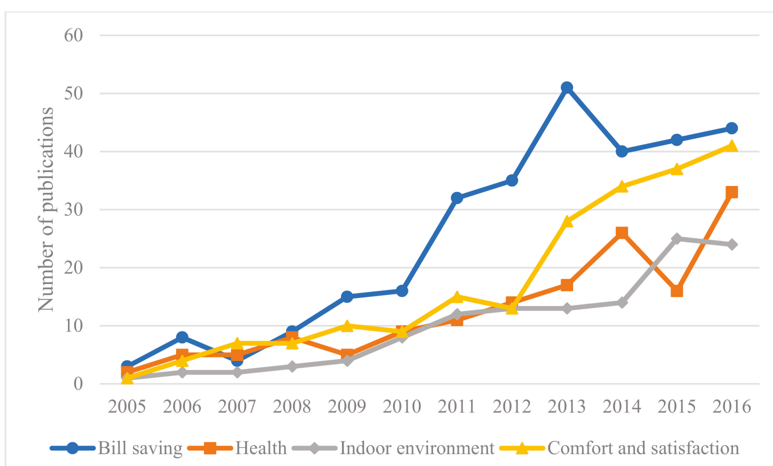

Figure 3. Annual publications of four dimensions of occupant well-being (Web of Science).

It also reveals that the focus has been shifting to more subjective and human-oriented issues, such as how green buildings increase occupant comfort, satisfaction, and health conditions. Publications concerning occupant comfort and satisfaction have constantly grown in recent years and may potentially surpass those of the conventional topics of energy and water saving in the near future. Occupant health has also been spotlighted, and related publications have dramatically increased in recent years, quickly catching up with the leading two groups. In addition, the study of indoor environmental quality has been growing steadily over the past decade. As Figure 3 indicates, current research resonates with the change in professional and political discourses most recently, gradually changing from an impersonal perspective to a human/occupant-oriented perspective.

Current research is, and will likely continue to be, more focused on such "soft" aspects as occupant health, comfort, and satisfaction. These retrieved journal articles, together with industry reports, are examined in more detail in Sections 3 and 4 following.

We created three criteria for the detailed review of all the literature collected (shown in Figure 2). First, highly cited journal articles were reviewed with priority, as they had the potential to be of higher quality. This standard did not apply to the industry reports. Second, several articles retrieved by keywords were not closely related to our analysis. Therefore, we selected those most closely connected to green buildings and well-being dimensions. Third, as we were trying to identify the overlaps between green design/features and occupant well-being, we highlighted the articles and reports with a human-oriented perspective. However, this is not an exclusive standard. We also include many articles with a technical/impersonal focus, which is particularly true for those concerned with energy and water saving. Detailed reflections on how and to what extent green buildings will improve occupant well-being are then be provided as a result of the analysis, specifying how green features and designs exert an influence on different well-being dimensions. A conceptual framework is developed to facilitate the illustration in Section 3. Based on these reflections and the summary of the review, advice is provided for future green building development strategies.

3. Dimensions of Well-Being and Green Buildings

It is clear that the general well-being of occupants is a broad concept of which the aspects related to green buildings form only a subset. Well-being is a multi-faceted concept that can be understood from different perspectives. It can also be interpreted from various disciplinary backgrounds such as economics, philosophy, sociology, and psychology [8–12]. Therefore, although there are many different approaches to examining the concept of well-being, it is difficult to judge which is the best. Since the late 1980s, many attempts have been made from different disciplines to define the variables and indices constituting well-being [13–15]. Others tried to establish a well-being index with these variables and indices, but have not been generally accepted, as it is hard to create a system that merges these variables on the one hand, and meets the requirements of the wide range of well-being measures on the other [16]. However, a common practice is to categorize well-being into two subsets of objective and subjective, with the former covering such issues as physical health, social relationships, and environment conditions, and the latter encompassing mental health, satisfaction, etc. [17]. Neither of these two categories adequately serve the purpose to explain well-being alone and, as a result, a combination of the two is usually adopted to increase the reliability, validity, and consistency of the system [18].

The stress on occupant well-being is becoming more prominent as the sustainability discourse evolves into a new era, questioning how the newly emerged new towns, retrofitted areas, and innovative planning methods affect the well-being of people in cities [19,20]. Updated technologies, management approaches, and policy instruments have been constantly employed in the industry to improve people's quality of life [21]. It seems that the built environment has an ever-bonding connection to occupant well-being. To date, green building schemes are perhaps the most universally adopted and accepted approach to promoting urban sustainability worldwide. As the built environment is so crucial to occupant well-being, green buildings can potentially make a significant difference from this perspective. There are many regional, national, and international standards practiced worldwide, including famous certifying schemes such as LEED, BREAM, and HK-BEAM (plus) [22,23]. Accordingly, decades of practice in the industry and intensive academic research provide both theoretical and empirical evidence of how green features, design, and technologies have improved occupant well-being.

After the review of several industrial reports and journal articles, we find that green buildings are closely related to many dimensions of occupant well-being. Although it may not be the most decisive factor in all aspects, it is certainly crucial. As is indicated by many studies, the employment of green features will create, on the one hand, cost premiums, but on the other, extra benefits to many stakeholders [24]. This is a popular recurring theme in green building studies in recent years and resonates with many scholars [25,26]. However, the research is highlighted from the occupants' perspective and a review of the journals and reports of each specific dimension of the occupants' lives (shown in Figure 3). For instance, empirical evidence has shown that exterior and interior design, together with the adoption of other green features, are positively connected with the emotional and intellectual dimensions of well-being [27]. Hence, it is reasonable to argue that the built environment is supportive of the mental, psychological, and emotional functions of people. Many studies have revealed that green buildings tend to be better at saving energy and water, bill saving, and improving quality of life [28,29].

Many other minor aspects of occupant life might also be improved by green buildings. For example, that the green features will possibly enhance overall indoor environmental conditions, including air quality, lighting, and ventilation [30]. Consequently, the changes in these conditions will affect many other subjective dimensions of occupant well-being. Empirical studies have shown that green features are effective in improving the level of occupant comfort and satisfaction and boost productivity accordingly [31,32]. There is research revealing that green buildings will even enhance the social capital of the community and have a positive influence on the performance of schoolchildren [33,34]. They are also directly linked to the retired life of the elderly people in the community [35]. Despite these studies being rare, they provide meaningful reflections on how green buildings have changed the occupant-building relationship. It is commonly recognized that green design, technology, and features contribute positively to different subjective and objective dimensions of occupant well-being. The benefits of green features in the academic journals and industrial reports are directed at the aspects of occupant health, bill saving, better indoor environmental conditions, more comfort, and higher levels of satisfaction in general [8,14,27]. To understand this further, a more detailed discussion of green buildings and the dimensions of occupant well-being is required.

3.1. Green Buildings and Objective Well-Being

Many green features and techniques are highly relevant to the various dimensions of well-being. For instance, the indoor environment, including apartment conditions, daylighting, ventilation, microbial contamination, thermal comfort, and glare control as well as annual savings in energy and water bills are factors influencing objective well-being dimensions [36]. Figure 4 provides a conceptual representation of how the aspects of green buildings contribute to the different dimensions of occupant well-being, which outlines the structure of Section 3. Some of the connections are more direct and obvious (solid lines), while others are more indirect and subtle (dotted lines). Section 4 provides more discussion on how each aspect is related to the different dimensions of well-being.

3.1.1. Bill Saving Energy, Water, and Gas

Bill saving is most relevant to the studies of water and energy saving items and is the most intensively investigated dimension (over 300 articles shown in Figure 3). Green buildings also overtake conventional buildings in terms of energy/water efficiency and reduction in carbon emissions [37,38]. There is a total saving of around 30% of household consumption on such resources as water and energy throughout the building's life cycle [39]. Thus, green features provide financial benefits to households and directly improve their overall objective well-being.

3.1.2. Physical Health

Health is a comprehensive issue that is affected by many other factors other than green buildings. However, empirical studies have investigated this in various ways. An example is a longitudinal study, tracing the health conditions of the same households before and immediately after they move into green buildings, with continuous follow up visits and surveys every 3 months/half a year for two or three rounds [40–42]. This found that the overall health conditions improved after the move. Other studies have found a reduction in overall household spending on health services [42] and indoor environment-related diseases after green retrofitting residential buildings [43].

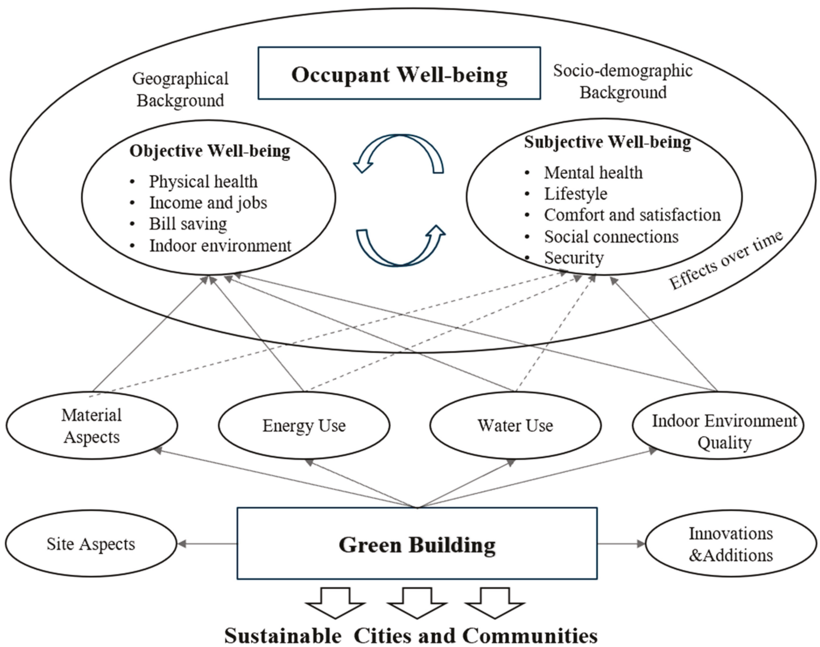

Figure 4. Conceptual framework for improvement in occupant well-being brought about by green housing.

3.1.3. Indoor Environment

Many green features and designs not only improve the physical health of occupants but also, with the stricter standards prescribed in green building schemes, provide an enhanced indoor living environment. Nevertheless, there are not as many studies on this topic as those involving financial improvements. Two separate studies have investigated indoor environment conditions, encompassing indoor environment quality, ventilation, lighting, and temperature as well as the facilities involved, concluding that the green buildings have better conditions than conventional ones [44,45]. Moreover, indoor environmental conditions have a significantly positive effect on the psychological and subjective well-being of occupants [46].

3.2. Green Buildings and Occupant Subjective Well-Being

In contrast, there is much less research into the subjective dimensions of green building occupants. The comprehensive review of the literature identified three recurring themes of occupant comfort and satisfaction, mental health, and lifestyle. Green building occupants should have a higher level of comfort due to better thermal conditions, for instance, and generally express a higher level of comfort and satisfaction with their living environment compared to their conventional counterparts [47,48]. This is not only the case with residential buildings but has also been repeatedly found in office buildings. American scholars [37,49] argue that green retrofitting buildings should reduce the level of mental disorders, and some studies of indoor environmental quality hint that green buildings benefit the mental state of occupants due to improved overall living conditions. Two surveys support this contention in indicating that residents of conventional buildings are exposed to a higher level of noise and a poorer living environment, which provides a stimulus for a variety of mental disorders [40]. However, more empirical evidence is needed to generalize these conclusions to newly built green buildings in the future.

Furthermore, other aspects are classified as lifestyle, with green building residents in some cases predicted to have a healthier way of life and share an eco-friendlier consciousness than others [50,51]. However, such studies are more theoretical than empirical, and therefore more empirical studies need to be carried out in the future to determine the reasons and mechanisms involved. It is also intriguing to find that green features have a positive relationship with occupant productivity of both adults and schoolchildren alike [34] as well as the social capital of the community as a whole [35]. This and sporadic studies of other scattered issues are all categorized here into the lifestyle dimension in the subjective realm.

3.3. How Different Kinds of Green Features Contribute to Each Well-Being Dimension

The primary stage of the literature review helped to confine the influence of green buildings into six dimensions, comprising bill saving, physical health, and indoor environment quality (objective well-being) and mental health, comfort and satisfaction, and lifestyle (subjective well-being). The next step was to identify the specific aspects that directly or indirectly influence each dimension of occupant well-being from the myriad of green designs and features available. Therefore, as indicated earlier, a search was conducted of all the keywords of green building and each well-being dimension and the articles with the three criteria reviewed. As is well known, most green building certifying schemes contain similar evaluation categories of material aspects (MA), energy use (EU), water use (WU), indoor environment quality (IE), site aspects (SA), and innovation and additions (ID) [52,53]. The names of these evaluation standards can vary in different schemes, but they share more similarities than differences. During the review process, we identified how these aspects linked to the dimensions of occupant well-being and summarized their relationships in Table 1. The full matrix is provided in Table A1 (Appendix A).

Some studies, particularly industry reports, have a wide enough scope to address almost all the dimensions of well-being. They discuss all the six aspects of green building schemes and generally how the different dimensions of well-being will be affected. However, such studies are mostly theoretical and unsystematic. More empirical evidence from other more detailed and targeted studies needs to be obtained to support the links between green features and well-being dimensions. For instance, the energy and water savings of green buildings is the aspect that has been most intensively discussed in the literature, arguing that green buildings have better energy performance and will reduce expenditure [37,38]. From Table 1, it is clear that the technologies and methods related to the standards of energy aspects, water aspects, and material aspects are of special importance for households' bill saving. Table A1 (Appendix A) provides a more vivid description of how these aspects link to expenditure reduction.

Table 1. Different green building aspects matched with the dimensions of occupant well-being ("+" denotes a positive relationship, T that the study is theoretical, and E empirical).

Well-Being		Green Features	R	E/T
Overall well-being		**Green buildings in general**: (Abrams [44]; Bay [46]; Bluyssen et al. [54]; Taylor and Pineo [55]; WBI [50]; and WGBC [51])	+	T 5
		Material aspects, indoor environment quality, and site aspects: (Abrams [44]; Bay [46]; Bluyssen et al. [54]; Taylor and Pineo [55]; WBI [50]; and WGBC [51]) **Energy aspects**: (WBI [50]) **Water aspects**: (Abrams [44]; WGBC [51]; Taylor and Pineo [55]; and Ahn et al. [56]) **Innovations and additions**: (WBI [50]; and WGBC [51])	+	T 5 E 1
Objective	Bill-saving	**Material aspects**: (Eichholtz et al. [39]) **Energy aspects**: (Bordass et al. [57]; Dowson et al. [58]; Eichholtz et al. [39]; Gbadegesin et al. [59]; Ornetzeder et al. [27]; and Turner and Frankel [37]) **Water aspects**: (Cook et al. [60]; Eichholtz et al. [39]; and Meng et al. [61]) **Indoor environmental quality**: (Gbadegesin et al. [59]; Ornetzeder et al. [27])	+	E 8
	Physical health	**Material aspects and indoor environmental quality**: (Breysse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Jacobs et al. [63]; Jacobs et al. [64]; MacNaughton et al. [65]; Poland and Dooris [66]; and Ucci and Yu [67]) **Site aspects**: (Breysse et al. [40]; Ucci and Yu [67]; Jacobs et al. [63]; MacNaughton et al. [65]; Poland and Dooris [66]; and Coombs et al. [62])	+	T 1 E 8
	Indoor environment	**Material aspects**: (Bluyssen et al. [54]; Breysse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Jacobs et al. [64]; Jacobs et al. [63]; MacNaughton et al. [65]; Middel et al. [68]; Poland and Dooris [66]; and Ucci and Yu [67]) **Energy aspects**: (Altomonte and Schiavon [45]; Gbadegesin et al. [59]; and Ornetzeder et al. [27]) **Indoor environmental quality**: (Abbaszadeh et al. [69]; Altomonte and Schiavon [45]; Breysse et al. [40]; Colton et al. [70]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Gbadegesin et al. [59]; Hwang and Kim [71]; Jacobs et al. [64]; Jacobs et al. [63]; MacNaughton et al. [65]; Middel et al. [68]; Ornetzeder et al. [27]; Paul and Taylor [72]; and Poland and Dooris [66]) **Site aspects**: (Altomonte and Schiavon [45]; Gbadegesin et al. [59]; Ornetzeder et al. [27]; and Ucci and Yu [67])	+	T 1 E 18
Subjective	Mental health	**Material aspects and Indoor environment quality**: (Breysse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Jacobs et al. [64]; Jacobs et al. [63]; and Poland and Dooris [66]) **Site aspects**: (Breysse et al. [40]; Jacobs et al. [63]; and Poland and Dooris [66])	+	E 7
	Lifestyle	**Material aspects**: (MacNaughton et al. [65]) **Indoor environmental quality**: (Li et al. [22]; MacNaughton et al. [65]; and Xia et al. [47]) Site aspects: (Li et al. [22]; MacNaughton et al. [65]; Mutdoğan and Wong [73]; and Xia et al. [47]) **Innovations and additions**: (Li et al. [22]; Mutdoğan and Wong [73]; Pastor and Morello-Frosch [74]; and Zhao et al. [75])	+	E 7
	Comfort and satisfaction	**Material aspects**: (Breysse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Jacobs et al. [63]; Poland and Dooris [66]; and Ucci and Yu [67]) **Energy aspects**: (Altomonte and Schiavon [45]; Gbadegesin et al. [59]; and Ornetzeder et al. [27]) **Indoor environmental quality**: (Abbaszadeh et al. [71]; Altomonte and Schiavon [45]; Breysse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Gbadegesin et al. [59]; Hwang and Kim [72]; Jacobs et al. [63]; Kyu-in and Dong-woo [48]; Ornetzeder et al. [27]; Paul and Taylor [70]; Poland and Dooris [66]; Ucci and Yu [62]; and Xia et al. [47]) **Site aspects**: (Abbaszadeh et al. [71]; Altomonte and Schiavon [45]; Breysse et al. [40]; Gbadegesin et al. [59]; Jacobs et al. [63]; Ornetzeder et al. [27]; Paul and Taylor [70]; Poland and Dooris [66]; Ucci and Yu [62]; and Xia et al. [47])	+	T 1 E 14

Additionally, we retrieved 38 papers on the benefits to occupant physical health, typically involving multiple rounds of surveys to investigate the effects after green renovation [40,63]. Other studies have also confirmed the superiority of the indoor environmental and indoor air quality of green buildings [44,45]. However, all the studies only focus on certain aspects of green features such as indoor environmental quality, material aspects, and site aspects, which are closely linked with indoor air quality and the noise level of the environment, etc. These green features are also crucial for the overall indoor environment and some studies have investigated health issues (both physical and mental) together with indoor environmental quality.

In contrast, studies of subjective well-being due to green buildings are less proliferated although it should be highlighted that indoor environmental quality is the most important influence of all the green features on the three subjective dimensions of occupant well-being. Unlike the conventional techno-engineering perspective, which places greater stress on other green features and takes the building as an object, Table 1 reveals that the indoor environment is the fundamental factor affecting the subjective well-being of occupants. This is a new perspective for not only green building practitioners, but also for the standards and policymakers. Additionally, of note is that innovations and other aspects, although often neglected by researchers, are key to subjective dimensions such as lifestyle. Many innovative designs provide occupants with an inducement to change their lifestyle and enhance the eco-friendly consciousness urgently needed during the ongoing rapid urbanization process of many developing countries. The subjective dimensions are often underrepresented by the current green building standards and studies and yet are of key importance for the overall well-being of occupants.

4. The Way Forward: Healthy and Sustainable Green Buildings for the Occupants

Green buildings have acquired a global momentum in many different regions of the world, and many empirical and theoretical studies indicate they are indispensable for occupant well-being. In the coming era of cities, where most of the population lives in an increasingly green built environment, it is important to revisit how these designs, features, and technology will reshape occupant well-being. The comprehensive review of current research indicates that healthy buildings are likely to be a prominent aspect of future green buildings, as mental and physical health are pivotal dimensions of occupant well-being. On the one hand, more future empirical studies will help identify the most cost-effective green features for large-scale universal adoption. Current studies are all comparisons between green and conventional buildings. It would be equally meaningful for future research to investigate the differences between green buildings (at different grading levels or from different certifying schemes). On the other hand, more specific green building standards for hospitals, residences, and restaurants, for example, should be made to better cater for their separate functions. This has already been adopted in some certifying schemes, but the standards of material, site, and indoor environment aspects need to be further refined based on future empirical studies. Similarly, other assessment standards that apply throughout the construction and operation stages of buildings need to be developed in the future. Another potential merit of green buildings that have not been fully deliberated is their contribution to human capital. Many conventional green designs will substantially enhance the comfort and satisfaction of the occupants, indirectly promoting their productivity in some cases. This will be even more the case when conventional designs and technologies are combined with advancements in information and communication technologies, which enable smart interactions between inhabitants and green buildings. Under such circumstances, the green building becomes a live eco-environment that interacts and remolds the behaviors and lifestyle in the long run. Such subjective benefits are difficult to measure quantitatively by universal standards. The industry and government need to evaluate such aspects, which have always been hitherto understated. Moreover, many innovations, such as properly installed interactive facilities and designed green land in the community, will also strengthen the social capital of the community, which is a more important factor for maintaining its sustainable development. To date, these are seen as a bonus without few detailed standards in the certifying schemes, and their relationship with potential aspects of occupant well-being need to be further studied.

Compared to the more subjective dimensions that have been gradually gaining recognition, research into the energy, water, and material aspects involved has been in its prime throughout the last decade. With more emphasis on passive designs in upcoming new technologies and materials, such studies seem destined to continue to boom. However, an alternative perspective to the conventional techno-engineering discourse needs to be provided. Examining how these technologies, designs, and features mold occupant lives and how they will improve their well-being will help answer the question: do green buildings make a difference to their occupants? Furthermore, it will make the general public feel how green buildings can work in their life and increase public awareness and participation. The essence of sustainability in urban eras is to promote a more sustainable way of life and an occupant-oriented perspective will make green buildings more inclusive and more easily understood by the general population.

Finally, all the benefits of different well-being dimensions are longitudinal. Figure 5 provides an illustration. Some of the reviewed studies show that the benefits in occupant health, for example, are cumulative and change over time. This is also the case with other dimensions. Therefore, it would be useful to have longitudinal studies examining the changes in benefits to different well-being dimensions in successive years. The benefits to occupant well-being may increase and stabilize at a certain level or, as indicated in Figure 5 (h), may further increase with the upgrading of future technologies. Similarly, most current studies focus on only one well-being dimension, and more comprehensive studies of more dimensions targeting the same sample of occupants over successive years will be rewarding for the future development of green building schemes.

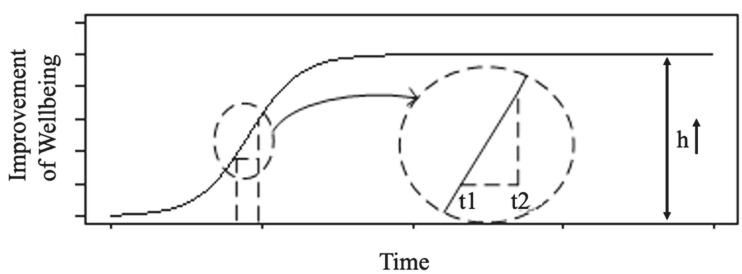

Figure 5. Longitudinal benefits to occupant well-being.

5. Conclusions

This paper provides an alternative occupant-oriented perspective to the techno-engineering centered discourse of green buildings in an era of cities. Greening of the buildings alone is a very different approach to promoting urban sustainability in general. In effect, it has remolded the lives of occupants in multiple ways and has been exerting an increasing influence on their well-being. A systematic and comprehensive perusal of current articles and reports reveals that green features and designs improve occupant well-being in both objective and subjective realms. Green buildings are potentially effective in making a difference to the occupants by improving their social, economic, physical, and psychological conditions. A conceptual framework is established to link the dimensions of well-being with green building rating criteria. The most recurring research theme is the material, energy, and water aspects as key factors in the economic well-being of occupants, as they reduce resource consumption while increasing energy efficiency. Other aspects discovered in the review are that, for instance, indoor environment, site aspects, and innovations will contribute considerably to the health and other subjective dimensions of occupant well-being. This is much neglected and understated to date by both academia and industry. However, they are at least of equal importance for maintaining a sustainable life.

Three suggestions are proposed to better tailor green buildings schemes to the needs of their occupants and be more inclusive of the public in general. First, as has been promoted to some extent in some schemes already, green buildings should be healthy buildings with more detailed and specific standards for different building types. The target is to find diversified yet cost-effective standards benefiting both the psychological and mental conditions of the occupants. Another target is for green buildings to be socially sustainable to their occupants by investing in the human capital of the occupants as well as the social capital of the community—most likely to be the core of sustainable urban life in the forthcoming urban era. Such aspects as the site, innovations, and overall design should be clarified to promote the green awareness of the occupants and eventually precipitate a sustainable way of life. In addition, it should be noted that the benefits to occupants are most probably of a longitudinal nature. Therefore, green buildings need to be treated as an eco-environment that constantly interacts with their inhabitants, and the benefits involved are revisited both comprehensively and longitudinally.

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Appendix A

Table A1. The influences of green building on different dimensions of occupants' wellbeing.

Citation	Title	Overall-Well-Being	Bill Savings	Physical Health	Indoor Conditions	Mental Health	Comfort and Satisfaction	Lifestyle	Overall Green Features	Material Aspects	Energy Aspects	Water Aspects	Indoor Environment Quality	Site Aspects	Innovations and Additions	Empirical/Theoretical	Relationship
World Green Building Council [51]	Health, Well-being & Productivity in Offices	1	0	1	1	1	1	1	1	1	0	0	1	1	1	T	+
International Well Building Institute [50]	The well buildings standard	1	0	1	1	1	1	1	1	1	1	1	1	1	1	T	+
Bluyssen [54]	Assessment of well-being in an indoor office environment	1	0	1	1	1	1	0	0	1	0	0	1	1	0	E	+

Table A1. *Cont.*

Citation	Title	Overall-Well-Being	Bill Savings	Physical Health	Indoor Conditions	Mental Health	Comfort and Satisfaction	Lifestyle	Overall Green Features	Material Aspects	Energy Aspects	Water Aspects	Indoor Environment Quality	Site Aspects	Innovations and Additions	Empirical/Theoretical	Relationship
Abrams et al. [44]	Making healthy places: designing and building for health, well-being, and sustainability	1	0	1	1	1	1	1	1	1	0	1	1	1	0	T	+
Bay [46]	TOWARDS A FOURTH ECOLOGY: Social and Environmental Sustainability with Architecture and Urban Design	1	0	1	1	0	1	1	1	1	0	0	1	1	0	T	+
Ucci and Yu [67]	Low-carbon buildings, health and well-being: current perspectives and critical challenges, Indoor Built Environ.	0	0	1	1	0	1	0	0	1	0	0	1	1	0	T	+
Turner and Frankel [37]	Energy performance of LEED for new construction buildings	0	1	0	0	0	0	0	0	0	1	0	0	0	0	E	+
Dowson et al. [58]	Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal	0	1	0	0	0	0	0	0	0	1	0	0	0	0	E	+
Eichholtz, Kok and Quigley [39]	The economics of green building	0	1	0	0	0	0	0	0	1	1	1	0	0	0	E	+
Bordass, Cohen, Standeven and Leaman [57]	Assessing building performance in use 3: energy performance of the Probe buildings.	0	1	0	0	0	0	0	0	0	1	0	0	0	0	E	+
Gbadegesin, Nna, Shitta, and Adegbenro [59]	Towards Increasing Energy Efficacy of an Old Building (A Case Study of the Main Auditorium of University of Lagos, Lagos, Nigeria.	0	1	0	1	0	1	0	0	0	1	0	1	1	0	E	+
Meng et al [61]	Virtual water accounting for building: case study for E-town, Beijing	0	1	0	0	0	0	0	0	0	0	1	0	0	0	E	+
Middel, Chhetri and Quay [68]	Urban forestry and cool roofs: Assessment of heat mitigation strategies in Phoenix residential neighborhoods	0	0	0	1	0	0	0	0	1	0	0	1	0	0	E	+
Cook, Sharma and Gurung [60]	Evaluation of alternative water sources for commercial buildings: A case study in Brisbane, Australia	0	1	0	0	0	0	0	0	0	0	1	0	0	0	E	+
Breysse et al. [40]	Health Outcomes and Green Renovation of Affordable Housing	0	0	1	1	1	1	0	0	1	0	0	1	1	0	E	+
Jacobs et al. [63]	Health and Housing Outcomes From Green Renovation of Low-Income Housing in Washington, DC.	0	0	1	1	1	1	0	0	1	0	0	1	1	0	E	+
Fabian et al. [42]	A simulation model of building intervention impacts on indoor environmental quality, pediatric asthma, and costs	0	0	1	1	1	1	0	0	1	0	0	1	0	0	E	+
Fabian et al. [41]	The effects of indoor environmental exposures on pediatric asthma: a discrete event simulation model	0	0	1	1	1	1	0	0	1	0	0	1	0	0	E	+
MacNaughton et al. [65]	Environmental perceptions and health before and after relocation to a green building	0	0	1	1	0	0	1	0	1	0	0	1	1	0	E	+
Poland and Dooris [66]	A green and healthy future: the settings approach to building health, equity and sustainability	0	0	1	1	1	1	0	0	1	0	0	1	1	0	E	+
Colton et al. [69]	Indoor Air Quality in Green Vs Conventional Multifamily Low-Income Housing	0	0	0	1	0	0	0	0	0	0	0	1	0	0	E	+

Table A1. *Cont.*

Citation	Title	Overall-Well-Being	Bill Savings	Physical Health	Indoor Conditions	Mental Health	Comfort and Satisfaction	Lifestyle	Overall Green Features	Material Aspects	Energy Aspects	Water Aspects	Indoor Environment Quality	Site Aspects	Innovations and Additions	Empirical/Theoretical	Relationship
Coombs et al. [62]	Indoor air quality in green-renovated vs. non-green low-income homes of children living in a temperate region of US (Ohio)	0	0	1	1	1	1	0	0	1	0	0	1	0	0	E	+
Jacobs et al. [64]	Moving Into Green Healthy Housing	0	0	1	1	1	0	0	0	1	0	0	1	0	0	E	+
Ornetzeder et al. [27]	User satisfaction and well-being in energy efficient office buildings: Evidence from cutting-edge projects in Austria	0	1	0	1	0	1	0	0	0	1	0	1	1	0	E	+
Kyu-in and Dong-woo [48]	Comparative study for satisfaction level of green apartment residents	0	0	0	0	0	1	0	0	0	0	0	1	1	0	E	+
Xia et al. [47]	Delivering sustainable communities: a case study in China	0	0	0	0	0	1	1	0	0	0	0	1	1	0	E	+
Paul and Taylor [70]	A comparison of occupant comfort and satisfaction between a green building and a conventional building	0	0	0	1	0	1	0	0	0	0	0	1	1	0	E	+
Altomonte and Schiavon [45]	Occupant satisfaction in LEED and non-LEED certified buildings	0	0	0	1	0	1	0	0	0	1	0	1	1	0	E	+
Abbaszadeh et al. [71]	Occupant satisfaction with indoor environmental quality in green buildings	0	0	0	1	0	1	0	0	0	0	0	1	1	0	E	+
Hwang and Kim [72]	Effects of indoor lighting on occupants' visual comfort and eye health in a green building	0	0	0	1	0	1	0	0	0	0	0	1	1	0	E	+
Li et al. [22]	Green Building and Social Sustainability: Study on Mosuo Folk Housing in China	0	0	0	0	0	0	1	0	0	0	0	0	1	1	E	+
Mutdoğan, Selin and Wong [73]	Towards Sustainable Architecture: The Transformation of the Built Environment in Istanbul, Turkey	0	0	0	1	0	0	1	0	0	0	0	0	1	1	E	+
Li [34]	Impact of housing design factors on children's conduct at school: an empirical study of Hong Kong	0	0	0	1	0	0	1	0	0	0	0	1	1	0	E	+
Pastor and Morello-Frosch [74]	Integrating Public Health And Community Development To Tackle Neighborhood Distress And Promote Well-Being	0	0	0	0	0	0	1	0	0	0	0	0	1	1	E	+
Zhao et al. [75]	Social problems of green buildings: From the humanistic needs to social acceptance	0	0	0	0	0	0	1	0	0	0	0	0	1	1	E	+

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buildings

Article

The Benefit of Rail: Estimating the Impact of Station Accessibility on Residential Property Prices

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Abstract: This article focuses on the relationship between the prices and the distance from a metro or commuter railway station to residential properties. Relevant efforts have already been dedicated to estimating the effect of station accessibility, but one of the key limitations of previous studies was the heterogeneity of real estate. Here, the data on homogeneous real estate type in Budapest, Hungary, namely panel flats (built with uniform technology between the 1960s and 1990s) are analysed by statistical methods. First, it is demonstrated that this real estate type is indeed highly homogenous. Second, linear regression is used to understand the relationship and its magnitude between flat prices and distance of stations. The results show a statistically significant relationship, i.e., that five additional minutes of travel time to the nearest station providing fast access to the city centre makes real estate prices drop by nearly 1%. In light of current policies promoting rail for passenger transportation, the findings may be applied for value capture policies to increase the viability and feasibility of urban railway projects.

Keywords: residential property; public transportation; metro; rail; flat

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1. Introduction

In light of the speed of urbanization around the world, making cities more sustainable has become a key global challenge [1]. Enhancing urban transportation and mobility by environmentally sound technologies and measures is found to be one of the best practices, particularly in Europe [2]. The New Urban Agenda of the United Nations envisages cities that promote sustainable, safe and accessible urban mobility by means of resource-efficient transport systems worldwide [3]. The mobility strategy of the European Commission [4] aims to improve current policy and financial frameworks regarding mobility management, urban planning and connectivity in order to achieve sustainable and healthy mobility in urban areas. It sets the ambitious targets of 100 climate-neutral cities and fully carbon-neutral scheduled collective travel for short journeys (under 500 km) in Europe by 2030. It is expected that shifting more activity towards more sustainable transport modes, especially commuting by public transport and travelling by rail, may significantly contribute to reaching these goals.

The backbone of most urban transportation systems is railway networks. Metro and suburban rail provide fast and high-capacity service towards the central business district (CBD) at a relatively low operational cost. However, cities usually face difficulties in building and developing such networks, primarily due to technical system complexity and related high upfront investment costs. The costs of these projects may be partly funded or recovered through value capture policies, such as cities extracting and internalizing some of the externalities of new railway infrastructure that appears in the value of properties close to newly built stations. To implement such policies, it is crucial to understand how the accessibility to CBD provided by public transport affects residential property prices. Nevertheless, heterogeneity in attributes and quality of real estate makes this pretty complicated.

This paper intends to extend the knowledge about the relationship of accessibility by public transport and real estate price. It focuses on a homogeneous type of real estate in Budapest (Hungary), namely flats in panel buildings (hereinafter: panel flats). Panel flats were built in the second half of the 20th century to address the housing crisis by applying an almost uniform technology [5] of a large-panel system and featuring similar characteristics in terms of comfort level, design principles and living quality. It is expected that through the analysis of this unique subset of real estate, a more robust conclusion can be reached.

First, the homogeneity of panel flats will be presented to reveal that their quality is unrelated to their location, especially their closeness to rail services (Hypothesis_1). On this basis, travel time to CBD by public transportation and to the nearest metro or commuter railway station will be examined. As another hypothesis of this research, it is supposed that flats with better connectivity are priced higher, i.e., travel time between a property and the nearest railway station is negatively correlated with its purchase price (Hypothesis_2).

The extensive literature about the relationship of public transportation accessibility and real estate value is generally based on the bid-rent theory first introduced by William Alonso [6] to describe how increased distances from the CBD affect the demand for and price of real estate, i.e., indicating that instead of paying high prices for land (real estate) in city centres, commuters spend their money and time when they travel daily from their place of residence to the CBD. In this theoretical framework, a new public transportation connection to the city centre should increase the price of nearby real estate, as it provides a faster and cheaper route to the CBD, as if the property moved closer to the city centre.

From the 1990s, scholars applied this theory to analyse real life data and most have found the expected positive relationship, with very different magnitudes (Table 1), between high-capacity public transportation and residential real estate prices in a variety of cities worldwide, e.g., Laakso [7] for Helsinki, Grass [8] for Washington DC, Dubé et al. [9] for Montreal, Ibeas et al. [10] for Santander, and Cordera et al. [11] for Rome and Santander. Others have found no significant impact, or even a negative impact, of better public transportation accessibility on property prices, e.g., Debrezion et al. [12] in the Netherlands and Anderson et al. [13] in Taiwan.

Table 1. Findings in the literature on the effects of railway on residential property prices.

Source	Location	Type of Rail	% Change
Laakso [7]	Helsinki, Finland	metro	3.5 to 6%
Grass [8]	Washington, DC, USA	metro	19%
Dubé et al. [9]	Montreal South Shore, Canada	commuter rail	2.6% on average
Ibeas et al. [10]	Santander, Spain	suburban train	−4.9%
Andersson et al. [13]	Southern Taiwan	high-speed railway	~0
Debrezion et al. [12]	3 cities in The Netherlands	railway	0 to 2%

In their review of the previous literature, Debrezion et al. [14] summarized the findings of 57 papers about the impact of railway stations on real estate prices. They found that both heavy (by 0.9%) and commuter rail (by 14%) stations have larger overall effects on residential property prices than light railway stations. They also found that the inclusion of other accessibility factors significantly reduces the impact of metro stations. A meta-analysis on the basis of 102 observations from the review of 23 papers by Mohammad et al. [15] led to similar outcomes about commuter rail providing fast access to the CBD, but their results suggest that heavy rail has equal or even lower impact than light rail, probably due to effects of the former on the environment, i.e., that it adds less economic value to the environment around stations. A literature review by Higgins and Kanaroglou [16] in North America also found that properties closer to railway stations are generally more valuable, and stated that the sources of diversity in the related research outcomes are omitted variables, unobserved land value uplift impacts and misvalued results. A property in the near proximity of a station can also lose value due to the negative externalities, such as noise and increased traffic, especially in the case of heavy rail. As there has seemingly been little or no previous effort or no opportunity to include a homogeneous set of real estate in this type of analysis, the above-mentioned approach, namely the study of a specific subset in a specific location (i.e., panel flats in Budapest) promises new results in this line of research.

The paper is structured as follows: Section 2 details the data and methods used in this paper, and Section 3 provides the results, followed by a discussion in Section 4.

2. Materials and Methods

The analysis consisted of two steps to show the effect of high-capacity railway connection on residential property prices, both based on commonly used statistical models. First, the characteristics of panel flats were plotted for visualization and regression analysis was applied to show that the quality of panel flats is unrelated to the proximity of railway stations. As part of this analysis, travel times to the nearest railway station and to the CBD were calculated. In the second step, another linear model was used to estimate the impact of the travel time to the CBD on real estate prices.

Budapest (1.7 million inhabitants in early 2021) is the capital city of Hungary. In this case study, the key elements of its extensive public transportation network were considered: metro (4 lines, approx. 40 km, 52 stations) and commuter rail (4 lines + 1 side line, 97 km, 69 stations). A total of 31 stations are outside city boundaries and there are 2 stations with direct metro–commuter rail connection, i.e., the number of stations included in this analysis was 88.

The metro and commuter railway lines were built during very different time periods: metro (underground) line M1 opened in 1896, M2 in 1970 (a later stage was added in 1972), M3 in 1976 (later stages were added until 1990) and M4 in 2013. Commuter railway lines were built between 1887 and 1952. In the early 2020s, modern trains (built in 2008 to 2014 or modernized in 2016 to 2018) circulate on all metro lines. Commuter rail services are operated by trains built between 1963 and 1983, which underwent only minor refurbishment over the years.

These lines are the backbones of the urban public transportation system, providing fast and reliable connection between several areas of the outskirts or some of the major transportation hubs and the CBD. Headway during peak hours is 2 to 3 min in the metro and 6 to 8 min in the commuter rail network. The tariff system encourages the use of monthly (or quarterly or yearly) passes, which provides passengers with unlimited journeys for an economic price: e.g., a monthly Budapest Pass costs 9500 HUF (approx. 27 EUR (approx. 27 EUR, by applying the average conversion rate of 355 HUF/EUR by the National Bank of Hungary in April 2020)for adults and 3450 HUF (10 EUR) for students, while single tickets cost HUF 350 HUF (1 EUR) for all.

In this research, two datasets are used:

- dataset_1: data containing characteristics of individual panel flats. This is a self-collected dataset scraped from online property advertisements on a real estate advertisement site;
- dataset_2: data on the size and purchase price of panel flats. This contains average values from aggregated data for each census tract in Budapest, acquired from the official database of the Hungarian Central Statistical Office (hereinafter: KSH).

The workflow is presented in Figure 1.

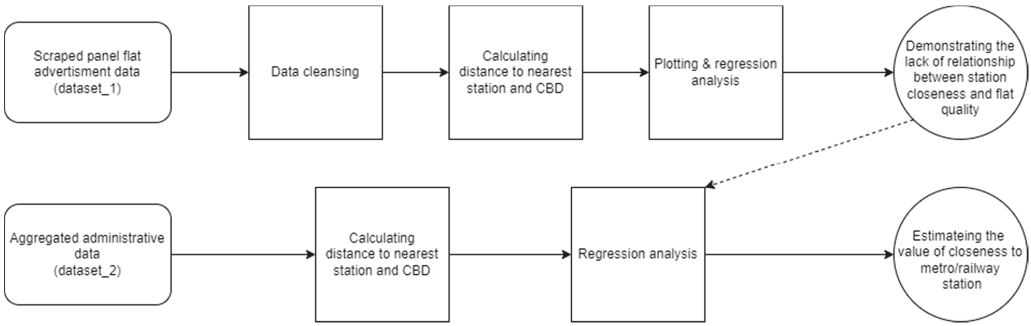

Figure 1. Workflow of the paper.

2.1. Panel Flats in Budapest

In Budapest, approx. 190,000 panel flats were built from the 1960s to the 1990s, generally in large housing estates using mostly prefabricated elements, usually pre-cast concrete panels. Four housing factories were built in Budapest from 1965 to 1974, which used a modified version of the Soviet large-panel system and, briefly, the Larsen–Nielsen system developed in Denmark. On the basis of centralized plans, panel flats were intended to solve the housing issues of the quickly growing population of the Hungarian capital city by providing cheap and, at the time, modern accommodation to families [17].

In order to determine whether the proximity to a station is related to the quality of panel flats, all advertisements of panel flats in Budapest in April 2020 (in sum, 3754) were searched from ingatlan.com (accessed on 15 January 2022), the leading [18] property advertisement site in Hungary, resulting in dataset_1. To collect all characteristics of these advertised flats, a self-written code was used (the code is available here: https://bit.ly/2Y6BKSg (accessed on 15 January 2022)), which looked for every real estate advertisement within the city boundaries of Budapest, listed as a panel flat by the advertiser, and then downloaded all available information. The dataset was cleansed by dropping outliers (the top and bottom 1% in terms of price and size) and unrealistic values, leading to a sample of 3607 items. Despite the fact that this was a non-representative sample of the full subset of panel flats in the city and that the amount of information about real estate characteristics in the advertisements was rather diverse, both the sample size and the availability of basic characteristics for all items indicated that the sample was appropriate for the purpose of this study.

As expected, the panel flats in the sample were very similar in many respects:

- As all of the sample items featured modern conveniences such as heating, flush toilets, bathrooms and kitchens, it could be deduced that all panel flats in Budapest do too;
- In approx. 85% of sample flats, heating is provided through district heating (a way of heating where hot steam is generated in a distant plant and then the steam is transported to the residential buildings in pipes);
- The bathroom and toilet were in separate rooms in 78% of flats;
- The clear height was less than 3 m in almost all apartments (98.98%);
- Almost none of them (1.65%) had direct access to a garden;
- Other characteristics differentiated the panel flats:
- Floorspace, which diverged between 30 and 80 m^2 with an average of about 54 m^2 (Figure 2).
- The vast majority of such flats had either two (44.05%) or three rooms (44.14%). (Half rooms were included in this study as full rooms, as definitions are varied and advertisements may not be consistent in this regard.)
- Year of construction, as approximately half of the sample items were built in the 1960s and 1970s (47.09%), and half were built in the 1980s or, eventually, the 1990s (52.16%).

(Most blocks were built before the end of Socialism in 1990 and only ongoing projects were finished in the early 1990s.)

- Seemingly, about half (50.84%) of the flats had a balcony, most of which were found to be rather small (95% were under 6.76 m^2, mean: 4 m^2). However, data on balconies were not included in further analyses, as providing information is optional on the advertisement site and, therefore, advertisers may have (un)intentionally omitted it from the advertisements.
- Overall, 75.45% of the flats were located in 10-story or higher buildings and 15.25% were located in 4-story buildings, which were representative of the panel blocks in the city. The rationale behind building 4 or 10 levels was that regulations required the construction of an elevator above 4 levels. So these two sizes were the most economical to build: 4-level houses without an elevator and 10-level ones, where the higher number of flats compensated for the extra cost of the elevator.

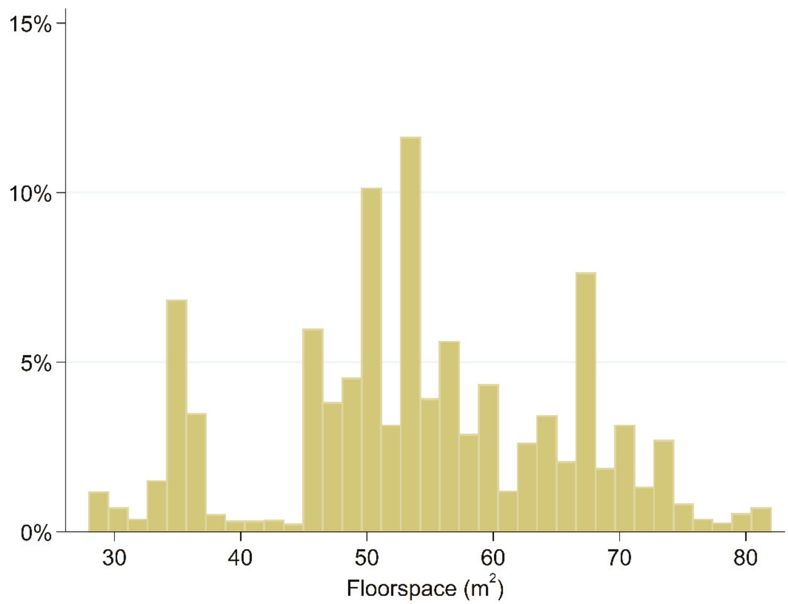

Figure 2. Distribution of floorspace.

The flat price varied between 12 and 62 million HUF (approx. 33,802 and 174,647 EUR, respectively), with an average of 30.6 million HUF (86,197 EUR). The per-square-meter price of flats varied between 386,000 and 955,000 HUF (1087 and 2690 EUR, respectively), with an average of 575,000 HUF (1619 EUR). Histograms of both variables are presented in Figure 3. In light of the fact that panel housing estates were built in areas with different characteristics (e.g., in the very popular hilly areas of Buda or the less attractive outskirts of Pest), this wide range of prices for an otherwise homogeneous property type indicates that panel flats in Budapest are inhabited by a diverse population.

2.2. Travel Time Calculation

Travel times between the flats to the nearest station and between the flats and the CBD were calculated using the publicly available API of HERE Maps. This combines all travel options by public transport in Budapest (except for suburban, regional and long-distance bus services, but this is negligible, as these services are rather irrelevant in terms of urban journeys within city boundaries).

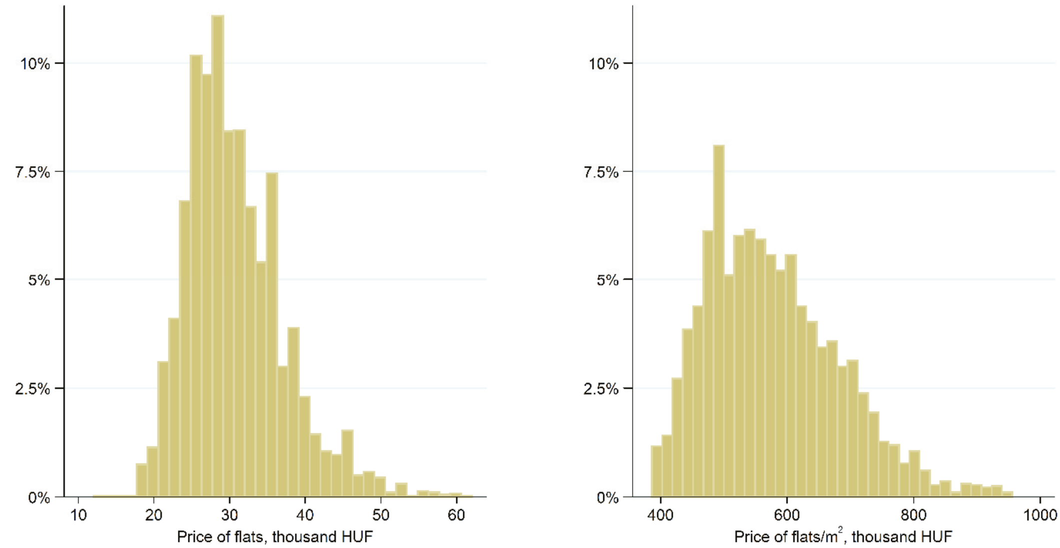

Figure 3. Distribution of flat prices.

To calculate the shortest travel time within which railway services could be accessed from a flat, the algorithm calculated the fastest route by public transport (or by foot, if faster) between an individual flat and all the railway stations and chose the shortest one.

To reveal travel times to the CBD, the API calculated the travel time between a flat and a reference point in the city centre, namely Astoria metro station (hereinafter in the analysis: CBD). Astoria is a major road intersection and a metro station of line M2 (named after a luxury hotel), between two large central interchanges: Deák Ferenc tér, where M1, M2 and M3 stop, and Kálvin tér, where M3 and M4 stop. By this choice, passengers are not excessively penalized for the use of any of the commuter railway or metro lines, since Astoria is within walking distance to all metro lines. Line M2 has 2 stations where passengers can directly transfer from metro to commuter rail lines (H5, H8 and H9). Additionally, there are 8 bus and 2 tram lines crossing the road intersection at Astoria.

All journeys to the CBD were planned to start at 8 a.m. on the same working day (a Monday) morning.

Travel times to the CBD were mostly found to be between 20 and 60 min (min: 14 min; max: 70 min; Figure 4), clearly indicating that only a small proportion of panel flats are located in the city centre (and if this is the case, panel flats are located in outer areas of inner districts, about 20–30 min from the CBD).

Travel times to the nearest metro or commuter railway station varied depending on the location (mean: 17.44 min; min: 1.17 min; max: 48 min; Figure 5).

2.3. Real Estate Prices

For the sake of data protection, only aggregate data on real estate purchases, i.e., not the record of individual flats but the aggregate data of a minimum of 3 purchases may be requested from the KSH. In light of this, three criteria were considered for this data request for dataset_2: (1) census tracts (including 100–150 addresses) are homogeneous neighbourhoods featuring near-identical panel houses of uniform distribution of flats; (2) two consecutive years of data ensure a relatively long timeframe so that the above mentioned threshold is reached; and (3) two different periods would let us reveal if rising real estate prices [19] lead to relevant changes in the context of this study. Consequently, the requested dataset contained two aggregate datasets of two consecutive years (2014–2015 and 2018–2019) for all the census tracts including panel flats in Budapest. The average number of transfers in a census tract that was aggregated in dataset_2 was 9.1 (minimum: 3; maximum: 35; standard deviation: 4.2). As both the average flat size and average contract price were provided, the average price per square meter in a tract could be calculated.

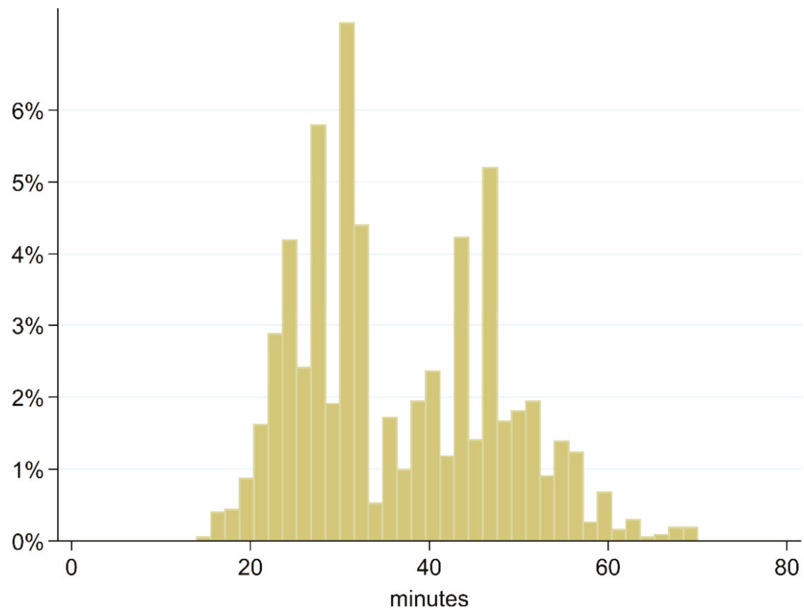

Figure 4. Distribution of the travel times to CBD.

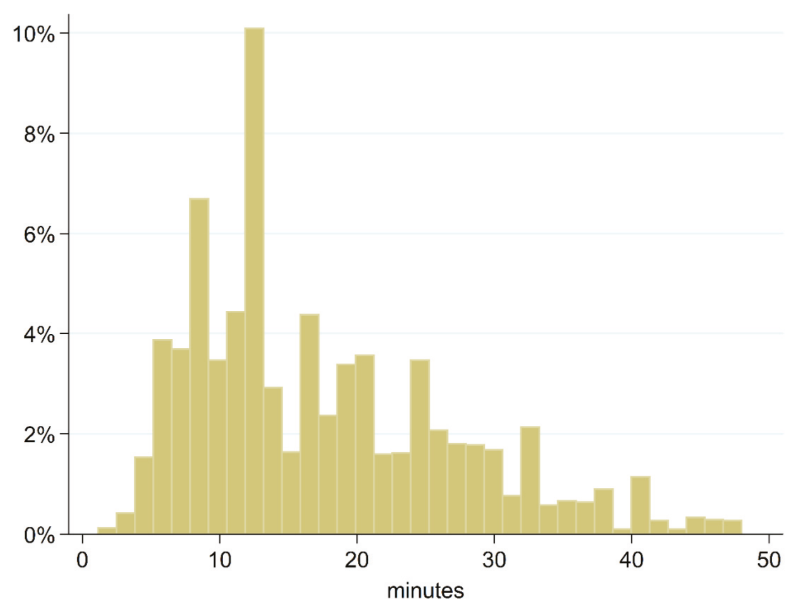

Figure 5. Distribution of travel times to the closest metro and commuter railway station.

The two explanatory variables used in dataset_2 were travel time to the nearest station and travel time to the CBD, both measured in minutes. For the calculation of these variables, the same HERE Maps API was used (as in the case of dataset_1, detailed in Section 3.1). The starting point of journeys was the geographical centre of a census tract and the travel mode was set to public transportation in both cases. Distributions can be seen in Figures 6 and 7, as well as in Appendix A.

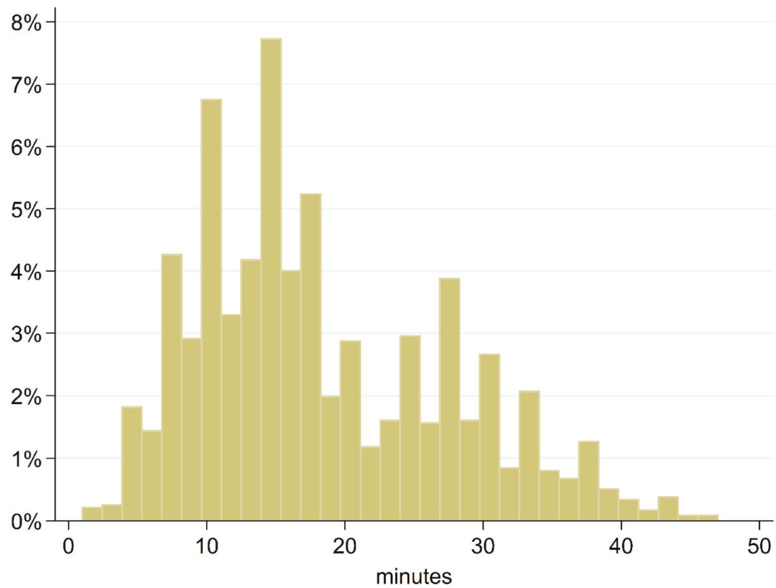

Figure 6. Distribution of travel time to the station.

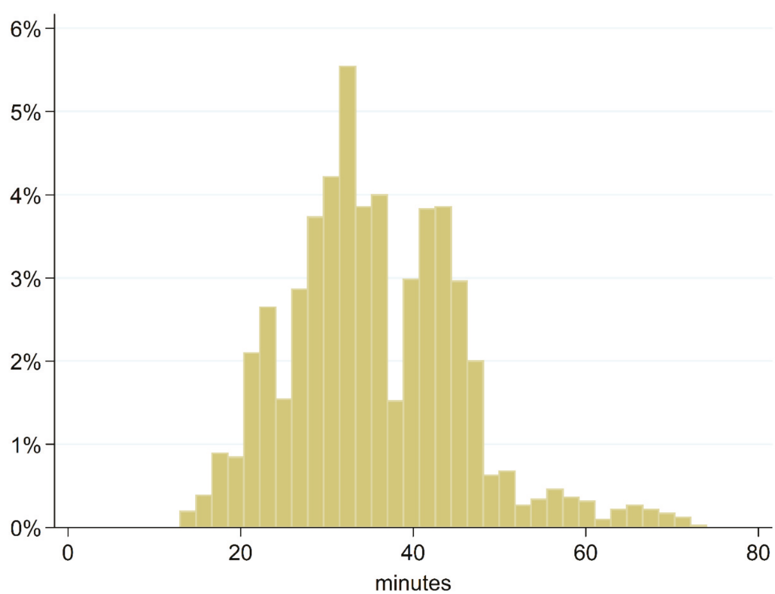

Figure 7. Distribution of travel times to the CBD.

3. Results

3.1. Travel Time to Stations and Quality of Flats

As the first step to test Hypothesis_1, i.e., if the location and the quality of a panel flat are unrelated, floorspace was plotted against travel time from the nearest station (Figure 8). A kernel-weighted local polynomial regression was also visualized (fitted values are displayed with a red line and the 95% confidence interval is marked by a grey area). As the slope of the line is very close to zero, it can be seen that there was basically no relationship between floorspace and the travel time from the nearest station. In other words, it could be assumed that the effect of the quality of the flats would not be taken up by the travel time variable in later steps of this study. The same attribute was plotted against the travel time to the CBD (Figure 9), showing a similar outcome, namely, that there was no or no significant relationship. The rest of the attributes showed even less variance, as detailed in Section 2.1.

In order to explore the relationship between variables in a more robust way, the travel time to the nearest station and to the CBD on square meter prices were regressed in six variations, using different combinations of variables. In the first one, only the two distance variables were included, imitating the regression that was run on dataset_2, due to the difference in available information in dataset_1 and dataset_2. In the other models, further attributes of flats (or the building) were controlled for, with diverse specifications to show the robustness of the model, i.e., the number of rooms, floorspace, if the toilet is located in the bathroom, availability of an elevator in the building, year of construction (before or after 1980) the floor on which the flat is and the state of the flat as indicated by the advertiser (excellent, to be renovated, etc.). Based on the results (Table 2), out of models 2 to 6, model 6 (including all the above variables) seemed to be the most appropriate one in terms of the information criteria. Plotting the residuals against the variables indicated that the relationship between the independent and dependent variables was indeed linear.

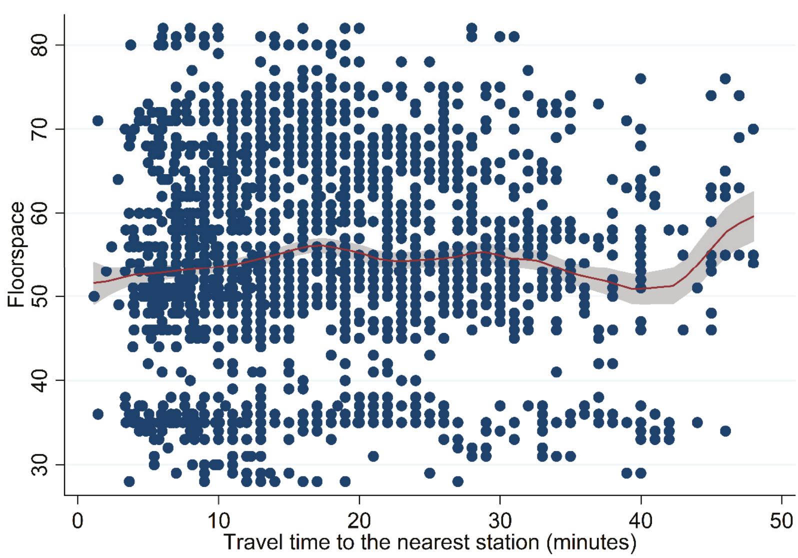

Figure 8. Floorspace plotted against travel time to the station.

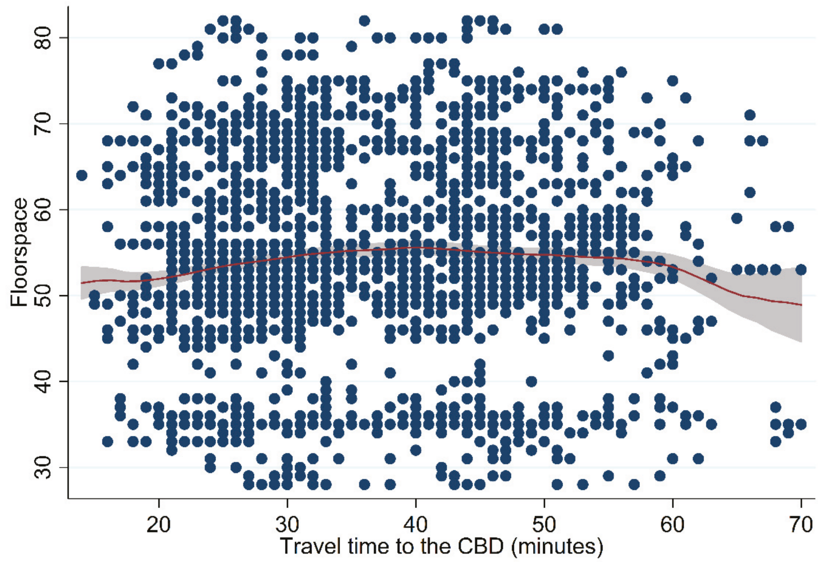

Figure 9. Floorspace plotted against travel time to the CBD.

Table 2. Regression results for panel flat attributes' impacts on price.

	(1)	(2) [1,2]	(3) [2]	(4) [1,2]	(5) [1,2]	(6) [1,2]
	Price/m^2	Price/m^2	Price/m^2	Price/m^2	Price/m^2	Price/m^2
Travel time to station (minutes)	−2.446 ***	−2.696 ***	−2.714 ***	−2.703 ***	−2.679 ***	−2.728 ***
	(0.221)	(0.189)	(0.202)	(0.234)	(0.204)	(0.250)
Travel time to the CBD (minutes)	−1.975 ***	−2.266 ***	−2.292 ***	−2.327 ***	−2.276 ***	−2.259 ***
	(0.189)	(0.164)	(0.174)	(0.208)	(0.176)	(0.222)
Number of rooms		12.80 ***	14.98 ***	15.92 ***	13.51 ***	16.01 ***
		(3.334)	(3.556)	(4.143)	(3.606)	(4.401)
Floorspace		−5.240 ***	−5.090 ***	−5.287 ***	−4.976 ***	−4.885 ***
		(0.205)	(0.252)	(0.259)	(0.257)	(0.318)
Elevator		−53.49 ***	−53.87 ***	−53.62 ***	−54.28 ***	−54.16 ***
		(4.317)	(4.220)	(5.348)	(4.692)	(5.700)
Bathroom in separate room from toilet			−6.025		−7.060	−11.86 *
			(4.725)		(4.811)	(6.035)
Built after 1980				6.527		7.334
				(3.595)		(3.824)
Observations	3607	2819	2470	1826	2400	1609
BIC	43,185.4	32,302.0	28,238.9	21,017.9	27,508.1	18,528.7
RMSE	96.00	72.48	72.31	73.35	72.10	72.92

Note: Additional controls—level on which the flat is located, state of the flat indicated by the advertiser. * $p < 0.1$; *** $p < 0.01$ [1] Controlled for the floor on which the flat is; [2] Controlled for the stated quality of the flat.

The Wald test was used to formally check whether the coefficients of the variable showing travel times to the closest station or CBD were the same. The results (Table 3) indicate that the null hypothesis could not be rejected in either of the two models.

Table 3. Wald test results.

Model 1 (Travel time to station) = Model 6 (Travel time to station)	
chi^2 (1)	1.54
Prob > chi^2	0.21
Model 1 (CBD distance) = Model 6 (CBD distance)	
chi^2 (1)	1.97
Prob > chi^2	0.1606

However, just because the hypothesis could not be rejected, the coefficients of the variables were not necessarily the same. Regardless of the exact specification of the model, the coefficients of the two explanatory variables were larger (in absolute terms) in Model 2–6 than in Model 1. If Model 1 was used to estimate the impact of the proximities of a station and the CBD on the quality of a flat, the size of this impact would be underestimated. Thus, the results of this estimation could be used on a larger dataset, too, as overestimation of the effects of these variables is unlikely.

In summary, it may be stated that the quality of panel flats was unrelated to travel time to the nearest station or the CBD. In many attributes, flats in this dataset featured identical characteristics (kitchen, bathroom, inner height) and other varying attributes (e.g., floorspace, number of rooms) were weakly or non-related to the distance of either the nearest station or the CBD. Finally, even if the attributes of the properties were related to the distance, leaving them out from the regression could have led to underestimation of the coefficients, so there was no chance of overestimation when evaluating the effects.

3.2. Travel Time to Station, Accessibility and Panel Flat Prices

As it was proven that the quality of panel flats in Budapest is not related to the travel time to the nearest station (and the CBD), the effect of this distance on the real estate price could be estimated. For that, dataset_2—i.e., a dataset with less information on the quality of flats but containing information on actual sales of all panel flats in Budapest—was used. First, average real estate prices in census tracts in 2014–2015 were plotted against travel times to the nearest station in Figure 10 and to the CBD in Figure 11.

The fitted non-parametric trend indicates that their relationships were close to linear; thus, a linear model could be used for this estimation (Equation (1)).

$$mean\ price = \beta_0 + \beta_1 * travel\ time\ to\ the\ nearest\ station + \beta_2 * travel\ time\ to\ CBD \quad (1)$$

Models calculated using the log of the mean prices of 2014–2015 and 2018–2019 as dependent variables can be seen in Table 4. Post regression analysis here also confirmed the linear relationship between the variables.

The results were statistically significant and show that residential real estate nearer to a station and to the CBD is more valuable: e.g., each five additional minutes of travel time to the nearest station caused the per-square-meter prices to drop by nearly 1%. This applied to both examined periods, i.e., independently of the changing price levels from 2014–2015 to 2018–2019.

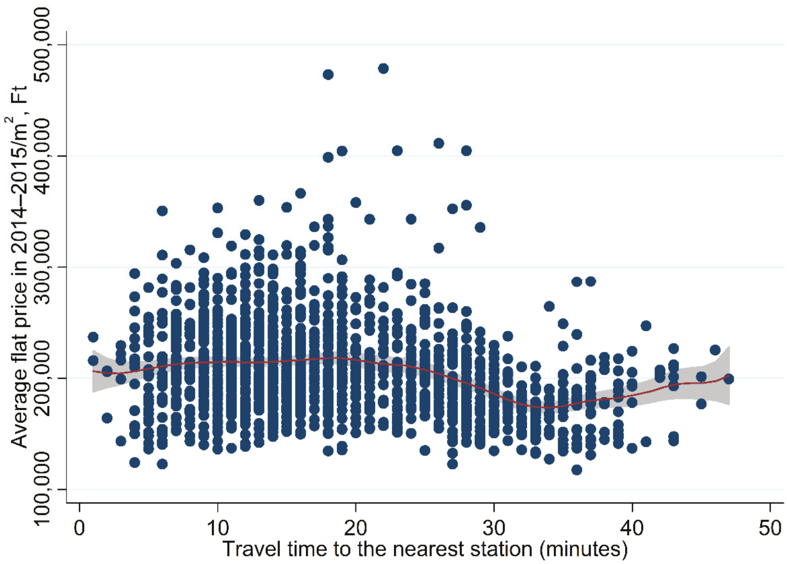

Figure 10. Average panel flat price plotted against travel time to the station.

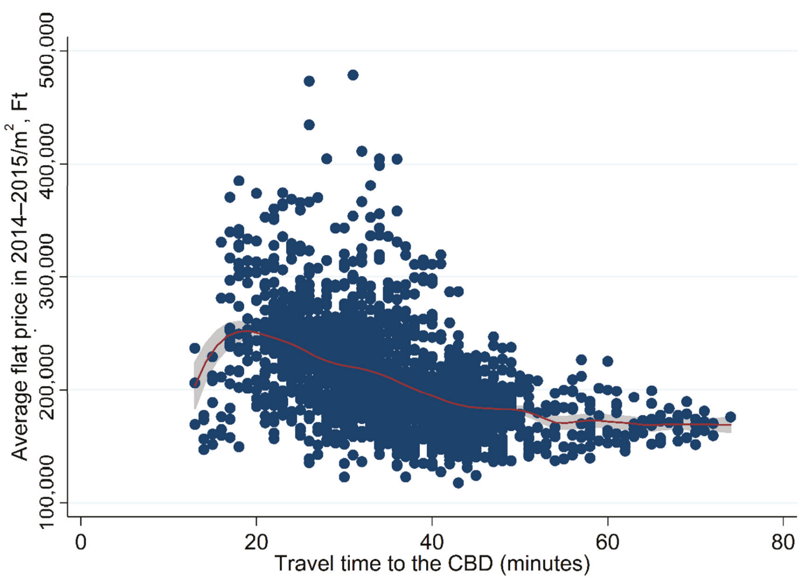

Figure 11. Average panel flat price plotted against travel time to the CBD.

Table 4. Regression results of travel time to the nearest station and CBD on flat price.

	Log (Mean Price/m^2), 2014–2015 (1)	**Log (Mean Price/m^2), 2018–2019 (2)**
Travel time to the CBD (minutes)	−0.009 ***	−0.008 ***
	(0.0005)	(0.0004)
Travel time to the nearest station (minutes)	−0.002 ***	−0.001 **
	(0.001)	(0.0005)
Constant	12.574 ***	13.367 ***
	(0.017)	(0.015)
Observations	1578	1361
R^2	0.223	0.254
Adjusted R^2	0.222	0.253
Residual Std. Error	0.171 (df = 1575)	0.140 (df = 1358)
F Statistic	225.663 *** (df = 2; 1575)	231.379 *** (df = 2; 1358)

Note: ** $p < 0.05$; *** $p < 0.01$

4. Discussion

Urban planners and decision makers seek to boost liveability in cities by—among other approaches—providing sustainable and affordable housing in an era of rising house prices around the world [20] and maintaining compact cities in spite of the phenomenon of urban sprawl [21]. Promoting sustainable mobility through the use of reliable and carefully planned public transport systems in response to congestion and emissions caused by private cars is one of the key measures to ensure accessibility in urban areas [22,23].

In this article, one of the key aspects of these challenges was analysed, namely the relationship between the price of a flat and its closeness to a metro or commuter railway station that provides fast connection to the city centre. To fill in a gap in the related extensive literature, a specific type of real estate was studied, namely panel flats in Budapest, featuring similar characteristics in terms of location, quality and design. Data on real estate from online advertisements and an administrative database were included in the study. The statistically significant results indicate that both hypotheses can be accepted, i.e., the quality of panel flats is unrelated to their closeness to metro and commuter railway stations or the CBD in terms of travel time (Hypothesis_1) and the price of panel flats is negatively correlated with this closeness (Hypothesis_2).

Previous evidence indicates that there is significant variation in the estimated effect of railway station accessibility on property prices. On the one hand, some studies suggest that direct nearness of residential buildings to railways or railway stations can have a negative impact on the price of flats due to negative externalities, such as noise and vibration. On the other hand, closeness in terms of accessibility is usually found to be positively linked with real estate value [14]. The magnitude of this effect may depend on the type of railway and the type of real estate. Here, a homogeneous type of real estate and the railway network of a specific city were considered. Numerical results showed that five additional minutes to/from the nearest metro or commuter railway station would add approximately 1 percent to the contract price in the case study. As the panel flats in dataset_2 are located 1 to 47 (on average: 18) minutes of travel time from the nearest metro or commuter railway station, in light of the above results, an average flat has an approximately 3.4 percent lower value than a flat located in the close vicinity (1 min) to the station. In spite of the different approaches and methods applied in the literature (see Table 1), this seems to be comparable to previous findings.

Besides the analysed variables, many other factors may influence (and have major effects on) real estate prices. Obviously, the quality of a flat is largely influential and other circumstances, such as the characteristics of the surrounding area, including available services, public safety and further mobility options, also play a relevant role in house sales [24]. As a potential future research topic, comparing residential property prices before and after major public transport development projects could significantly extend the results of this study. Opportunities to do so may arise from the ambitious strategy developed in Hungary in 2019–2020 (Budapest Suburban Railway Node Strategy), which defines comprehensive goals to increase the number of passengers by 80% on suburban railway lines by 2040, mainly by connecting suburban railway lines and increasing their capacity within city boundaries.

Taking into account the limitations of this research, particularly the limited data on sales (i.e., aggregate data of census tracts) and available information on housing estates, the above findings could be extended with the addition results obtained in similar contexts, e.g., in cities of other post-socialist countries, preferably on the basis of prices and characteristics of individual units. However, the application of a similar approach—even on the basis of a similar set of data—would allow the comparison among cities to reveal if the same relation with a similar magnitude exists between public transport connections and prices of highly uniform properties.

The policy implications of this research are twofold. First, the city in this case study may exploit outcomes in its ongoing and future public transport projects (as part of or independently from the above-mentioned strategy), particularly by land value capture instruments. Second, findings may be transferable to other contexts: (1) to real estate projects of flats with similar characteristics, where a similar magnitude of price differences may be attached to the distance from railway stations or the city centre and (2) even to diverse sets of houses, where this diversity has to be taken into account for the adaptation of the present outcomes.

In light of local, European and global initiatives to make urban areas more sustainable, most cities aim to extend and improve railway networks to provide fast, reliable and environmentally friendly commuting opportunities. Thus, understanding how these infrastructure investments impact residential property prices seems to be crucial. On the basis of the above and similar findings, the introduction of tailor-made value capture policies may help to co-fund investments and the careful design of land use and real estate projects can ensure that housing- and mobility-related objectives are mutually being met.

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Data Availability Statement: Some or all data that support the findings of this study are available from the corresponding author upon reasonable request.

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

Appendix A

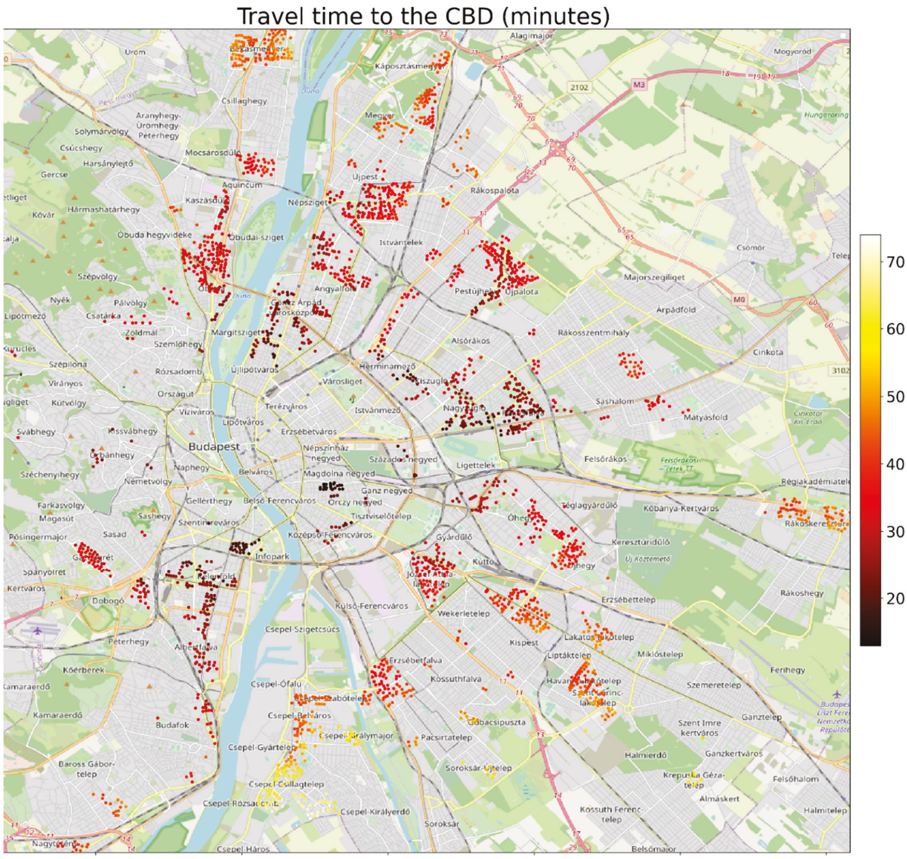

Figure A1. Travel time to the CBD from panel flats by public transport. Map data copyrighted OpenStreetMap contributors and available from https://www.openstreetmap.org, accessed on 20 December 2021.

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Green Land Use Efficiency and Influencing Factors of Resource-Based Cities in the Yellow River Basin under Carbon Emission Constraints

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Abstract: Green and low-carbon strategies represent governance orientations for resource-based cities to respond to global changes and achieve sustainable development. Designating the Yellow River Basin (YRB), an important ecological functional area and an ecologically fragile area, as the research area, this study used the super-efficiency SBM model while considering undesirable outputs, including carbon emissions, to analyze green land use efficiency (GLUE) and its temporal and spatial differentiation, then used the Tobit regression model to analyze the influencing factors. The results were as follows: (1) The GLUE of the YRB presented a spatial pattern of "high in the west and low in the east". (2) Overall, the efficiency values of all areas and types increased annually, but differences occurred in various areas and types of resource-based cities. (3) Overall, the efficiency values of the Yellow River Basin showed a "high-low" polarization. (4) Economic development and population growth factors substantially impacted the GLUE of resource-based cities in this region. It is concluded that increasing the efficiency improvement of low-efficiency regions or cities can improve regional GLUE. To ensure regional green and low-carbon transformation and development, it is essential to enhance urban economic vitality, promote an orderly population flow, and strive to improve social and public services.

Keywords: resource-based city; green land use efficiency (GLUE); carbon emissions; the Yellow River Basin (YRB)

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1. Introduction

As a space carrier for the exchange and interaction of all urban elements, urban land plays an important basic role in developing cities and even regions [1,2]. Although urban land area accounts for only 2% of the global land area, urban energy consumption and carbon emissions account for 75% and 78%, respectively [3], the most important carbon sources in the global terrestrial ecosystem. With the development of urbanization and industrialization, the population continues to gather in cities. To maintain the normal operation of production and life, coupled with people's pursuit of a high-quality lifestyle, under the current energy consumption structure and land use mode, cities will consume more and more energy sources and will continue to emit more and more carbon dioxide into the atmosphere. The resulting climate warming will damage the global ecological environment [4,5]. As the country with the largest carbon emission in the world [6] from 2005 to 2015, China's urban built-up area increased from 32,221 km^2 to 52,102.31 km^2, and the urban resident population increased from 562.1 million to 7711.6 million [7]. Therefore, China has also become an important participant in global climate governance. To cope with the crisis brought about by global climate change, the Chinese government has put forward the double carbon goal, which requires achieving a "carbon peak" by 2030 and "carbon neutralization" by 2060. Various industries and regions have carried out many theoretical and practical explorations of green and low-carbon transformation and Development [8–11]. Resource-based cities have provided important energy and resource guarantees for China's economic and social development and promoted the process of industrialization and urbanization. However, as the industrial systems of resource-based cities focus on resource extraction, transportation, and processing, they have the characteristics of high pollution and high energy consumption. With the gradual depletion of regional resources in resource-based cities, it is vital to explore what is needed to ensure transformation and development. Based on the dual "carbon peak" and "carbon neutralization" visions, resource-based cities must be guided by green and low-carbon governance, upgrade urban industrial systems, and achieve sustainable development. In recent years, national and international scholars have thoroughly examined the transformation obstacles and countermeasures of resource-based cities [12–16], high-quality development [17–22], and land use efficiency [23–27]. However, research on green transformations and the development of resource-based cities [28,29] is still insufficient, especially regarding potential green and low-carbon governance strategies of resource-based cities in combination with the carbon source/sink effect. Therefore, this study examines the green land use efficiency (GLUE) of resource-based cities under the constraint of treating carbon emissions as an undesirable output factor. Using the resource-based cities in the Yellow River Basin (YRB) as an example, this study investigates their GLUE, temporal and spatial differentiation characteristics, and evolution characteristics. Moreover, we further explore the influencing factors and action mechanisms of these characteristics and provide a decision-making basis for promoting the green and low-carbon transformation and development of resource-based cities.

2. Materials and Methods

2.1. Study Area

The Yellow River is the second-largest river in China. It originates from the northern foot of the Bayankala Mountains on the Qinghai Tibet Plateau, flows through the nine provinces and autonomous regions of Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong, and enters the Bohai Sea in Kenli County, Shandong Province [30]. It has a total length of 5464 km and a drainage area of 795,000 km^2, and it is located between 32–42° N and 96–119° E (Figure 1). The YRB is the birthplace of Chinese civilization and is an important area for population activities and economic development. This region has rich reserves of coal, oil, natural gas, and nonferrous metals. In addition to its importance as an energy, chemical, raw material, and basic industrial base in China, it also acts as an important ecological functional area. This is an important part of China's "Two Screens and Three Belts" strategic ecological security pattern. However, the natural conditions in this area are poor, with many practical problems such as shortages of water resources, serious soil erosion, a weak carrying capacity of the resources and environment, and unbalanced and insufficient development of its various subregions. In response, the state has issued an outline of the plan for *the Ecological Protection and High-quality Development of the Yellow River Basin*. Combined with *the National Sustainable Development Plan for Resource-based Cities (2013–2020)*, the YRB includes 38 resource-based prefecture-level cities. According to the data acquisition and changes in administrative divisions, we selected 35 resource-based cities, except Aba in Sichuan, Haixi in Qinghai, and Laiwu in Shandong, as our research objects. This list includes eight cities in the upstream area, 21 cities in the midstream area, and six cities in the downstream area.

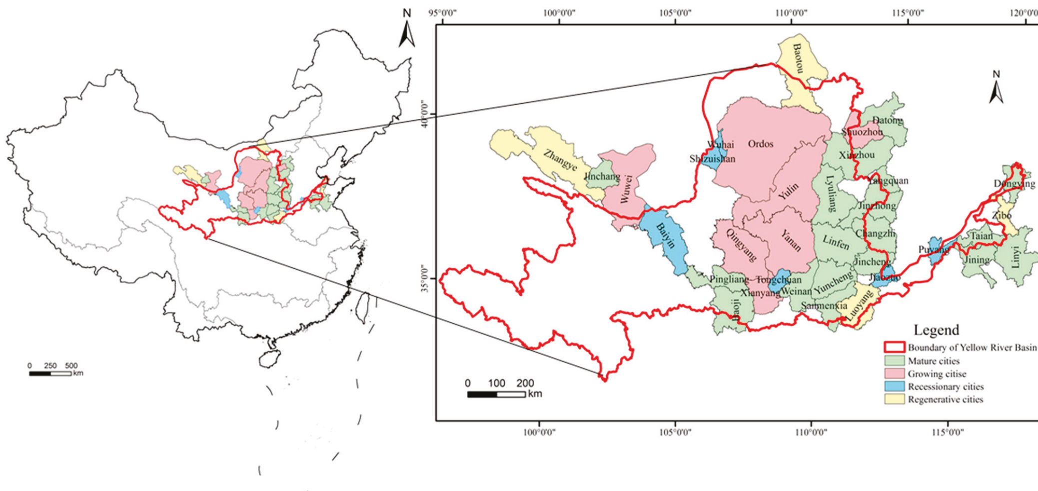


Figure 1. Location of resource-based cities in the YRB.

2.2. Data Sources

The data used in this study were obtained from the *China Urban Statistical Yearbook*, *China Urban Construction Statistical Yearbook*, and *China Energy Statistical Yearbook* from 2005 to 2020. Some data were supplemented by statistical yearbook data of the corresponding year of the city, and missing data were supplemented by interpolation.

2.3. Methods

First, the super-efficiency SBM model considering undesirable outputs was used to calculate the GLUE of resource-based cities in the YRB from 2004 to 2019, and its spatial visualization was expressed using the ArcGIS 10.6 software. Second, the nonparametric Kernel Density Estimation method was used to describe the evolution trend of GLUE in the Yellow River Basin, its various areas, and differing types of resource-based cities. Finally, the Tobit regression model was used to analyze the influencing factors affecting the GLUE of resource-based cities in the YRB (Figure 2).

2.3.1. Super-Efficiency SBM Model Considering Undesirable Output

To scientifically evaluate the relative effectiveness of decision-making units in the case of multiple inputs and outputs, researchers have mostly used the nonparametric DEA method to evaluate land use efficiency [31–34]. With continuous advancements in ecological civilization, the concept of green development has gradually encompassed all aspects of economic and social development. An evaluation of land use efficiency must therefore consider economic and social output indicators, environmental pollution, and greenhouse gas emissions caused by development and construction. Therefore, green land use has become a popular topic in land science research [35–42]. Tone proposed the SBM model based on undesirable outputs [43], which can specifically address the undesirable output problems attached to land use. Moreover, it can accurately reflect the comprehensive realization degree of land use in multiple dimensions such as economic growth, social welfare improvement, resource conservation, pollution, and emission control [44]; however, it still cannot solve the decomposition problem of the efficiency value of effective decision-making units (the efficiency value is 1). Therefore, based on the traditional SBM model, Tone proposed a super-efficiency SBM model considering undesirable outputs [45], which can accurately estimate the super-efficiency value of a decision-making unit and avoid the information loss from an effective decision-making unit. In recent years, this approach has been widely used in research on green efficiency evaluations of land use [38,44,46–49]. The specific model [50–52] is as follows:

$$\min\rho = \frac{\frac{1}{m}\sum_{i=1}^{m}(\overline{x}/x_{ik})}{\frac{1}{r_1+r_2}\left(\sum_{s=1}^{r_1}\overline{y^d}/y_{sk}^d + \sum_{q=1}^{r_2}\overline{y^u}/y_{qk}^u\right)} \tag{1}$$

$$\begin{cases} \overline{x} \geq \sum\limits_{j=1,\neq k}^{n} x_{ij}\lambda_j;\ \overline{y^d} \leq \sum\limits_{j=1,\neq k}^{n} y_{sj}^d\lambda_j;\ \overline{y^d} \geq \sum\limits_{j=1,\neq k}^{n} y_{qj}^d\lambda_j; \\ \overline{x} \geq x_k;\ \overline{y^d} \leq y_k^d; \overline{y^u} \geq y_k^u; \lambda_j \geq 0; \\ i = 1,2,\cdots,m; j = 1,2,\cdots,n; \\ s = 1,2,\cdots,r_1; q = 1,2,\cdots,r_2 \end{cases} \tag{2}$$

n decision-making units are assumed, and each decision-making unit is composed of input m, desirable output r_1 and undesirable output r_2. x, y^d, and y^u are the elements in the corresponding input matrix, desirable output matrix, and undesirable output matrix, respectively, and ρ is the value of GLUE in resource-based cities.

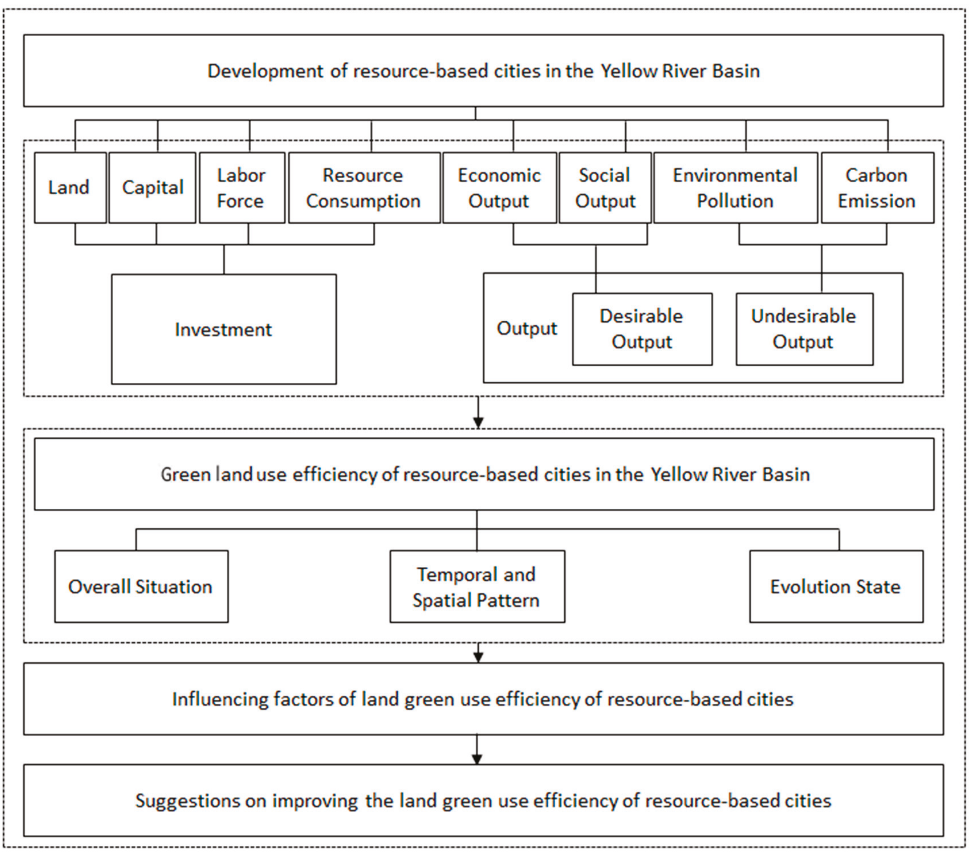


Figure 2. Research technology methodology.

2.3.2. Nonparametric Kernel Density Estimation

Kernel Density Estimation (KDE) is a nonparametric method for estimating the probability density function. The center of gravity position of the nuclear density curve reflects the evolution characteristics of the size of the efficiency value. The number and height of the peaks can detail the polarization and differential evolution characteristics of the efficiency. The tailing situation can describe the evolution characteristics of the efficiency value in the high/low-value region. The specific model [53] is as follows:

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{n} K\left(\frac{x_i - \overline{x}}{h}\right) \tag{3}$$

where n is the number of samples, h is the window width, x_i is the sample observation value, $K(\cdot)$ is the random kernel function, and $\overline{x}$ is the mean. The type of random kernel function is the Epanechnikov Kernel.

2.3.3. Tobit Regression Model

The GLUE calculated in this study was greater than zero and represented a limited dependent variable. Therefore, the Tobit model was used to analyze the factors influencing GLUE each year. The specific model construction [49] is as follows:

$$y_{it} = \begin{cases} y_{it}^* = \beta_0 + \sum_{j=1}^{8} \beta_j X_{j,it} + e_{it},\ y_{it}^* > 0 \\ 0, y_{it}^* \leq 0 \end{cases} \tag{4}$$

where y is the value of GLUE, i is a resource-based city, t is the year, x_j is the independent variable, β_0 is the constant term, β_j is the vector of the regression coefficient of the independent variable, and e_{it} is the random error term in the regression obeying $N(0, \sigma^2)$.

2.4. Index Determination and Data Processing

2.4.1. Evaluation of GLUE in Resource-Based Cities

The evaluation indicators selected in this study were combined with the characteristics of resource-based cities [54]. During the selection of input indicators, in addition to the traditional factors of land, capital, and labor, resource consumption was also included in the cost. Regarding undesirable output indicators, in addition to the emissions of industrial wastewater, waste gas, and smoke and dust, the carbon emission indicator was included in combination with the goal of "carbon neutralization" (Table 1).

Table 1. Evaluation index system of GLUE in resource-based cities.

Indicator Type	Considerations	Specific Indicators	Unit
Input	Land Input	Area of urban construction land in municipal districts	km^2
	Capital Input	Investment in fixed assets in municipal districts	10^4 yuan
	Labor Input	Employees in secondary and tertiary industries in municipal districts	person
	Resource Consumption	Total urban water supply	10^4 m^3
		Total electricity consumption in municipal districts	10^4 kWh
Desirable Output	Economic Output	GDP in municipal districts	10^4 yuan
	Social Output	Average wage of on-the-job employees in municipal districts	yuan
Undesirable Output	Environmental Pollution	Industrial sulfur dioxide emissions	t
		Industrial smoke and dust emission	t
		Industrial wastewater discharge	10^4 t
	Carbon Emission	Carbon emission of energy consumption and household	t

Urban carbon dioxide emissions are mainly generated during the process of energy consumption and residents' lives. Among them, the calculation formula for energy consumption and carbon emissions is:

$$E_1 = \sum_{i=1}^{n} M_i = \sum_{i=1}^{n} e_i \times \alpha_i \times \beta_i \quad (5)$$

where E_1 is the carbon emission from energy consumption, M_i is the carbon emission generated by the ith energy consumption, e_i is the consumption of class i energy, α_i is the conversion coefficient of standard coal for class i energy, and β_i is the carbon emission coefficient of class i energy. The conversion coefficient and carbon emission coefficient of various energy standard coals were obtained from relevant research [55–58] and the IPCC national greenhouse gas inventory guidelines [59] (Table 2). Because the obtained energy consumption data are counted using provincial administrative units, this study designates the energy consumption ratio of each province/autonomous region to the number of prefecture-level cities under its jurisdiction as the energy consumption of each resource-based city.

Table 2. Carbon emission coefficients of energy.

Types of Energy	Conversion Coefficient of Standard Coal	Coefficient of Carbon Emission (kg/kgce)	Types of Energy	Conversion Coefficient of Standard Coal	Coefficient of Carbon Emission (kg/kgce)
Coal	0.714,3	0.755,9	Diesel Oil	1.457,1	0.592,1
Coke	0.971,4	0.855,0	Fuel Oil	1.428,6	0.618,5
Crude Oil	1.428,6	0.585,7	Liquefied petroleum Gas	1.714,3	0.504,2
Gasoline	1.471,4	0.553,8	Natural Gas	1.214,3	0.448,3
Kerosene	1.471,4	0.571,4	Electric Power	0.122,9	0.733,0

Note: in the conversion coefficient of standard coal, the unit of liquefied petroleum gas and natural gas is kgce/m^3, the unit of electric power is kgce/kW, and other units are kgce/kg.

Residential carbon emissions denote the sum of carbon emissions generated by all residents in the city in a year, and its estimation formula is:

$$E_2 = p \times q_i \quad (6)$$

where E_2 is the total carbon emissions from residents, p is the carbon emission coefficient per capita, which is 79 kg/a in this study with reference to relevant research [55], and q_i is the population of the ith city.

The carbon dioxide emissions of each city in each year can be obtained by summing the carbon emission E_1 of energy consumption and the carbon emission E_2 of residents.

2.4.2. Influencing Factors of GLUE in Resource-Based Cities

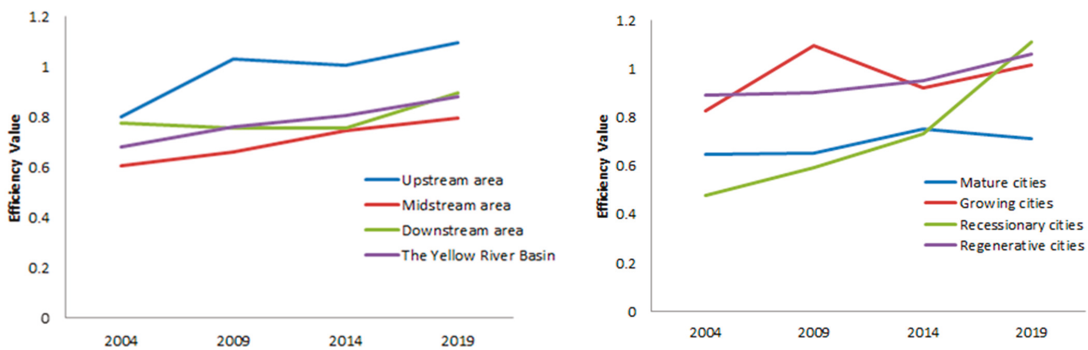
After combining the characteristics of resource-based cities and comprehensively considering the impact of economic, social, and environmental conditions on the development of resource-based cities, eight factors (population growth, economic development, industrial structure, cultural development, medical conditions, education investment, science and technology investment, and environmental management) were selected to investigate the influencing factors of GLUE of resource-based cities in the YRB (Table 3).

Table 3. Index system of influencing factors of GLUE in resource-based cities.

Variable Name	Influencing Factors	Specific Indicators	Unit
Peop	Population Growth	Natural population growth rate	%
Econ	Economic Development	Per capita GDP	yuan/person
Indu	Industrial Structure	Proportion of output value of tertiary industry and secondary industry	%
Cult	Cultural Development	Proportion of people with a college degree or above	%
Hosp	Medical Conditions	Hospital beds per 10,000 people	bed
Educ	Education Investment	Proportion of education expenditure	%
Scie	Science and Technology Investment	Proportion of science and technology expenditure	%
Envi	Environmental Management	Comprehensive utilization rate of industrial solid waste	%

3. GLUE in Resource-Based Cities in the YRB

From 2004 to 2009, the overall GLUE of the YRB showed a steady growth trend (Figure 3). The average efficiency values were 0.681, 0.761, 0.806, and 0.883 in 2004, 2009, 2014, and 2019, respectively, with a total increase of 29.65% over 15 years.



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

Figure 3. GLUE of the resource-based cities in the YRB. (**a**) GLUE of each area; (**b**) GLUE of each type.

3.1. Comprehensive Study of GLUE

3.1.1. Characteristics of GLUE of Each Area

There are clear regional differences in the GLUE of resource-based cities in the YRB: (1) Distribution. From 2004 to 2019, the average efficiency of the upstream area was the highest (0.984), followed by the downstream area, with an average efficiency of 0.797, and the average efficiency in the midstream area was the lowest (0.702). (2) Change in trends. During the study period, the efficiency values in the upstream, midstream, and downstream areas showed an overall growth trend. Only the upstream and downstream areas decreased slightly, in 2009–2014 and 2004–2009, respectively, whereas the efficiency values of other regions and periods increased. (3) Changes in range. Over the past 15 years, the growth rates of efficiency values in the upstream and midstream areas exceeded the overall growth rate of the YRB, reaching 36.87% and 31.33%, respectively. This indicates that the upstream and midstream areas actively worked towards a green and low-carbon transformation of industry and strove to achieve high-quality development of land use efficiency; by contrast, the growth rate of efficiency in the downstream area was slow, at only 15.11%. This area will face pressures and challenges in implementing a green land use transformation in the future.

3.1.2. Characteristics of GLUE of Each Type

Significant differences were observed in GLUE among different types of resource-based cities: (1) Distribution. From 2004 to 2019, the average efficiency values of growing and regenerative cities were large (0.966 and 0.952, respectively), followed by recessionary cities (average efficiency of 0.729) and mature cities (0.692). (2) Change in trends. During the study period, the efficiency value of all types of resource-based cities showed an overall growth trend, except that growth and mature cities decreased in 2009–2014 and 2014–2019, respectively. The efficiency values of other types of resource-based cities increased during each period. (3) Changes in range. Recessionary cities showed the largest increase in efficiency, with an increase of 132.21% over the past 15 years, more than five times that of other types of resource-based cities. The growth rate from 2014 to 2019 was the highest. This showed that recessionary cities completed developmental transformation and gradually eliminated industrial dependence on the path of high resource consumption. The growth rate of the efficiency of growing and regenerative cities was relatively large, at 23.13% and 19.40%, respectively, whereas that of mature cities was only 10.70%. Owing to its low efficiency, mature cities will face a relatively large transformation pressure in future development.

3.2. Spatial and Temporal Pattern of GLUE

Using the natural breakpoint method, the GLUE values of resource-based cities in the YRB for each year were divided into five levels in different colors: low, medium-low, medium, medium-high, and high levels. The efficiency value ranges for each level in the different years are shown in Figure 4. Spatially, the GLUE value of resource-based cities in the YRB presented an overall pattern of "high in the west and low in the east", although efficiency rebounds occurred within the extreme eastern areas. Resource-based cities with high-efficiency values were mostly distributed in Gansu, Inner Mongolia, Shaanxi in the upstream area, and Shandong in the downstream area; however, resource-based cities in Shanxi and Henan in the midstream area had low-efficiency values. The efficiency values of Shanxi and Northern Shaanxi in the midstream area decreased significantly during the study period, especially from 2004 to 2009, and the northern region showed a downward trend following continuous improvement. In addition, the efficiency values of the northern cities in the eastern extreme of the YRB were high and rose steadily, whereas those of the southern cities were low and showed a significant downward trend.

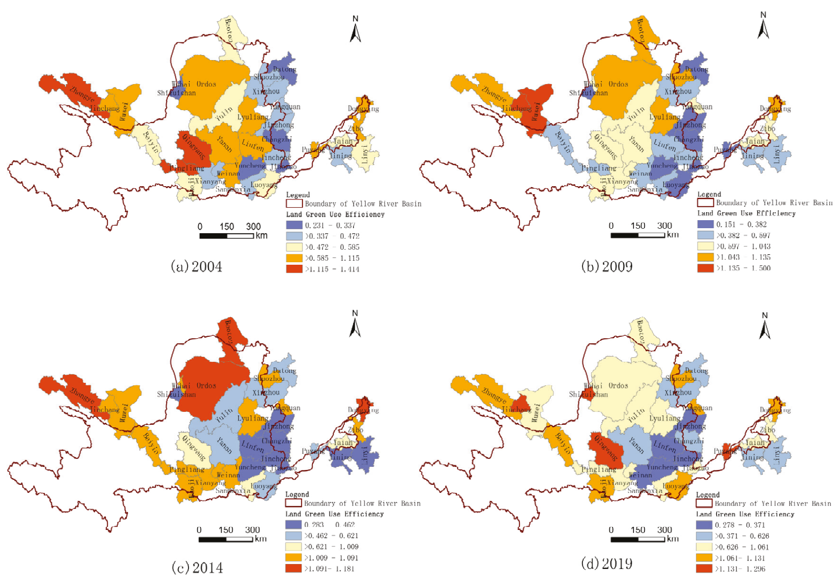


Figure 4. Temporal and spatial pattern of GLUE of resource-based cities in the YRB. (**a**) 2004; (**b**) 2009; (**c**) 2014; (**d**) 2019.

3.3. Evolution Characteristics of GLUE

In this study, Eviews software (version 10.0) was used to draw the nuclear density curve of GLUE of resource-based cities in the YRB and the temporal dynamic evolution characteristics of GLUE at the global and local scales, respectively (Figure 5). During the study period, the nuclear density curves of the YRB showed typical bimodal characteristics, indicating that the efficiency value of the region showed polarization overall. The peak position of the low-value area on the left moved significantly to the right, whereas the peak position of the high-value area changed minimally. This indicated that the efficiency values of the low-value area significantly improved. It also showed that the improvement of the efficiency of the low-value area comprised the main reason for the increase in the efficiency value of resource-based cities in the YRB. Over time, the left peak gradually decreased and the right peak gradually increased, indicating that the difference in efficiency in low-value areas gradually converged among resource-based cities, whereas the difference in efficiency in high-value areas continued to expand. The tail on the right side of the curve was larger than that on the left. The whole right tail showed the phenomenon of "lengthening-shrinking-lengthening"; this indicated that the efficiency value in the high-value area showed a fluctuating trend of first increasing, then decreasing, and increasing again.

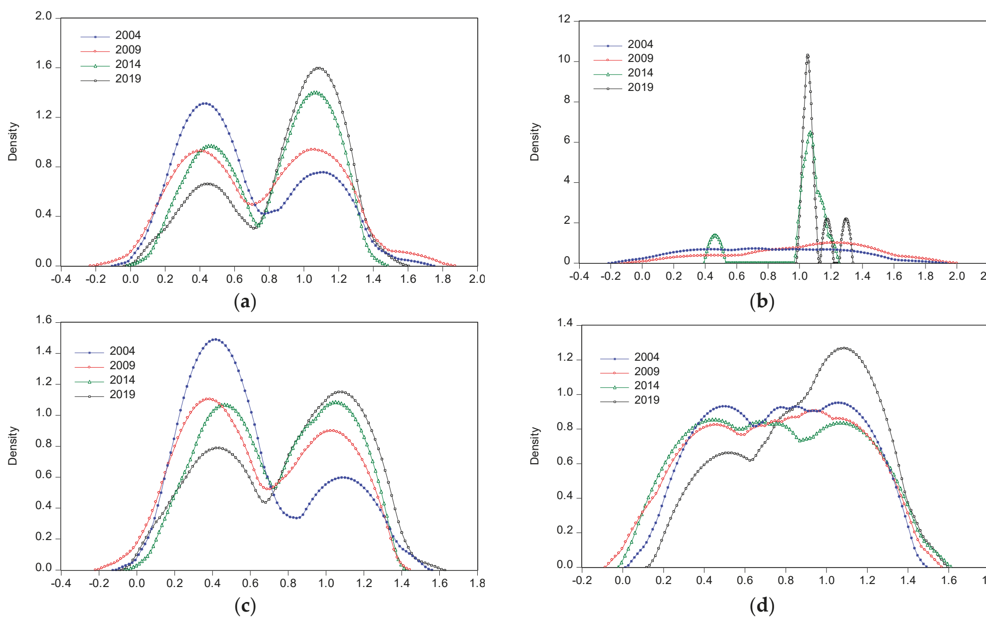


Figure 5. Evolution of GLUE of resource-based cities in each area of the YRB. (**a**) The YRB; (**b**) Upstream area; (**c**) Midstream area; (**d**) Downstream area.

3.3.1. Time Series Evolution of Each Area

(1) Upstream area. From 2004 to 2009, the nuclear density curve in the upstream area was flat, and the variation range was not obvious, indicating few differences and changes in the efficiency during this period. From 2014 to 2019, the nuclear density curve showed obvious peaks, and these peaks rose sharply, indicating that the efficiency values in the upstream areas significantly differed during this period, and the differences among cities were rapidly widened. In 2014, there were two peaks, which indicated that the efficiency values during this period showed a strong differentiation in high and low values. Whereas in 2019, there were three peaks, and all were concentrated in the high-value area, indicating that the efficiency values in this period were relatively high, and the differences were obvious.

(2) Midstream area. Owing to the relatively large number of resource-based cities in the midstream areas, this region showed characteristics similar to the overall efficiency evolution of the YRB. The main differences were the variation in the amplitude of the wave crest and the shape of the tail. The degree of contraction of the left peak in the midstream area was higher than that of the YRB, and the uplift degree of the right peak was less than that of the YRB. This indicated that the reduction in the degree of differentiation in the middle reaches was more obvious in the low-value area, whereas the expansion trend of differentiation in the high-value area was smaller than that in the YRB. In the tail of the curve, the right tail shrank first and then grew, thereby indicating that the efficiency value of the high-value area increased after a continuous reduction.

(3) Downstream area. From 2004 to 2014, the variation range of the nuclear density curve in the downstream area was not obvious, and the position of the wave peak showed an overall downward trend. The left peak shifted slightly to the left, whereas the right peak remained relatively stable; this indicated that during this period, the efficiency of resource-based cities in the downstream area changed minimally, the efficiency difference between cities continued to narrow, the efficiency in the low-value area decreased slightly, and the change in the high-value area was not significant. By 2019, the left peak decreased significantly, whereas the right peak rose sharply, and the left peak moved slightly to the right; this indicated that the difference in the efficiency in the low-value area decreased significantly, whereas the difference in the efficiency value in the high-value area expanded rapidly, and the efficiency value in the low-value area increased. During the study period, the left tail was relatively obvious, first reduced and then extended, indicating that the efficiency value in the low-value area first decreased and then increased.

3.3.2. Time Series Evolution of Various Types

The GLUE values of different types of resource-based cities showed different evolution laws (Figure 6).

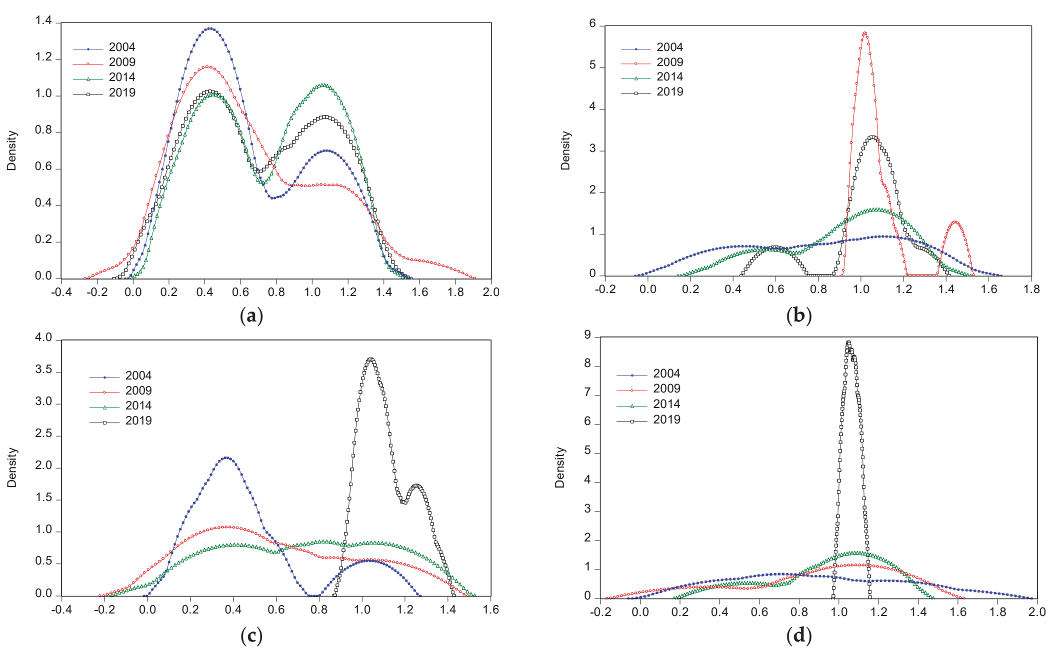


Figure 6. Evolution of GLUE of resource-based cities in each type of the YRB. (**a**) Mature cities; (**b**) Growing cities; (**c**) Recessionary cities; (**d**) Regenerative cities.

(1) Mature cities. From 2004 to 2019, the core density curve of the efficiency value of mature cities had a typical bimodal structure, indicating that the efficiency value of mature cities presented the differentiation characteristics of high value and low value. The wave crest in the low value area decreased gradually, while the wave crest in the high value area showed the characteristics of increased volatility, indicating that the difference of efficiency value in the low value area decreased gradually, while the difference in the high value area changed greatly and increased as a whole.

(2) Growing cities. During the study period, the efficiency value curve of growing cities changed greatly. The nuclear density curve in 2004 and 2014 was relatively flat, and the peak was not obvious, indicating that there was little difference in the efficiency value in this period. The annual average for 2009 and 2019 was in the form of double peaks, indicating an obvious differentiation in the efficiency value in this period. In 2009, the two peaks shifted significantly to the right, indicating that the efficiency value of low value area and high value area increased rapidly in this year; The wave crest in the low value area rose first and then decreased, while the wave crest in the high value area continued to rise, indicating that the difference of efficiency value in the low value area changed greatly, expanded first and then tended to converge, while the difference in the high value area increased continuously.

(3) Recessionary cities. In 2009 and 2014, the efficiency value curve of recessionary resource-based cities was relatively flat, while in 2004 and 2019, the curve changed significantly and showed bimodal characteristics, indicating that the efficiency value of this type of city changed from obvious differentiation to convergence, and the evolution characteristics of differentiation had appeared in recent years. Both the left peak and the right peak migrated significantly to the right, and the left peak decreased first and then increased significantly, and the right peak continued to rise, indicating that the efficiency values of the low value area and the high value area had increased, the low value area tended to converge and then expanded the difference, while the difference of the high value area continued to increase.

(4) Regenerative cities. From 2004 to 2014, the efficiency value curve of this type of city was relatively flat, with only a slight bimodal structure in 2014, while in 2019, the change was large, and the single peak was significantly prominent, indicating that the change and difference in efficiency value in the early stage were not obvious, only there were signs of differentiation in the middle stage, while the difference in the later stage was sharply enlarged. The trailing indentation on the right side of the curve was obvious, indicating that the efficiency value in the high value area decreased significantly.

4. Analysis of Influencing Factors of GLUE in Resource-Based Cities

Tobit regression analysis of influencing factors of GLUE of resource-based cities in the YRB was performed using the Eviews 10.0 software. The model operation results showed that the log likelihood values in 2004, 2009, 2014, and 2019 were −4.340, −5.436, 1.790, and 1.423, respectively, and the *AIC* values were 0.819, 0.882, 0.469, and 0.490, respectively, thereby indicating that the model fitting effect was satisfactory (Table 4).

Table 4 demonstrates differences in the influence of various variables on the GLUE of resource-based cities. According to the average value of the influence coefficient for each year, the impact of economic development factors was the strongest. For every percentage point increase, the GLUE of urban land increased by 0.724 percentage points. The second strongest factor was population growth; for every percentage point increase, the efficiency value decreased by 0.406 percentage points. By contrast, the influence strength of the medical conditions, cultural level, and science and technology investment factors were weak, and environmental management, industrial structure, and education investment showed no impact whatsoever. (1) Population growth factors. Except for 2009, population growth in other years had a reverse control effect on the value of GLUE, of which 2014 and 2019 had the strongest effect, and both passed the significance level test of 1%. This indicated that excessive population gathering led to excessive consumption of resources, which was not conducive to facilitating green land use in urban areas. (2) Economic development factors. During the study period, the effect of economic development factors on GLUE was positive, and the regression coefficients passed the significance test. This impact was the strongest in 2009, with a regression coefficient of 1.054; this indicates that, when improving GLUE in resource-based cities, the vitality of urban economic development should be increased, and regional green transformation and development should be promoted through offering economic incentives. (3) Industrial structural factors. The impact of industrial structure on GLUE was negative. This indicates that resource-based cities should constantly optimize their industrial structure during transformation and development, eliminate their dependence on high energy consumption and heavy pollution industries such as mining and manufacturing, and attempt to increase the output value proportion generated by tertiary industry. (4) Cultural development factors. The regression coefficient of the cultural level factor passed the significance level test of 10% in 2014 and 2019, and the action direction was negative; this indicated that improving the cultural level cannot effectively improve GLUE in resource-based cities, but it does provide a certain degree of inhibition. (5) Medical conditions The regression coefficient of medical condition factors passed the significance test in 2004 and 2009, and the action direction was negative. However, this direction was positive in 2014 and 2019, indicating that this factor's impact on the value of GLUE was not stable. (6) Education investment factors. The regression coefficient of this factor was positive in 2004 and 2019 and passed the significance test at the 5% level in 2004; this indicated that education had a relatively obvious and positive role in improving GLUE in resource-based cities. (7) Science and technology investment factors. The regression coefficients of science and technology investment factors were negative, which indicates that excessive science and technology investment inhibited improvements in GLUE within resource-based cities to a certain extent. This result also indicated that the science and technology transformations of resource-based cities in this region did not effectively promote a green transformation and development in land use. (8) Environmental management factors. The effect of environmental management factors on the GLUE was positive, thereby indicating that strengthening environmental management can effectively improve the value of GLUE and promote regional green-and low-carbon transformation.

Table 4. Tobit regression results of influencing factors of GLUE on resource-based cities in the YRB.

Variable Name	2004	2009	2014	2019
Peop	−0.307 (0.283)	0.225 (0.240)	−0.854 *** (0.253)	−0.687 *** (0.205)
Econ	0.918 * (0.551)	1.054 *** (0.292)	0.410 ** (0.178)	0.514 ** (0.260)
Indu	−0.185 (0.287)	−0.230 (0.235)	−0.066 (0.163)	−0.171 (0.259)
Cult	−0.338 (0.277)	0.059 (0.216)	−0.288 * (0.169)	−0.399 * (0.231)
Hosp	−0.437 * (0.248)	−0.958 *** (0.363)	0.075 (0.212)	0.328 (0.248)
Educ	0.595 ** (0.302)	−0.312 (0.262)	−0.159 (0.213)	0.225 (0.272)
Scie	−0.401 (0.606)	−0.252 (0.265)	−0.122 (0.157)	−0.098 (0.169)
Envi	0.286 (0.215)	0.007 (0.200)	0.283 (0.187)	0.106 (0.147)

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; the figures in brackets are standard errors.

5. Discussion

5.1. GLUE with Carbon Emissions Included in Undesirable Output

It is of great significance to study the GLUE of resource-based cities under the constraint of carbon emission. With the continuous advancement of ecological civilization construction, the concept of green development has gradually penetrated all aspects of economic and social development. Land use efficiency evaluation needs to consider not only economic and social output indicators but also environmental pollution and greenhouse gas emission caused by development and construction. By comparing the traditional DEA model with the SBM undesirable model considering undesirable output, Zhang found that the latter's efficiency is only 77.04% of the former [60]. It shows that pollution emission reduces the social welfare benefits of output and has an obvious negative effect on land use efficiency. By studying the GLUE of resource-based cities in the YRB concerning unexpected output (excluding carbon emission), Ding found that the number of cities with an efficiency value of more than 1.06 in 2009 and 2014 was higher than that in this study [54], indicating that when the carbon emission factor is included in the undesirable output for the calculation of GLUE, it will further reduce the social welfare effect of output and lead to the reduction of efficiency value. Therefore, it is very necessary to consider the impact of carbon emissions on the green transformation of resource-based cities under the goal of "carbon peaking" and "carbon neutralization", which can urge local governments to take effective measures to control urban carbon emissions, to help alleviate the crisis caused by global climate change.

5.2. GLUE Considering Carbon Emissions and Influencing Factors

By studying the GLUE of resource-based cities under the constraint of carbon emission, it is possible to grasp the changing trend and temporal and spatial differentiation of GLUE of resource-based cities, analyze the reasons for its overall change and spatial difference, and study the action direction and strength of various factors through influencing factor analysis, to provide a basis for local governments to make decisions to improve the GLUE.

(1) The GLUE regarding carbon emissions of resource-based cities in the YRB has increased annually, but the efficiency values of various river basins and types of resource-based cities differed. Among them, the upstream area had the highest efficiency values and the fastest growth rate, whereas the midstream and downstream areas had low efficiency values and low growth rates. The efficiency values of the growing and regenerative resource-based cities were high, whereas those of recessionary and mature resource-based cities were low. However, the fastest growth rate was in recessionary cities, and the growth rates of the other three efficiency types were relatively slow.

(2) The GLUE of resource-based cities in the YRB showed obvious temporal and spatial differences. Overall, the efficiency values presented a spatial pattern of "high in the west and low in the east", but those of some cities in far east Shandong Province increased. During the study period, the upstream area maintained a stable development at a high level, the midstream area decreased significantly, and the northern region decreased following a continuous improvement. The efficiency values of northern cities in the east wing were high and steadily increased, whereas those of the southern cities in the eastern wing were low and decreased significantly.

(3) The GLUE of resource-based cities in the YRB presented the characteristics of "high-low" polarization overall, indicating that the GLUE of resource-based cities in this region presented unbalanced development. During the study period, the low-value areas demonstrated a gradual improvement in efficiency, and the differences tended to converge, whereas the growth of high-value areas was not obvious, and the differences between cities gradually expanded.

(4) Economic development and population growth factors had a substantial impact on the GLUE of resource-based cities in the YRB, followed by the medical conditions, cultural level, and science and technology investment factors. In contrast, environmental management, industrial structure, and education investment factors had minimal impact.

5.3. Suggestions for Improving the GLUE

Combined with the above research, some suggestions are put forward to improve the GLUE of resource-based cities in the YRB from the region, type, industry, and factors.

(1) Improve the GLUE of resource-based cities in the midstream and downstream areas to reduce the overall regional difference. Increasing the efficiency improvement of resource-based cities with low efficiency values can effectively improve the overall GLUE value of the region. Therefore, the midstream and downstream areas with low efficiency values should receive extra focus, especially Weinan, Linfen, Yan'an, Jinzhong, Jincheng, and other cities with an obvious decline in efficiency grades in the midstream area. Specifically,

reasons for their low efficiency values and continuous declines should be analyzed, and improvements in urban green and low-carbon governance should be sought.

(2) Promote the GLUE of recessionary and mature cities to reduce the differences between different types of cities. Boost the green and low-carbon transformation of land use in recessionary and mature resource-based cities with low efficiency values, especially the mature cities with the slowest growth rate. Gradually phase out their dependence on industries such as resource mining, processing, and transportation, actively pursue industrial structure reform and transformation, and develop primary and tertiary industries combined with regional characteristics. Examples include exploring the integration of mining and agriculture, developing high-quality agricultural products, integrating mining and tourism, and fostering partnerships with mining schools to build green and low-carbon economic models, such as a science popularization education base.

(3) Adjust the industrial structure and promote the green and low-carbon upgrading of the industrial system of resource-based cities. Respect the life cycle law of resource-based cities, study and judge the resource reserves and exploitation potential of each resource-based city, and realize the reconstruction or upgrading of the industrial system in the early stage of resource depletion in combination with the location conditions and natural endowment characteristics. For resource-based cities without support [61], strive to cultivate and expand the non-mining economy and actively seek to combine with the existing advantageous industries of the city for resource-based cities with support.

(4) Improve and optimize the driving factors to realize the green and low-carbon development of resource-based cities. It is important to improve the urban economic vitality, promote the orderly flow of population, strive to improve social and public services such as medical and cultural conditions, and improve the GLUE of resource-based cities by increasing investment in science, technology and education and strengthening environmental management, especially increasing scientific and technological innovation, strengthen the role of scientific and technological innovation in promoting the upgrading of regional industrial structure and the transformation of green development, to promote the comprehensive, sustainable and high-quality development of the YRB.

6. Conclusions

This study considers carbon emissions as an undesirable output factor and evaluates the GLUE of resource-based cities in the YRB, an important ecological functional area in China. It analyzes its temporal and spatial differences and explores its influencing factors and action mechanisms to provide a scientific basis for promoting the green and low-carbon development of the region. Although this study improves the research methods of urban land green use efficiency under the objectives of "carbon peak" and "carbon neutralization", due to the limitation of the refinement of carbon emission data, the scientificity of this study can be further improved in the future. Of course, it is also necessary to further explore how the resource-based cities in the YRB can realize the industrial integrated development of the mine-agriculture-city complex area [62] under the hard constraints of natural conditions, promote the transformation and upgrading of the industrial system to achieve high-quality regional development under the guidance of green and low-carbon governance, and contribute to mitigating the crisis of global climate change.

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Identification of Urban Functional Areas Based on the Multimodal Deep Learning Fusion of High-Resolution Remote Sensing Images and Social Perception Data

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Abstract: As the basic spatial unit of urban planning and management, it is necessary to know the distribution status of urban functional areas in time. Due to the complexity of urban land use, it is difficult to identify the urban functional areas using only remote sensing images. Social perception data can provide additional information for the identification of urban functional areas. However, the sources of remote sensing data and social perception data differ, with some differences in data forms. Existing methods cannot comprehensively consider the characteristics of these data for functional area identification. Therefore, in this study, we propose a multimodal deep learning method with an attention mechanism to fully utilize the data features of these two modalities and apply it to the recognition of urban functional areas. First, the pre-processed remote sensing images, points of interest, and building footprint data are divided into block-based target units of features by the road network. Next, the remote sensing image features and social perception data features of the target unit are extracted separately using a two-branch convolutional network. Finally, features are extracted sequentially along two separate dimensions, being channel and spatial, to generate an attention weight map for the identification and classification mapping of urban functional areas. The model framework was finally applied to the Ningbo dataset for testing, and the recognition accuracy was above 93%. The experimental results deduce, as a whole, that the prediction performance of the deep multimodal fusion model framework with an attention mechanism is comparatively superior to other traditional methods. It can provide a reference for the classification of urban land use and provide data support for urban planning and management.

Keywords: multimodal data; attention mechanisms; data fusion; urban planning

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1. Introduction

Urban functional areas are the important spatial carriers of various urban economic and social functions, as well as the specific performance units of natural and socio-economic resources. As rapid urbanization is taking place around the world, various elements are being taken into different spaces of the city, thus forming functional area differentiation at different regional scales. As such, unreasonable urban planning will lead to an array of tangible problems, such as a single-function structure, spatial differentiation, and improper resource allocation in cities. Therefore, accurately identifying the urban spatial and social structures is important to reasonably delineate urban functional areas, thereby functionally coordinating human-land relations, effectively optimizing urban spatial strategies, and improving urban planning [1–6].

With accelerated advances in remote sensing technology, we are able to acquire high-resolution satellite and aerial imagery, allowing us obtain more texture detail from high-altitude images than ever before. Traditionally, urban functional zone identification relies on planning maps of land use and field surveys. Nevertheless, the survey-based methodology often consumes significant labor resources and a large amount of time, and even the reliability is presumably influenced by the subjectivity of human perceptions. Moreover, the information obtained from a single data source is not comprehensive enough and is, therefore, limited. There is enormous potential in extracting and analyzing the functions of urban areas from high-resolution spatial remote sensing imagery, which influences the evolution of research regarding urbanization. Further, this technique has proven to be one of the most convenient and effective methods in many applications such as Earth observation and urban structure analysis [7–9]. For instance, Pacifici [10] employed multi-scale texture metrics from very high-resolution panchromatic images to classify urban land use categories. Pacifici's outcomes demonstrate that, in a multi-scale approach, it is possible to discriminate different asphalt surfaces, such as roads, highways, and parking lots due to the different textural information content. Later, Soe [11] experimentally verified that the spectral information presented by pixels plays a pivotal role in the process of classification. Zhang [12] developed a joint deep learning model that fully incorporates a multilayer perceptron (MLP) and convolutional neural network to enhance the spatial and spectral representation, subsequently achieving land refinement classification. Li [13] completed the urban land classification based on the geometric, morphological, and contextual attributes of the target objects with the corresponding land use indicators. However, most of these studies employ physical features of ground components (e.g., spectral, shape, and textural features) to extract urban land use patterns, which can only be associated with low-level semantic land covered with the information of ground features, and it is difficult to harvest high-level semantic information of urban spatial structures [14–18].

It is noteworthy to mention that the fusion of remote sensing images with social perception data is a new, alternative direction [19]. A series of recent studies have reflected that the exploitation of social sensing data, such as Point of Interest (POI), taxi track data, cell phone data, social media data, and street view data, performs well in identifying functional urban areas [20–25]. Take, for example, the case of TU [26] combining remotely sensed images with cell phone location data, landscape, and activity indicators that are calculated to cluster functional areas. Gong [27] combined nighttime remote sensing images, satellite images, POI, and cell phone data in order to create a national land use map. Liu [28] integrates probabilistic thematic models and support vector machines (SVM) to fuse natural physical features from high-resolution images and socio-economic semantic features from multi-source social media data, working to build a lexicon of land use words in a framework to analyze fine-grained urban structures and to monitor urban land use changes. These studies encourage the great potential of multimodal data in revealing the functional zoning of urban areas.

However, remotely sensed and socially sensed data are relatively different in terms of sources and modalities. In general, remotely sensed images cover a study area, where as social sensing data are location-based and are represented as points, dashes, or polygons. In addition, the features of social sensing data may be time-based rather than space-based [29]. To fuse these two types of multi-source and multi-modal data is not an easy task, especially when mitigating the modal gaps and heterogeneity between them [30,31]. Nicolas [32] exploited the multi-source satellite sensor data through an improved Segnet network, thus providing better performance for urban feature recognition compared to the one that uses fully connected convolutional networks (FCN). Cao [33] integrated the long short-term memory (LSTM) extraction of user time series feature data with Resnet extraction of remote sensing image features as it seeks to work out functional area identification. Although the extracted modal data features are able to accomplish the classification task, the features independently existed without any interrelationship between them. It is likely that when the deficiency occurred in data collecting, the recognition effect could be influenced by the gap between data forms.

Deep-learning-based fusion methods have great potential for integrating multi-source, multi-modal remote sensing and social remote sensing data. Significant improvements have been made in many domains so far, including hyperspectral image analysis [34], image scene classification [35], target detection [36], and so forth. The main advantage of deep learning methods lies in its capability of learning high-level features from large amounts of data automatically, which is crucial to bridge the gap between different data patterns at the feature level. In particular, the recently emerged attention mechanism [37] further strengthens the feature representation and advances the functions of multi-source multimodal data in urban functional area identification applications.

In this paper, we propose a deep-learning-based framework where multi-modal data are perfectly fused in urban functional zoning recognition, which consists of three main contributions. First, a multimodal data fusion framework is proposed to reveal the layout of urban functional zones by introducing building footprint and POI data. Second, after feature extraction by deep convolutional neural networks, an attention mechanism is introduced to focus on the main features of multimodal data and enhance the interconnection of different modal data. The results show that using the multimodal network model based on the attention mechanism to extract features can improve the prediction performance. Third, we further compare different fusion methods with different fusion stages to further validate the robustness of the method. Therefore, our method can help to refine the urban land use classification and provide data to support the refinement of urban management.

The paper is organized as follows: Section 2 brings forward how the dataset was created for the region of Ningbo. In Section 3, we present the proposed model in detail. Section 4 illustrates the experimental setup and results, while in Section 5 the applicability of the method is comprehensively discussed. Section 6 concludes the paper.

2. Study Area and Data Sources

2.1. Study Area

Located on the southeast coast of China, Ningbo is home to 9.4 million people, with an area of 9816 km^2. As an important economic center of the Yangtze Delta megalopolis, Ningbo has continuously established rich types of urban functions to meet the needs of the booming advances in tertiary industries and fast expansion in foreign trade. The research area of this paper encompasses several parts of Ningbo. Study area 1 is situated on the intersection of the Jiangbei District, the Haishu District, and the Yinzhou District, with an area of about 48.78 km^2, including Tianyi Square, which is the largest urban commercial area that integrates recreation, commerce, tourism, catering, and shopping in Ningbo. Study area 2 is Vanke Square, a newly developed commercial center with its surrounding areas in Zhenhai District, covering an area of 17.63 km^2. There is much common ground between these two regions. Both are highly concentrated on the commercial and industrial development, residential and public services, medical and health care, and sports and leisure facilities, with a similar distribution of regional buildings and rich POI data, setting good examples to give the full picture of a comparative study of urban functional zoning in this paper. The two study areas are shown in Figure 1.

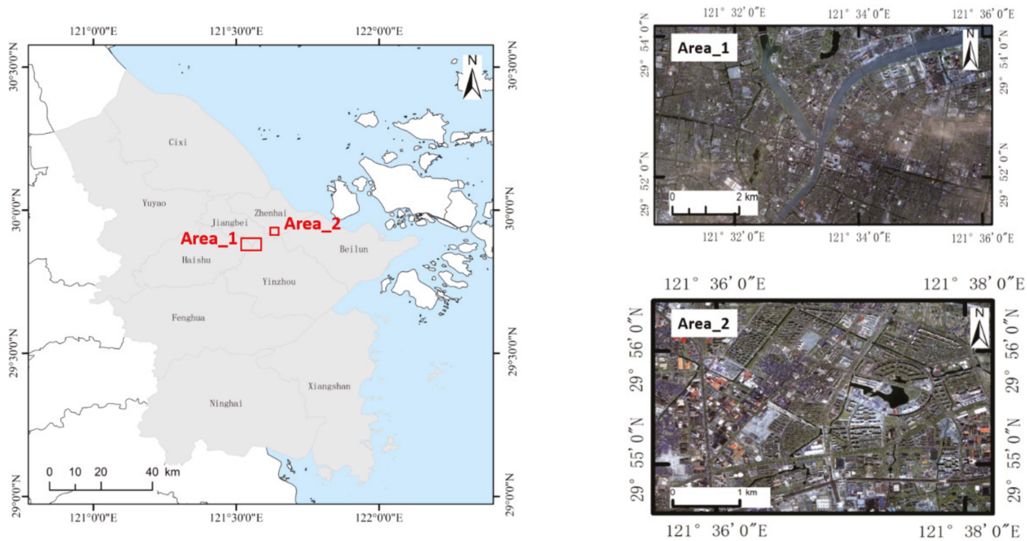
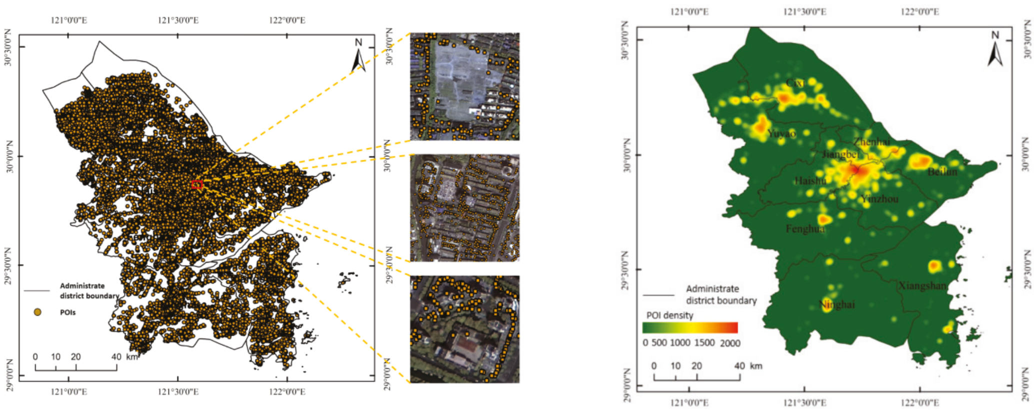


Figure 1. The two study areas utilized in this paper.

2.2. Data Sources

Gaofen (GF)-2 data are used as the high-resolution spatial remote sensing data source in this experiment. Launched in 2014, the satellite was equipped with panchromatic and multispectral sensors with resolutions of 1 m and 4 m, respectively. The images of the study areas were acquired on 16 June 2019. Preprocessing the illustrations intensively helps us make the full use of high-resolution spatial image information and spectral feature information. First, the parameters given by the China Resources Satellite Data and application center are used for radiometric calibration. Second, atmospheric correction is carried out to eliminate the errors caused by atmospheric scattering, absorption, and reflection. Third, the rational polynomial model is used for positive correction. Next, multispectral images and panchromatic images are fused to obtain multispectral data with a 1 m spatial resolution. Finally, according to the range of the study areas, the images of two study areas are cut from the preprocessed images. The size of study area 1 is 6217 × 11,544 pixels and that of study area 2 is 4327 × 4782 pixels.

Drawing from Gaode map API (https://lbs.amap.com/tools/picker) in 1 June 2019, four types of attributes involving the name, function, address, longitude and latitude constitute the POI data. It is worth noting that POI is not generated by physical information on the surface, but by attribute labels and geographical points triggered by human economic activities. To some extent, it shed light on the people's activities in specific places. We collected 48,886 records covering the study area from Gaode API. Although POI data contains semantic information that largely mirrors the socio-economic attributes inside the buildings, not all POI data can help identify urban functional areas and may even provoke interference to a certain degree. It is those invalid factors, such as public toilets, newspaper kiosks, traffic stations, etc., that are removed from the original data. First POI data is filtered to exclude the data without detailed category identification and coordinate information. Second, derived from the standard of classification and planning of urban land for Construction, issued by the Ministry of Housing and Urban Rural Development of the People's Republic of China, the POI is reclassified into 14 categories, including public facilities, catering services, education and cultural services, shopping services, companies and enterprises, medical services, accommodation services, commercial residences, life services, landscapes, transportation facilities services, financial and insurance services, sports and leisure services, government agencies, and social organizations. Finally, the aforementioned POI data is corrected from the Mars Coordinate System referenced by Gaode Map to the WGS84 Coordinate System with the remote sensing image techniques. After going through these intense processes, study area 1 contains 31,240 POI data records and study area 2 contains 5632. The distribution of the POIs is shown in Figure 2.



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

Figure 2. Point of interest (POI) data for Ningbo in June 2019. (**a**) Spatial distribution of POIs. (**b**) Density of POIs counted in segmentation units.

Building contour data, obtained in 1 June 2019, are from Bigemap (http://www.bigemap.com). Study area 1 contains 6808 data records, with 3510 records being contained in study area 2. It is obvious that a closed topological relationship exists between buildings and their corresponding plot units. The differences in the physical properties of a building complex reflect the functional attributes of a region, such as a residential area. The building contour data we obtained encompasses three types of attributes: area, length, and floor. First, area represents the actual floor area of a building. We calculated the total area and average area of all buildings in the region, and counted the frequency of buildings in a certain area range. Some differences appear in the fluctuation range of the average area of different functional areas. For example, the internal building area of the residential area is similar, and the building height is unified. The floor area of the office building is small, while the floor area of the shopping center is large. Regional functional attributes can be inferred from the difference of the area. Second, the building perimeter distinctly expresses the length of the building outline, which measures the length difference between buildings in an area. Different types of functional zoning can be inferred by calculating the total perimeter and average perimeter, as well as by counting the frequency of buildings in a certain range interval. The differences in the height of buildings reflected in floors are variously distributed in different functional areas. For example, business office constructions are usually located in the center of the area, with a floor height that is higher than ordinary residential buildings. Here, we employ floor height, average floor height, and statistics of the frequency of buildings within a certain height range to infer the functional attributes of the area. The distribution of the building footprint is shown in the Figure 3.

It is worth mentioning that OSM data, obtained in 1 June 2019, comes from OpenStreetMap (https://www.openstreetmap.org), which is currently the largest open authorized geospatial data database. OpenStreetMap gives a full picture of different sorts of GIS information, including road infrastructure, built environment, etc., thus, to some extent, providing an alternative solution to proprietary or authoritative data in many projects, as several studies have evaluated the spatial accuracy of OSM. In short, an array of literature verifies the reliability of OSM data.

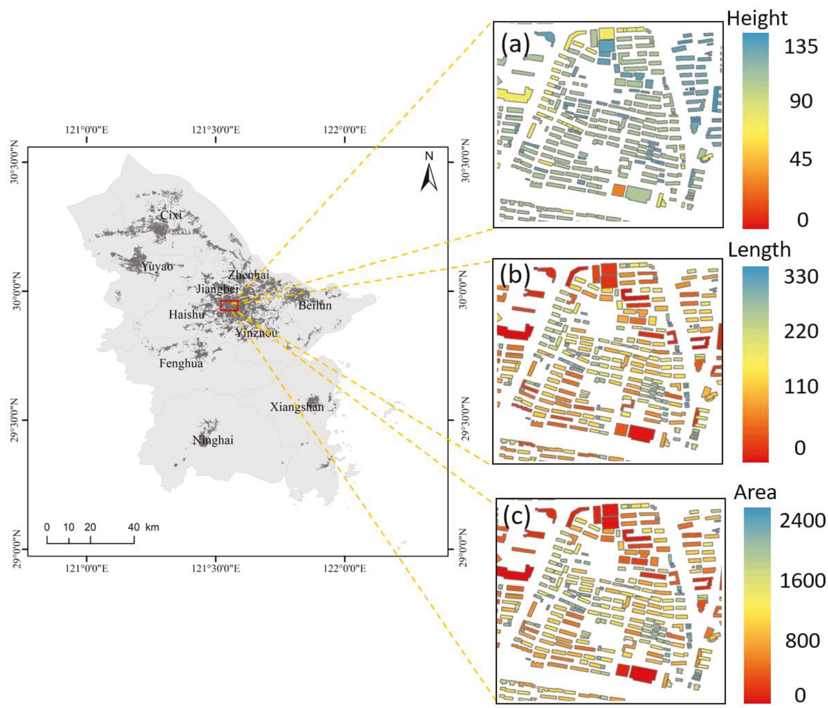


Figure 3. Building footprint of the study area. (**a**) building height distribution. (**b**) building length distribution. (**c**) building area distribution.

3. Method

The features extracted by traditional methods of identifying urban functional area are independent of each other among the modal data since the features are not interrelated with each other. However, multimodal feature fusion on the basis of deep learning maps all features into a common subspace as well as completes the classification task in the light of the similarity and measurability of data between modalities, somehow marginalizing the main features of the modal data and weakening the feature extraction expression capability of the network. Therefore, this study improves the ability of the convolutional structure in the network to extract each modal data by using the modal data reconstruction loss function. In addition, an attention mechanism is introduced to strengthen the feature expression capability and optimize the network performance by giving more weight to the main features from both spatial and channel dimensions.

In this paper, the urban functional area identification framework is implemented by a perfect combination of remotely sensed images and socio-economic attribute data, such as points of interest (POI), road networks, and building footprints. As shown in Figure 4, three major steps are involved in the process of the multi-modal urban functional area identification framework. First, it is clear that the road network segments the preprocessed remote sensing image, POIs, and building footprint data. Next, in the light of the segmented block, the convolution network is applied to further extract the features. Third, the features picked up by step 2 are input into the spatial attention mechanism and channel attention mechanism modules as it looks to fetch the attention weight map. Finally, we multiply the features used in step 1 with the generated feature attention map in step 2 to harvest the final feature map, a key factor to settle city functional area recognition classification mapping.

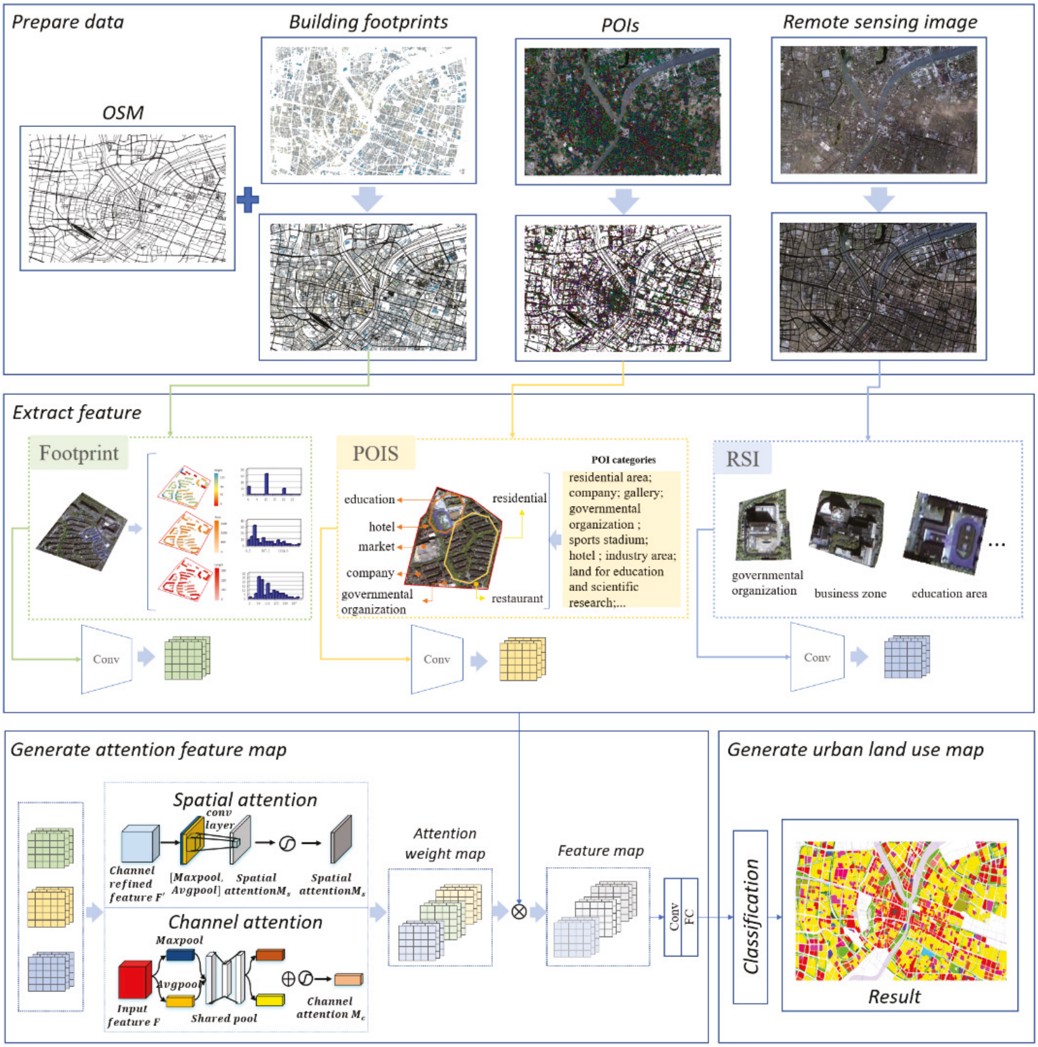


Figure 4. Framework of urban functional area identification.

3.1. Block Generation by Osm

Blocks are the basic units that carry social and economic functions in urban management and urban planning. Long and Liu contend that the land parcel is a polygon surrounded by a road network as the dividing boundary of the urban area [38]. In this study, we adopted this method, using OSM road network data to form block units. As shown in Figure 5a–c, first, preprocessing operations such as simplification, merging, and geometric correction are performed on the road network data. Second, it is important to forge a buffer zone hinged on the road network of different levels. Finally, we divide the research area into a string of independent blocks determined from the established buffer zone.

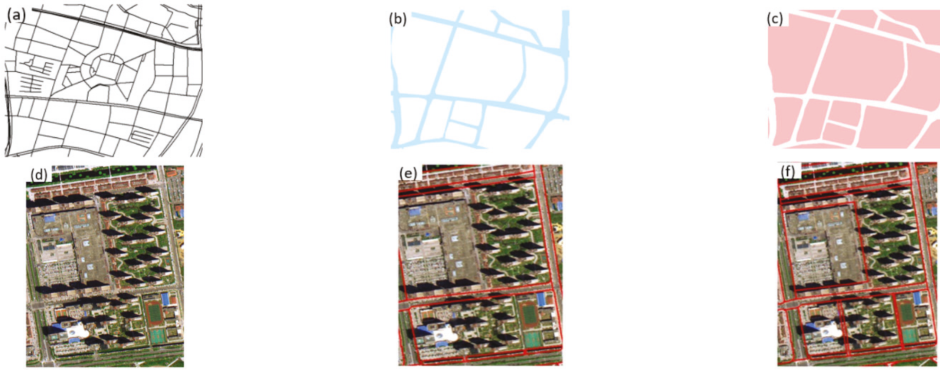


Figure 5. Road network processing and block generation: (**a**) original OSM road network; (**b**) road buffers from OSM; (**c**) segmentation results based on OSM road buffers; (**d**) raw image; (**e**) the OSM before editing; and (**f**) the OSM after editing.

However, in the whole process, few high-purity samples prevail, since the medical and administrative categories are usually mixed with other land uses. Therefore, in order to ensure the integrity and independence of the function blocks, we manually edit the following samples in Figure 5d,e, seeking to connect original unconnected lines into road sections. These steps help to form an independent unit and to guarantee a purity of each sample that exceeds 90%.

3.2. Generating the Feature Tensor

Generation of the footprint feature tensor: As shown in Figure 6, the spatial connection method of ArcMap10.6 (Environmental Systems Research Institute, Inc., Redlands, CA, USA) is first applied to connect buildings with intersecting parcels while obtaining information of all buildings within a parcel. Next, the metrics are calculated according to the statistical method. Finally, the feature vectors representing the building information are generated.

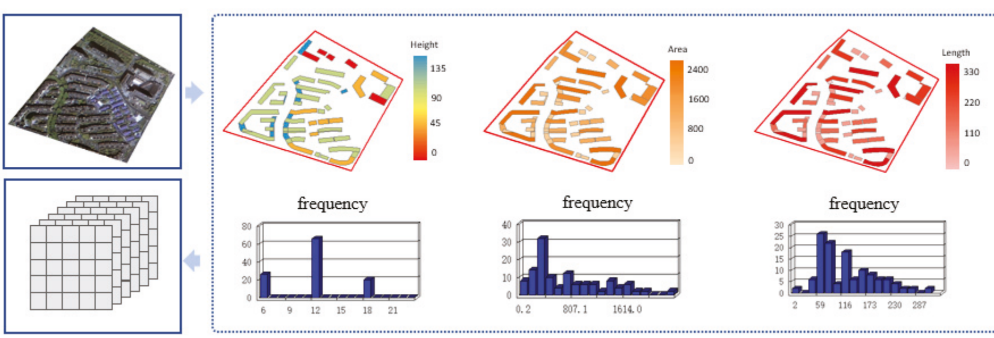


Figure 6. Generation of the footprint feature tensor.

Generation of the POI feature tensor: As shown in Figure 7, the spatial connectivity method is first implemented in ArcMap10.6 as it seeks to count the number of various POIs in the neighborhood. Second, the type ratio of each unit is calculated on the basis of the formula, and the type ratio value is used as a criterion to judge the functional nature of the neighborhood. Finally, feature vectors are generated to represent building information [39]. The calculation method is as follows:

$$F_i = \frac{n_i}{N_i}(i = 1, 2, 3, \cdots, 14) \quad (1)$$

$$C_i = \frac{F_i}{\sum_{i=1}^{14} F_i}(i = 1, 2, 3, \cdots, 14) \quad (2)$$

where i represents the type of POI, n_i serves as the number of the i-th type of POI in the block, N_i stands for the total number of the i-th type of POI, F_i acts as the frequency density of the i-th type of POI in the total number of POIs of this type, and C_i represents the ratio of the frequency density of the i-th type of POI to the frequency density of all types of POI in the block.

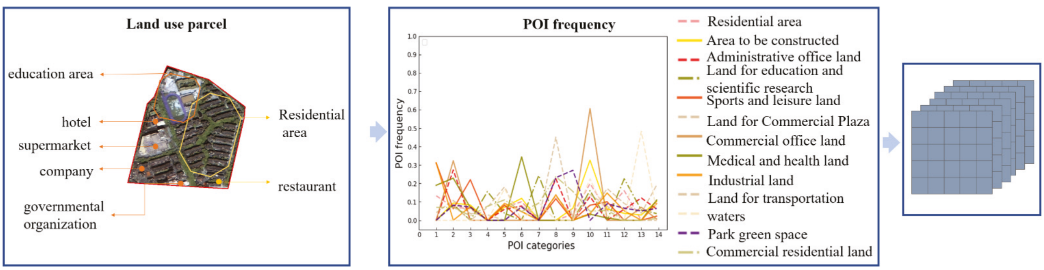


Figure 7. Generation of the footprint feature tensor.

Generation of the image feature tensor: When extracting the features of high-resolution remote sensing images, instead of separately attaining the low-level semantic features, such as texture, spectrum, and SIFT of the image, we take advantage of CNN to capture high-level semantic features from images. Next, we will continue our research with respect to the items of multi-modal network feature extraction and fusion in greater detail.

3.3. Feature Extraction and Feature Fusion

In this section, our team explores the details of the proposed deep multimodal fusion network, laying a foundation for integrating remote sensing images with social-economic attribute data. This encourages one to better recognize the urban region functions in our study.

The illustration (Figure 8) below clearly unveils the overall architecture of the proposed deep multimodal fusion network. The convolution structure has efficient feature extraction and representation capabilities, so two identical convolutional branch structures are employed here to obtain remote sensing image features and socioeconomic attributes, respectively. The network ϕ is composed of three major parts, being the image encoder and socioeconomic attribute encoder, the data fusion module, and the decoder of the image and socioeconomic attributes. The network takes satellite images I and socioeconomic attribute S as the inputs. The outputs are demonstrated by the predicted probability distribution P over all the categories, i.e., $p = \phi(I, S)$. In particular, it is better to garner the images and socioeconomic attributes data features with the assistance of encoder and decoder structures. Moreover, the extracted features are further fused through the spatial attention mechanism as well as the channel attention mechanism while being classified by introducing the softmax layer after passing through the convolutional layer and being fully connected. The key of the network is to learn a joint embedding space through two attention mechanisms, such that the image and social-economic characteristics are able to be well combined for prediction. Apart from the conventional cross entropy loss for classification task, we propose an auxiliary loss.

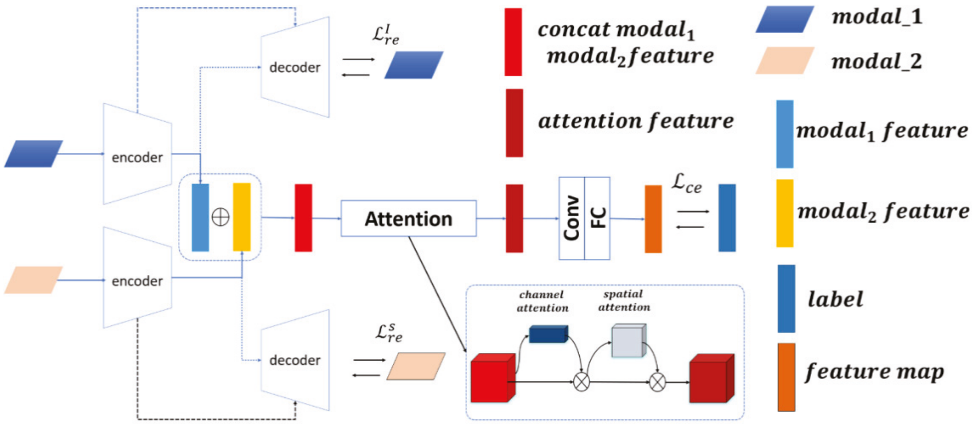


Figure 8. Multimodal fusion network.

3.3.1. Feature Extraction

The network is an encoder–decoder backbone network with a residual network architecture and two convolution branches [40,41], i.e., the remote sensing image branch and the socioeconomic attributes data branch. The backbone network, specifically designed for conducting the diversity of remote sensing data and socioeconomic attribute data, aims to integrate complementary information, alleviate the complexity of heterogeneous information, and accomplish the purpose of classification.

Each branch encoder section utilizes a similar structure to the VGG16 [42]., with four convolution blocks, each of which contains a convolutional layer with a kernel size of 3×3 with a rectified linear unit (*Relu*) and a batch normalization (*BN*). The second and fourth blocks use a max-pooling layer of size of 2×2. The features extracted by the encoder are divided into two channels; one is the decoder branch corresponding to the encoder branch for reconstruction and the other is a fusion with the features garnered by other branch networks. The extracted features are transferred to a module with an attention mechanism, working to create an attention feature map for classification. Specifically, two methods need to fuse the extracted features of two different patterns before sending them to the attention module, i.e., concatenation and element summation. For concatenation, $F = \left[F^I, F^S\right]$, and $F \in \mathbb{R}^{2n}$. For the element-wise sum, $F = F^I + F^S$, and $F \in \mathbb{R}^n$. The illustration of the two fusion methods is shown in Figure 9. Furthermore, the fused feature x is then fed into the attention module to create the attention feature map.

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

Figure 9. Method of feature fusion: (**a**) feature cascade; (**b**) feature element-wise sum.

The structure of the decoder part is symmetrical with respect to the encoder part. First, four deconvolution layers with 2×2 up-sampling are sequentially added at the end of the encoder section. Second, the final layer is a single 2×2 deconvolution layer and the size of the final output is equal to the input. We add these encoders' features into the decoder features using the skip concatenation function, enabling the decoder network to form finer feature maps. Finally, the reconstructed data is exported.

3.3.2. Feature Fusion

The features obtained after the convolution and pooling operations of the encoder are of equal importance among the features. In addition, the convolutional and the fully connected layer are expected to construct the feature space with the aim of completing the classification of the similarity and measurability between the modal data task. This method has been used previously [43,44]. However, for specific extraction and classification tasks, the importance of the features of each channel is not the same, and the feature cannot be fully concentrated on "where" is the most informative part and "what" is the most meaningful input feature map during the interactive fusion. In order to avoid the influence of invalid features on the network model, a channel and spatial attention module is embedded to distribute the weight of spatial information and channel information [45]. Hence, we adopt the channel and spatial attention module (Figure 10). Each branch could potentially learn the "what" and "where" in the channel dimension and the spatial dimension separately, thus effectively helping the information flow in the network.

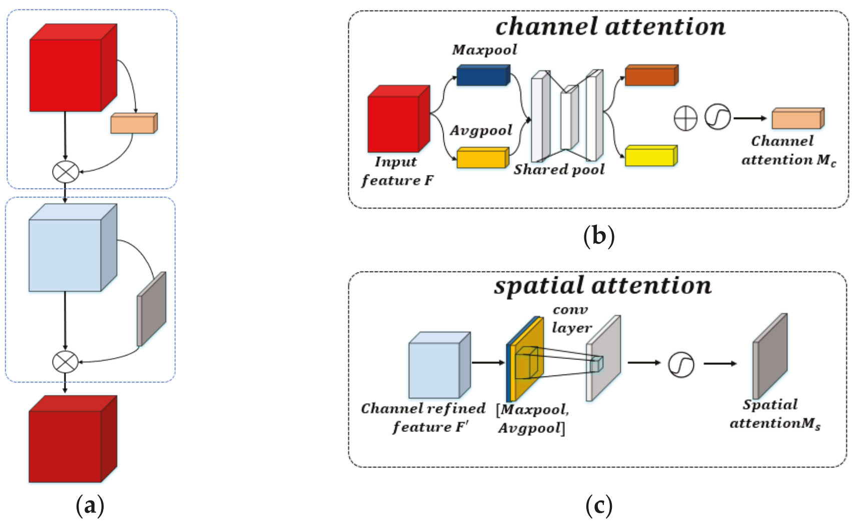


Figure 10. (**a**) CBAM module, (**b**) channel attention module, and (**c**) spatial attention module.

The intermediate feature map $F \in \mathbb{R}^{C\times H\times W}$ acts as the input to infer the 1D channel attention map $M_c \in \mathbb{R}^{C\times 1\times 1}$ and the 2D spatial attention map $M_s \in \mathbb{R}^{1\times H\times W}$, as illustrated in Figure 10a. The overall attention process can be summarized as:

$$F' = M_c(F) \bigotimes F, \tag{3}$$

$$F'' = M_c(F') \bigotimes F', \tag{4}$$

where $\otimes$ represents element-wise multiplication and F'' is the final attention output feature.

Channel attention: As shown in Figure 10b, the average pooling and maximum pooling operations are first used to aggregate the spatial information of the feature map, bringing about two different spatial context feature descriptions. F^c_{avg}, F^c_{max} respectively serve as the average pool feature and the maximum pool feature. Next, these two features go through a shared neural network. The number of neurons in the first layer is C/r, the activation function is *Relu*, and the number of neurons in the second layer is C, as the neural network parameters of the two layers are shared. After adding the two features gathered through a Sigmoid activation function, the weight coefficient $M_c \in \mathbb{R}^{C\times 1\times 1}$ is grabbed.

Finally, the weight coefficient and the original feature F are multiplied to obtain the scaled new features. The channel attention is calculated as follows:

$$M_c(F) = \sigma(\mathrm{MLP}(AvgPool(F)) + \mathrm{MLP}(MaxPool(F))) = \sigma\left(W_1\left(W_0\left(F^c_{avg}\right)\right) + W_1(W_0(F^c_{max}))\right) \quad (5)$$

where σ is the sigmoid activation function, $W_0 \in \mathbb{R}^{C/r \times C}$, $W_1 \in \mathbb{R}^{\frac{C}{r} \times C}$ is the weight of the fully connected layer, and r is the compression ratio, using the *Relu* activation function to process W_0.

Spatial attention: As shown in Figure 10c, the average pooling and maximum pooling operations are first used to aggregate the channel information of the feature map as it looks to work out two 2D feature maps $F^s_{avg} \in \mathbb{R}^{1 \times H \times W}$ and $F^s_{max} \in \mathbb{R}^{1 \times H \times W}$. Next, the two feature descriptions to be spliced together are used according to the channel after a 7×7 convolutional layer, where the activation function is Sigmoid, and the weight coefficient M_s is obtained. Finally, multiply the weight coefficient and the feature F' to get the attention feature. The spatial attention is calculated as follows:

$$M_c(F) = \sigma\left(f^{7 \times 7}([AvgPool(F); MaxPool(F)])\right) = \sigma\left(f^{7 \times 7}\left[F^s_{avg};\ F^s_{max}\right]\right) \quad (6)$$

where σ is the sigmoid activation function and $f^{7 \times 7}$ is a convolution operation with a size of 7×7.

Eventually, the fused features pass through both the convolutional layer and the fully connected layer for the output classification.

3.4. Loss Function

Aiming to achieve an effective classification and make the network more robust to missing patterns, two losses, the main loss and the auxiliary loss, are introduced to constrain the network training. The major loss is the cross entropy $\mathcal{L}_{ce}$ for the classification task. The auxiliary losses, $\mathcal{L}_{au}$, are used to complement the major loss in an attempt to increase the model robustness with missing modalities. The overall loss is formulated as follows:

$$\mathcal{L} = \mathcal{L}_{ce} + \mathcal{L}_{au} \quad (7)$$

Widely used in classification tasks, the cross-entropy loss is used to regularize the network to learn from category labels. It can be formulated as follows:

$$\mathcal{L}_{ce} = -\sum_i \sum_{k=1}^{C} y_{i,k} \log(p_{i,k}) \quad (8)$$

where $y_{i,k}$ and $p_{i,k}$ are the ground truth label and predicted probability value of class k for the i-th sample, respectively, and C is the total number of classes.

The auxiliary loss is the mean square error (MSE) loss, which is mainly employed to rein in the extracted features to be more representative through the loss triggered by the reconstruction. It can be formulated as follows:

$$\mathcal{L}_{au} = \mathcal{L}^I_{re} + \mathcal{L}^S_{re} \quad (9)$$

$$\mathcal{L}^I_{re} = \frac{1}{N} \sum_{I=1}^{N} \left(I_i - R^I_i\right)^2 \quad (10)$$

$$\mathcal{L}^S_{re} = \frac{1}{N} \sum_{I=1}^{N} \left(S_i - R^S_i\right)^2 \quad (11)$$

where $\mathcal{L}_{re}^{I}$ and $\mathcal{L}_{re}^{S}$ denote the remote sensing image and socioeconomic attribute data structure losses, respectively, with R^I and R^S being the reconstructed remote sensing image and socioeconomic attribute data, respectively.

4. Experiments

4.1. Experimental Setup

The experiments were performed on a Windows Operating System, using CPU (AMD Ryzen 9 5950X 16-Core 3.4 GHz), RAM (64 GB), and GPU (NVIDIA GeForce RTX 3080Ti 12 GB). Additionally, the deep-learning framework favored TensorFlow1.14. The hyper-parameters of momentum and epsilon in the batch normalization function were set as 0.95 and 1×10^{-5}, respectively. The adaptive moment estimation (Adam) algorithm was engaged in optimizing all models. The batch size was set as 64. Meanwhile, the maximum training iteration is set to 100 epochs. The cross-entropy function and mean squared error was sorted out as the loss function. All models were trained at once until the training loss converged.

The models can theoretically take images with an arbitrary size as input. However, the available memory is limited, and all input within a batch must have the same shape. Our method is based on CNN patches, so we processed the block into patch data that could be fed into the network for computation. Nevertheless, different functional areas possess different object compositions and spatial scales. Only one sort of objects develops in the window when the patch is too small, which fails to demonstrate the complexity of the functional area. Conversely, when the patch is too large, objects belonging to other functional areas will presumably be embodied in the patch. To accomplish the task of functional area identification, our team takes the smallest one as the reference basis for patch processing, where 725 functional blocks of study area 1 have been processed, with 205 in study area 2 (as shown in Table 1). Therefore, 71,000 patch images of size 32×32 were cropped from study area 1 and 20,500 were cropped from study area 2, where cropping was done by sliding the patch window with no overlap and cropping randomly to maintain the diversity of training samples. Ultimately, the data are divided at random into a training set and a test set at a ratio of 4:1.

Table 1. Number of functional blocks (A: Residential area, B: Administrative office land, C: Land for education and scientific research, D: Sports and leisure land, E: Land for Commercial Plaza, F: Commercial office land, G: Medical and health land, H: Industrial land, I: Land for transportation, J: Park green space, K: waters, L: Area to be constructed, M: Commercial residential land).

Name	A	B	C	D	E	F	G	H	I	J	K	L	M	SUM
Area_1	291	27	56	6	74	93	25	23	14	44	16	61	5	725
Area_2	47	3	17	24	18	5	3	46	6	9	3	13	11	205

It can be observed that when using the model for urban functional area identification, the original test image is first partitioned into small patches, and then, the predicted patches are concatenated into a final complete classification result. Obviously, the classification of patch images only acts as an intermediate stage in the classification process of urban functional area identification. Consequently, to evaluate the accuracy, the object of evaluation is actually not the small pieces directly output by the recognition model, but the complete classification result that eventually corresponds to the whole original test image.

4.2. Evaluation Metrics

To evaluate the classification results, our team resolves to embrace overall accuracy, the Kappa coefficient, and the $F1$ score as evaluation metrics. All of them can be computed by calculating the confusion matrix, which forms an informative table, allowing a direct visualization of the performance on each class, as well as analyzing the errors and confusions between different classes easily. OA is defined as the number of correctly classified data divided by total test data, which is the most intuitive measure to reveal the classification performance on the test data as a whole. Kappa is thought to be a more robust measure than a simple percent agreement calculation because it takes into account the possibility of the agreement occurring by chance. The $F1$ score, an effective metric for the categorical accuracy, is the weighted average of precision and recall. The aforementioned precision is the ratio of correctly predicted data to the total predicted data along with the recall, the ratio of correctly predicted data to all data in the actual label. The formulas are as follows:

$$\text{Overall accuracy:} \qquad p_0 = \sum_{i=1}^{n} \frac{x_{ii}}{N} \tag{12}$$

$$\text{Kappa coefficient:} \qquad K = \frac{p_0 - p_e}{1 - p_e} \tag{13}$$

$$F1 \text{ score:} \qquad F1_i = \frac{2p_i r_i}{p_i + r_i} \tag{14}$$

$$\text{Average}F1 \text{ score:} \qquad \overline{F1} = \frac{1}{n} \sum_{i=1}^{n} F1_i \tag{15}$$

where x_{ij} denotes the element of the i-th row and the j-th column in the confusion matrix, i.e., $p_e = \sum_{i=1}^{n} \left(\sum_{j=1}^{n} x_{i,j} \sum_{j=1}^{n} x_{j,i} \right) / N^2$, the number of samples of class i that is predicted to be in class j, n stands for the number of classes, and N serves as the total number of all the samples. p_i and r_i represent the precision and recall score of class i, respectively, $p_i = x_{ii} / \sum_{j=1}^{n} x_{ij}$, $r_i = x_{ii} / \sum_{j=1}^{n} x_{ji}$. $F1_i$ measures the classification result of a certain class i. The average $F1$ score ($\overline{F1}$) constitutes the average of all the $F1$ scores of different categories.

4.3. Experimental Results and Analysis

4.3.1. Results of the Network Model

We propose a multimodal deep learning fusion framework in preparation for the identification of urban functional areas using remotely sensed images and socioeconomic attribute data. The remote sensing images can extract the semantic features of low-level regional spatial distribution. Further, high-level semantic features of human economic activities show up through the analysis of social perception data. In general, they all reflect the use of functional areas from a certain perspective. By changing the input, different results can be obtained, depending on our framework. The overall classification outcomes of Area_1 and Area_2, as well as the results for each category, are presented in Tables 2 and 3, respectively.

Table 2. Overall classification results and per category results for Area_1. (I: image, F: building footprint, P: points of interest).

Name	A	B	C	D	E	F	G	H	I	J	K	L	M	OA	AA	Kappa	Avg.*F1*
I	56.98	36.30	31.83	65.17	44.94	40.42	7.42	29.81	42.70	60.65	96.23	68.10	43.06	61.83	51.69	73.50	29.69
I + F	60.33	49.17	10.26	65.01	31.50	34.71	6.59	37.82	66.76	21.98	97.76	60.89	48.30	58.84	49.36	71.45	30.54
I + P	96.24	88.36	95.97	99.89	98.84	96.88	53.56	96.12	79.82	82.49	94.41	67.80	99.98	91.26	89.31	90.57	86.46
I + P + F	96.86	91.00	96.54	99.94	97.91	86.75	72.14	97.46	97.42	71.38	94.07	75.88	99.98	93.55	91.24	91.26	88.46

Table 3. Overall classification results and per category results for Area_2. (I: image, F: building footprint, P: points of interest).

Name	A	B	C	D	E	F	G	H	I	J	K	L	M	OA	AA	Kappa	Avg.*F1*
I	58.33	35.26	63.09	76.59	59.45	43.95	42.45	66.27	56.01	58.20	91.20	59.61	46.86	71.64	61.23	79.39	45.85
I + F	66.86	53.15	70.03	77.52	63.13	58.35	55.19	73.10	63.53	48.34	91.89	69.81	54.73	76.39	67.54	82.40	56.92
I + P	95.88	66.30	98.13	84.24	86.56	77.97	92.61	87.85	78.65	67.15	89.28	76.40	87.40	91.95	84.89	93.02	83.23
I + P + F	96.97	70.73	98.12	85.62	87.29	77.59	93.13	88.44	83.02	75.97	92.29	78.52	85.67	92.76	86.67	93.52	84.77

As can be seen from Tables 2 and 3, the recognition accuracy is above 50% when using remote sensing images alone for functional area identification. The accuracy of study area 2 is higher than that of study area 1, mainly because of the simple structural composition of the functional areas. It is evident that our network enjoys some stability in the old urban areas with dense functional areas and the new urban areas with sparse functional areas.

When adding building footprint data, the overall accuracy of study Area 1 is decreased to 2%, with the accuracy of study Area 2 increasing to 4.75%. Since several differences vary in the building composition of functional areas, after the building footprint data have been attached, the identification accuracy of residential, education and research, administrative office, and commercial and industrial areas has been going through some improvement, and the increase of Research Area 2 reaches more than 6%. In terms of park green areas, building footprints are originally physical information shown by artificial features, and the structural composition of park green areas is simple, so it is convenient to procure this physical attribute information from remote sensing images. The step of adding building data is helpful for areas with large differences in building composition, such as residential areas, but data redundancy emerges with regard to park green space recognition, thus continuously impinging upon the recognition effect. In our experiments, the recognition accuracy of park green areas in study area 1 and study area 2 was significantly mitigated with the aid of building footprint data, with the reduction exceedingly more than 9%.

Unlike building footprint data, POI data showcases high-level semantic information tightly related to human economic activities. When POI data is added, the overall accuracy of study area 1 is boosted an impressive 29%, with the $F1$ score rising up considerably to 56%. At the same time, the overall accuracy of study area 2 increases to 20%, with the $F1$ experiencing an increase of 37%. Compared with the former, the latter is not improved as significantly as study area 1, which further upholds that the complete POI data better encourages urban functional area identification.

The noteworthy point is that employing building footprint data provokes some data redundancy in recognition concerning functional areas with simple compositions such as parks and green areas, but can enhance the corresponding physical features, as well as improve the recognition effect in terms of the regions with significant differences in building composition, such as residential and commercial areas. For this reason, we took remote sensing images, building footprint data, and POI data as input and further explored the social perception data contribution in urban functional areas. The overall accuracy is improved by 2% relative to remote sensing images and POI data input, as seen in Tables 2 and 3. In comparison to a single satellite image, many refinements have been seen in the recognition effect with the assistance of socioeconomic attribute data, which further underline the importance of social perception data in regional function recognition applications.

By conducting experiments in two study areas, we set forth two main objectives: (1) to investigate the influence of social perception data on the identification of urban functional areas by adding corresponding multimodal data; and (2) to investigate the impact of the completeness of social perception data on functional area identification by setting up two study areas, new and old.

4.3.2. Results of the Proposed Method and Compared Methods

In order to compare the classification performance, SVM, ResNet-18, FCN, MLP, and 3D-Densenet are selected to perform the classification in this study. It is acknowledged that the traditional methods designed to meet the needs of feature extraction and classification of high-resolution images, especially for complex urban cities, only consider shallow information. When fitting in the data with high-level semantic information, such as socioeconomic data, the traditional method fails to make the features interact with each other as it works to complete the classification work. Therefore, if one kind of data was missing, the classification effect would be profoundly disturbed. With respect to deep learning, this method effectively helps the features to interactively be fused with each other, thus making up for the effects generated by the missing data, and accomplishing the classification task. However, the features incautiously neglect some key features when they are cross-fused, but classify all the features after cross-fusion, which presumably gives rise to the redundancy of information features, as well as imposes an impact on the recognition effect. Due to this, we specify five comparison methods from three aspects to explore the reliability of our method: (1) classification based on direct feature extraction by traditional methods; (2) feature fusion classification based on deep learning; and (3) feature fusion classification based on deep learning by an attention mechanism.

A comparison of the overall accuracy, kappa, and $F1$ score of the five methods can be found in Table 4. From the table, it is obvious that the traditional method, SVM, does not take the feature interaction problem into account, potentially leading to the absence of the recognition effect, with the overall accuracy turning up at 69.51% and the kappa scoring 60.05%. Multi-layer perceptron layers are fully connected to each other. To avoid overfitting, we use three hidden layers in our experiments. Compared with the SVM, the overall accuracy of the study area 1 is improved by 2.64%, with a kappa of 3.65% and $F1$ score of 3.69%. Meanwhile, the overall accuracy of study area 2 is improved by 4.39%, with the kappa getting to 5.21% and the $F1$ score reaching 9.31%. The FCN uses convolutional layers for feature extraction, which enjoys a better feature extraction ability compared to the multilayer perceptron. The table below clearly reveals that study area 1 has an overall accuracy of 79.66%, a kappa of 74.05%, and an $F1$ score of 62.62%, while study area 2 bears an overall accuracy of 86.60%, a kappa of 70.58%, and an $F1$ score of 74.92%. Convolutional networks or fully connected networks will suffer from information loss and attrition when passing information, constantly causing gradient disappearance or gradient explosion, which is about to result in very deep networks that cannot be trained. However, Resnet solves this problem, to some extent, by introducing a skip-connected structure that efficiently protects the integrity of the information through directly driving the input information around to the output. As a result, study area 1 shows an overall accuracy of 86.80%, a kappa of 83.07%, and an $F1$ score of 73.69%. Study area 2 expresses an overall accuracy of 84.16%, a kappa of 50.47%, and an $F1$ score of 66.31%. Resnet mainly uses the repetition of the original data features only, and the completeness of the data does exert a certain influence on the recognition results, which corresponds to our previous experimental outcomes. This is also the reason why the recognition accuracy of Resnet is lower than that of FCN. In addition, compared to the ResNet, 3D-DenseNet is expected to exploit a more aggressive dense connectivity mechanism: interconnecting all layers. Specifically, each layer accepts all its preceding layers as its additional input. The essence of fusion is supposed to remove redundancy and increase the amount of predictive deterministic information by putting two or more feature maps through some sorts of computation. However, the large heterogeneity of multimodal data seemingly contributes to a reduction in recognition performance that is also begotten by the inability to focus more on the main features during interactive fusion. Based on the above approach, our method adopts the encode–decode idea, uses a similar skip structure as Resnet, uses an attention mechanism to focus on the main features during feature fusion, and uses two losses to impose control on the discrepancy. After enduring the extensive experiments, our method achieves a better performance. Study area 1 has an overall accuracy of 93.65%, a kappa of 91.36%, and an $F1$ score of 89.54%. Study area 2 has an overall accuracy of 93.27%, a kappa of 93.84%, and an $F1$ score of 86.00%.

Table 4. Overall classification results of the compared methods.

Method	Area_1			Area_2		
	OA	**Kappa**	**Avg.*F*1**	**OA**	**Kappa**	**Avg.*F*1**
SVM	69.51	60.05	54.77	72.06	66.24	47.08
MLP	72.15	63.70	58.46	76.45	71.45	56.39
FCN	79.66	74.05	62.62	86.60	70.58	74.92
3D-Densenet	76.88	69.44	59.46	73.61	43.00	34.85
Resnet	86.80	83.07	73.69	84.16	50.47	66.31
ours	93.65	91.36	89.54	93.27	93.84	86.00

The classification accuracy of each category is shown in Tables 5 and 6; our method possibly does not reap the best realization in all categories, but our method is the best in general. The visualization results of all compared methods are shown in Figure 11. Combined with the qualitative results in Figure 11, the traditional method, SVM, without involving the modal interaction fusion problem achieves an accuracy of 97.74% and 93.57% for regions lacking socioeconomic attribute data such as water. The multi-layer perceptron takes heed of the modal interaction problem, practically promoting the performance in areas with social attribute data such as residential and commercial areas compared to SVM. The superiority of convolutional layers not only lies in feature extraction but also in feature fusion. The above illustrates why FCN performs better than MLP. Although Densenet, in reusing features, places a great impact on the overall classification performance due to the large heterogeneity of multimodal data, a better classification performance of 93.73% and 98.67% was achieved for health care and industrial sites in study area 1. Resnet, unlike Densenet, employs a residual structure on the upper layer of features, allowing a better interactive fusion of multimodal data. In short, the results from study areas 1 and 2 show a greater improvement compared to 3D-Densenet. As claimed by the visualization results, our method has witnessed a more advanced performance in the identification of urban functional areas.

Table 5. Per category results for Area_1. The best results are highlighted in bold.

Name	A	B	C	D	E	F	G	H	I	J	K	L	M	Avg.*F*1
SVM	69.30	32.50	63.22	97.54	56.30	45.19	54.30	45.86	87.51	66.28	**97.74**	39.86	96.50	54.77
MLP	72.34	**84.95**	74.52	97.27	60.05	41.32	73.80	62.35	72.30	52.77	88.26	43.72	99.58	58.46
FCN	88.87	29.03	52.97	99.36	79.33	72.68	55.76	90.72	77.91	52.85	50.56	55.81	84.08	62.62
3D-Densenet	73.33	58.27	81.56	95.67	90.13	**93.73**	**98.67**	77.13	88.94	79.75	44.48	55.53	89.36	59.46
Resnet	**94.43**	32.35	67.47	90.80	93.50	93.32	69.66	78.98	81.19	68.06	68.51	75.81	51.00	73.69
ours	94.23	83.26	**90.60**	**99.93**	**99.51**	83.48	90.55	**97.31**	**98.07**	**81.56**	96.36	**81.78**	**99.99**	**89.54**

Table 6. Per category results for Area_2. The best results are highlighted in bold.

Name	A	B	C	D	E	F	G	H	I	J	K	L	M	Avg.*F*1
SVM	58.23	58.70	63.88	69.40	58.67	52.04	60.36	68.35	58.06	52.00	**93.57**	65.16	55.07	72.06
MLP	67.29	61.39	70.77	76.41	70.08	64.35	40.68	72.18	53.59	50.47	89.64	65.03	53.68	76.45
FCN	79.63	56.43	97.03	81.96	83.44	66.89	**95.27**	81.52	73.37	70.59	92.03	74.52	64.17	**86.60**
3D-Densenet	75.59	6.21	80.90	80.24	38.45	75.47	33.83	57.17	60.57	——	——	38.16	47.57	73.61
Resnet	87.80	0.10	81.73	63.86	**95.91**	**92.67**	93.34	84.72	70.26	50.65	85.57	76.52	58.91	84.16
ours	**96.83**	**77.06**	**98.47**	**86.30**	88.07	83.69	92.71	**88.89**	**87.13**	**73.86**	93.16	**80.28**	**89.01**	86.00

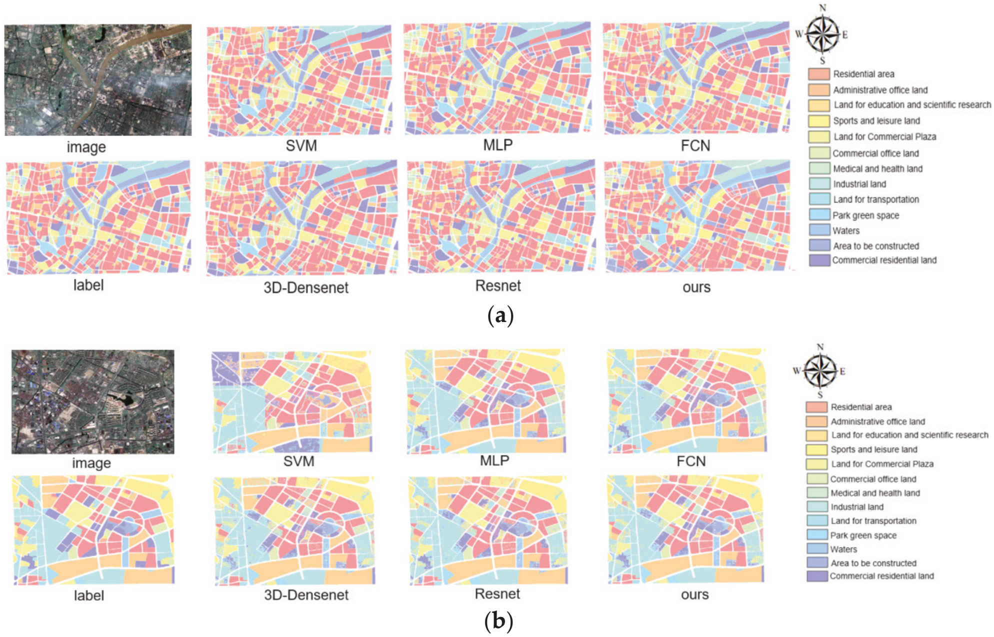


Figure 11. Visualization results: (**a**) Area_1 Visualization results; (**b**) Area_2 Visualization results.

5. Discussion

In this part, we discuss two main points: (1) the existence of social perception data and the impact of social perception data of different urban structures on the identification of urban functional areas; and (2) the stability of the method from different fusion methods and fusion stages.

5.1. Discussion of Social Perceptual Data Presence and Urban Structure Implications

The results of our experiments have been clearly shown in Tables 2 and 3. Including social perception data in the research has a strong comparative advantage over only using remote sensing images in identifying urban functional areas, with the overall accuracy obtaining an improvement greater than 20%. The composition of urban functional areas is not only characterized by natural physical attributes, but also by human socioeconomic activities. Therefore, it is relatively difficult to accomplish accurate results by only relying on natural features without taking into account the fact that social perception data matters in the recognition task. Given that study area 1 and study area 2 are at different levels of development phases, and have thus formed different structural compositions of urban functional areas, apparent differences exist in social perception data. A better performance in the recognition effect has been witnessed in study area 1 compared with study area 2, according to the aforementioned outcomes in Tables 2 and 3. It is further verified that the urban spatial structure of areas with high levels of urban development can provide more useful information in the identification task.

5.2. Discussion of Method Stability

5.2.1. Ablation Study of Loss Functions and Attention Mechanisms

For the multimodal data in study region 1, the proposed network in this paper gives the best overall results with the attention module and the auxiliary loss. The purpose of the auxiliary loss is to maximize the features of both data sources, making them more representative, while the attention mechanism is to focus on the main features with the suppression of unnecessary features, thus allowing a better integration of the extracted features. As shown in Table 7, the overall performance increases the accuracy rate by 2.41% compared to the loss-only case.

Table 7. Ablation study of loss functions and attention mechanisms. The best results are highlighted in bold (Area_1).

Auxiliary Loss	Attentional Mechanisms	Accuracy	Kappa	Avg.*F*1
●	○	91.24	91.26	88.46
○	●	91.96	90.74	**89.72**
●	●	**93.65**	**91.36**	89.54

● means use this module, ○ means do not use this module.

5.2.2. Comparison of Different Stages of Feature Fusion

The proposed feature-level (early) fusion method and the baseline decision-level (late) fusion method are shown in Figure 12a,b, respectively. From Table 8, it is obvious that the classification results of late fusion are significantly higher than those of early fusion, with the accuracy rate being raised more than 18% in both study area 1 and study area 2. Early fusion is performed at the feature level, where the features extracted from two different data sources are fused as the final classifier is trained, while in the latter one, a fusion classification evidently showcases the classification outcomes. Compared to early fusion methods, late methods are easily interpreted because the prediction scores of unimodal classifiers are much easier to extract before the decision fusion as it seeks to give weight to direct measurement of the contributions of different input data, thus predicting the classification results of the target in a more accurate way.

Figure 12. Different stages of integration: (**a**) early fusion; and (**b**) late fusion.

Table 8. Comparison of testing results with different fusion methods.

Region	Fusion Method	Metric		
		Accuracy	Kappa	Avg.*F*1
Area_1	Early fusion	65.78	72.52	47.85
	Late fusion	91.24	91.26	88.46
Area_2	Early fusion	68.60	79.34	47.54
	Late fusion	86.67	93.52	84.77

5.2.3. Comparison of Different Fusion Methods

In our experiments, illustrated in Table 9, a comparison between two study areas was made for the results of using different fusion methods (Figure 9), i.e., series and element-by-element summation. It can be observed that there is no significant difference between the test results between the two fusion methods, since almost all the variations of the obtained metric are close to 1%. This indicates that the choice of fusion methods employed in the proposed deep multimodal fusion network is of no great importance in assembling the experimental dataset.

Table 9. Comparison of testing results with different fusion methods. The best results are highlighted in bold.

Region	Fusion Method	Metric		
		Accuracy	**Kappa**	**Avg.*F*1**
Area_1	concat	91.24	91.26	88.46
	sum	90.14	91.37	87.62
Area_2	concat	86.67	93.52	84.77
	sum	87.91	93.70	85.69

6. Conclusions

The feature forms and semantic features possessed by remote sensing data and social perception data differ. How to make full use of the low-level semantic information related to remote sensing and high-level semantic information of social perception data is the key to improve the recognition accuracy of urban functional areas. In this paper, based on the advantage of feature extraction and expression of deep convolutional networks, we propose a framework to complete urban identification by fusing satellite images, POI, and building footprint data. This framework, compared with other modeling methods, achieves the feature fusion process by leveraging a multi-branch network structure with an attention mechanism that can focus attention on the most informative part of the most meaningful feature map, such that the semantic attributes of the input features can be fully expressed.

In terms of the method, this paper makes the convolutional structure extract as many features as possible by constructing a loss function, but not all features have the same importance, which may increase the computational burden of the network to some extent. The attention mechanism introduced in this paper strengthens the recognition ability by giving a large weight to the main features during feature fusion, but the attention mechanism may not be fully utilized compared to the network as a whole. The experimental results show that the model recognition ability is greatly improved by adding socially perceptive data. However, some problems that need to be further solved still exist. For example, the recognition effect is not significantly improved after adding building outline data, to some degree, influencing the accurate recognition of some functional areas. Presumably, the main reason for this is that the building footprint data that inherently exhibit is physical attribute features, invoking a data redundancy problem and impacts the recognition performance.

In future work, we will first fully explore the application of social perception data in urban function recognition, such as street view. Second, for the construction of the method, we will take the suitable feature extraction method from the data's own characteristics as much as possible, as well as make the network simpler and easier to reproduce to the furthest extent. Finally, our method has been proved to be effective for the analysis of Ningbo, but its adaptability to other regions in China and the world needs further validation.

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buildings

Article

Analyzing Electricity Consumption Factors of Buildings in Seoul, Korea Using Multiscale Geographically Weighted Regression

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Abstract: The recent increase in energy consumption worldwide has accelerated global warming. Thus, developed countries are aiming to reduce energy consumption in cities and promote eco-friendly policies. Buildings account for most of the energy used in a city. Therefore, it is necessary to identify the factors that affect electrical energy consumption in urban buildings. In this study, we use multiscale geographically weighted regression (MGWR) to analyze these urban characteristic factors at the global and local scales in Seoul, Korea. It is found that population and household characteristics, outdoor temperature, green and water areas, building area according to building usage, and construction age significantly affect the electrical energy consumption of buildings. In addition, the influences of these variables change with the region. Variables with different coefficients by region are winter temperature, green and water area, and households with three or more persons. The results confirm that even within a city, the influence of the aforementioned factors varies in terms of spatial distribution and patterns. This study is significant as it carried out basic research for energy consumption reduction in buildings by deriving related influencing factors.

Keywords: energy consumption; building energy; spatial autocorrelation; multiscale geographically weighted regression (MGWR)

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1. Introduction

Recently, global warming owing to an unprecedented increase in energy consumption has emerged as a growing concern. According to predictions made using the Shared Socioeconomic Pathways (SSP) scenario linked to socioeconomic activities in terms of population, economy, land use, energy use, and carbon emissions, the global average temperature will increase by 1.5 °C by 2040 compared to preindustrial levels, regardless of the scenario [1]. Climate change is the reality we are faced with. Therefore, efforts have been undertaken by various organizations and governments to develop carbon-neutral cities. Given increasing urban population and the development of high-rise buildings, buildings now use 2.5 times more electricity than they did in the past [2]. In addition, global building energy consumption accounts for 40% of the total global energy consumption. Owing to continuous urbanization, high-density, high-rise buildings are the primary residential constructions in cities [3]. In light of this, many studies have been conducted to elucidate the causes and consequences of global warming. The literature suggests that anthropogenic activities have accelerated warming of the atmosphere, ocean, and land [4]. To cope with climate change, the European Union (EU) has initiated various environmental policies and proposed to reduce energy consumption and carbon emissions from human activities by 40% by 2030 [5]. Similarly, various efforts have been undertaken to reduce the energy consumption of buildings in cities for mitigating the environmental toll of urbanization [6]. In this context, various physical factors that affect the energy consumption of buildings have been studied [7–9]. Furthermore, to reduce the energy consumption of cities, it is crucial to identify the primary causes and phenomena affecting the energy consumption of buildings [10,11].

Several researchers have studied the electrical energy consumption of buildings [12–17]. In addition, numerous studies have reported that the electrical energy consumption of buildings has a spatial correlation [18–21]. Similarly, in this study, the urban characteristics of buildings in Seoul, Korea, and their correlation with the energy consumption of these buildings were explored. Buildings in cities are spatially distributed, and buildings with similar level characteristics appear in a dense form [22]. According to the first law of geography, each building exhibits spatial autocorrelation owing to this distribution [23]. Therefore, the energy consumption of these buildings, too, must exhibit spatial autocorrelation owing to the spatial pattern of buildings. Considering the aforementioned factors, in this study, the distribution of spatial patterns and the local relationships of each factor are analyzed using a geo-weighted model, which is a known spatial analysis technique.

Seoul is a large city with a population of 10 million. It is expected that the characteristics of each region within Seoul vary because the city has a large urban and green areas, and the Han River runs through the city from east to west. As such, Seoul has peculiar spatial patterns of energy use, but the existing studies reflecting the urban characteristics of Seoul are insufficient. Although many researchers have analyzed the energy consumption of Seoul, they have not considered the influence of spatial patterns [24–28]. In addition, these researchers considered only partial variables in the analysis. By contrast, variables mentioned as significant or important are considered comprehensively in the present study. Among the previous studies on Seoul's energy consumption, the geographically weighted regression (GWR) model was used to analyze energy consumption in only one study [29]. However, even in this study, carbon dioxide emissions were used to measure energy consumption, which is an indirect method. In light of these points, we conduct a more developed study based on spatial analysis and variables that considers the characteristics of Seoul.

The objective of this study is to identify the variables that affect the electrical energy consumption of buildings by performing spatial regression analysis. Moreover, we attempt to determine the effects of significant variables on electrical energy consumption in urban spaces. GWR is a representative model for performing spatial analysis. It can be used to examine the influence of each regression formula considering the bandwidth corresponding to the analysis unit. Thus, the GWR model can provide results that are relevant to the objective of this study. Herein, the effect of diverse variables on electrical energy usage is examined comprehensively by using the multiscale geographically weighted regression (MGWR) model, which can check the local part among models that consider spatial influence. The MGWR model is based on the GWR model, and it sets the bandwidth differently for each independent variable. The characteristic that the spatial distribution of each variable is different is reflected in the analysis. Therefore, the MGWR model facilitates more accurate local unit analysis. Consequently, this analysis method that considers space is expected to yield significant results in this study. Finally, the analysis results of this study can be used as basic building energy consumption data at the local level to achieve the energy reduction goal set by the city in the future.

The remainder of this paper is organized as follows. Section 2 discusses the previous studies related to the use of electrical energy and spatial characteristics of buildings. Section 3 describes the methodology used in the present study. The dependent and independent variables constructed to provide spatial and temporal explanations and a description of the analysis target are provided. In addition, the analysis methods used herein, namely GWR and MGWR, are discussed. Section 4 describes the basic statistical results, as well as the results of ordinary least squares (OLS) and MGWR analyses. Section 5 discusses the policy implications of this study based on the results presented in Section 4. Section 6 describes the significance and limitations of this study (Figure 1).

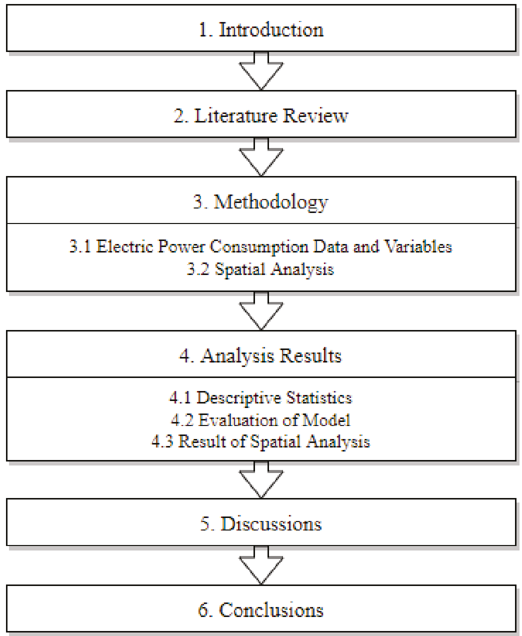

Figure 1. Flowchart of research methodology.

2. Literature Review

In this section, previous studies on the electrical energy consumption of buildings are discussed. Several studies have analyzed the electrical energy consumption of buildings based on their spatial characteristics and derived urban-characteristic factors that affect electrical energy usage in buildings. The characteristic factors considered include physical, socioeconomic, and environmental factors. Among them, studies on physical factors have made the most significant contributions to the literature. In these studies, it has been reported that various physical factors, such as the area, density, height, age of construction, and building materials, affect the electrical energy consumption of buildings [7–14]. In addition, more electrical energy is used for heating and cooling in high-density and high-rise buildings owing to solar radiation and restricted airflow around such buildings [30–32]. Furthermore, as the total floor area of buildings increases, the amount of electrical energy required increases. Several studies [33,34] have reported the use of glass windows and insulation materials as critical factors that influence the power consumption of buildings. It has been observed that older buildings have a weaker insulation effect. Therefore, they require more energy for heating and cooling.

Income, real estate, tax, and the number of household members are the socioeconomic factors that significantly influence energy consumption. In general, it is observed that the more affluent a region, the higher is the consumption of electrical energy. Similarly, income significantly influences energy consumption [35,36]. Studies on the effects of socioeconomic factors on energy consumption have analyzed the energy consumption of buildings based on their purpose [35–37]. It has been reported that the amount of energy consumed by a building varies depending on the primary use of the building. Therefore, the characteristics and electrical energy consumption patterns of residential, commercial, and industrial buildings differ [12–14,17]. The electricity consumption of a household is correlated to taxes, real estate prices [38], number of household members, and income [35]. In commercial buildings, factors such as population, income, building type, and amount of heating and cooling influence the amount of energy consumed [39]. The amount of electricity consumed based on building type can be ordered as follows: retail > office >

restaurant > school. While the aforementioned order can differ somewhat depending on building characteristics in each country, retail and business buildings consume the highest amounts of energy.

Environmental factors, such as indoor and outdoor temperature, climate, wind speed, humidity, and vegetation, have various effects on energy consumption. Among the environmental factors, temperature has the most significant effect on electrical energy consumption [17,31,40–45]. In general, in a city with hot weather, owing to the strong heat island effect, electricity consumption is related to cooling. Similarly, in a city with cold weather, electricity consumption is related to heating. In general, owing to the heat island phenomenon, more energy is used for cooling in summer, but less energy is consumed for heating in winters [40,41]. Therefore, it can be concluded that temperature outside a building plays a significant role in determining the amount of energy required to maintain the internal temperature of the building. Many studies [35–47] have reported that vegetation is one of the factors that reduces the heat island effect in cities and, therefore, energy consumption, by lowering the ambient temperature. Therefore, green spaces, such as urban parks, vegetation zones, and water systems, need to be promoted in urban environments.

Our review of previous studies confirmed that various city-specific factors influence the electrical energy consumption of buildings. Recent studies have suggested that to reduce the energy consumption of buildings, it is necessary to check the energy consumption patterns of multiple buildings [7,13]. Given that these energy consumption patterns change according to the characteristics of cities, various other factors must be considered as well [18,35–37]. Characteristics such as demographic factors indicate that humans consume energy when engaging in social activities, which seem to follow a certain spatial pattern [35]. However, the spatial correlations of and changes in all variables are not equal. The unique spatial patterns of each variable affect energy consumption in various manners. Therefore, it is crucial to identify unique spatial patterns for identifying the factors affecting energy consumption [18]. Although several studies have considered spatial autocorrelation in the use of electrical energy, studies that comprehensively address urban characteristic factors are lacking. In light of this, this study uses a more advanced model than the GWR model and comprehensively accounts for the variables employed in the literature.

In sum up, our literature review confirmed the existence of various factors affecting the energy consumption of buildings, such as demographic factors, socioeconomic factors, environmental factors, and building characteristics. However, previous studies have not considered the spatial autocorrelation that may occur when analyzing these factors individually or in complex analyses. Therefore, in this study, the aforementioned factors are analyzed comprehensively.

3. Methodology

3.1. Electric Power Consumption Data and Variables

In this study, the GWR model was used to identify the urban characteristic factors that affected the electrical energy consumption of buildings in 424 administrative districts in Seoul in 2020. The electrical energy consumption data of these buildings in Seoul were used as the dependent variables. The values obtained by taking the natural logarithm of the total amount of electrical energy used in the buildings in each administrative dong were used as the dependent variables. The electrical energy consumption data of the buildings in question was provided by the Korea Real Estate Agency. The independent variables were composed based on the variables considered as the factors influencing the electrical energy consumption in buildings in previous studies (Figure 2).

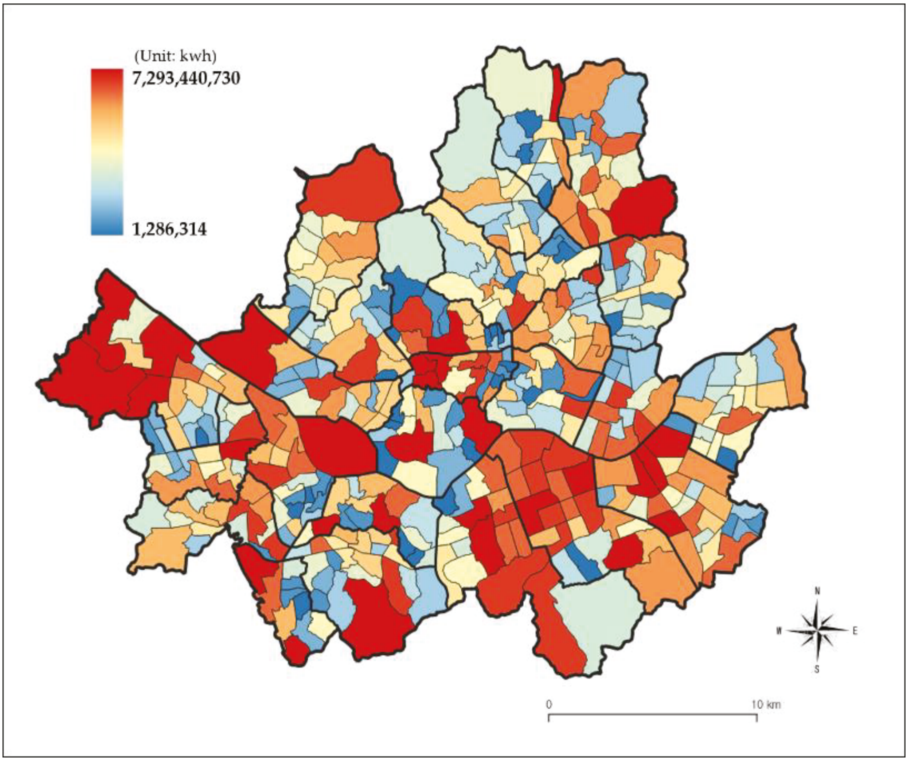

Figure 2. Electrical energy consumption by administrative dong in Seoul in 2020.

First, a set of variables related to temperature, a factor that significantly affects the energy consumption of buildings, was constructed. The average temperatures during spring, summer, autumn, and winter were constructed as variables because the temperature changes across these four seasons are distinct in Korea. In addition, because the temperature in the city is affected by vegetation, the total area covered by vegetation and water bodies was constructed as a variable. Next, as the population and household variables, the living population and the numbers of single-person households, two-person households, and three or-more-person households were selected as variables. Considering that electricity consumption is generally high in regions with large active populations, living population data that aggregate the active population in a region were used instead of resident population data. Smartphone communication data from an area were used to derive the living population data. According to previous studies, the energy consumption per person increases as the number of household members decreases. In this study, the variables were set by categorizing the households into one-, two-, and three-or-more-person households based on the number of household members. Household income, which has been considered a significant factor affecting electricity consumption in previous studies [35,36], was considered in this study as well. In previous studies, the physical characteristics of buildings and building types were considered significant factors affecting electrical energy consumption. Therefore, in this study, the average number of floors; average age of buildings in administrative dongs (the smallest administrative district in Korea); and total floor areas of apartments, detached houses, commercial facilities, education facilities, and business facilities were considered as building type variables. Given that most of the industrial facilities in Seoul are light industries (Table 1), industrial facilities were not considered as a separate variable.

Table 1. Definition of variables.

Division	Variable	Description	Source
Population and household factors	Living population	Total population of administrative dong estimated using public big data and communication data	Seoul Open Data Plaza
	One-person household	Number of households with one member	Seoul Commercial Analysis Service
	Two-person household	Number of households with two members	
	Three-or-more-person household	Number of households with three or more members	
Socioeconomic factors	Household income	Average household income in administrative dong	
Building characteristic factors	Average number of floors	Average number of floors in a building	EAIS (Electronic Architectural Administration Information System)
	Average building age	Average number of years of a building	
	Apartment area	Total floor area of an apartment	
	Detached house area	Total floor area of a single house	
	Commercial building area	Total floor area of a commercial building	
	Education building area	Total floor area of an educational building	
	Office building area	Total floor area of an official building	
Environmental factors	Spring temperature	Average air temperature in spring	Meteorological Agency in Korea
	Summer temperature	Average air temperature in summer	
	Fall temperature	Average air temperature in fall	
	Winter temperature	Average air temperature in winter	
	Green and water areas	Total area covered by vegetation and water bodies within an administrative dong	EGIS (Environmental Geographic Information Service)

3.2. Spatial Analysis

3.2.1. GWR

General regression analysis methods do not consider spatial influence relationships and they describe only global relationships among variables [48]. GWR applies spatial weights to the existing OLS model to facilitate local spatial analysis. Hence, spatial autocorrelation and heterogeneity were considered through spatial weights. Spatial weights were applied to the GWR model by using the coordinates (u, v) of each spatial analysis unit [49] according to the following Equation (1).

$$y_i = \sum_{j=0}^{m} \beta_j(u_i, v_i)x_{ij} + \varepsilon_i \quad (1)$$

In the above equation, y_i represents the electrical energy consumption of an administrative dong i, and β_j is the coefficient of the j independent variables of administrative dong i. The coordinates of each administrative dong u_i, v_i were applied to each space, as expressed in (1). A regression equation was derived for as many administrative dongs as possible, and the statistical analysis results of each target site were checked. In this study, the geographic weight of the GWR model was applied to the kernel function. Subsequently, a fixed kernel randomly selected by the authors and a statistically manipulated adaptive kernel were used. Because GWR yields local regression results, the spatial correlations and heterogeneity that conventional OLS cannot consider were accounted for. However, the GWR model is vulnerable to multicollinearity [50]. Various GWR models have been developed to mitigate this problem [51].

3.2.2. Multiscale GWR

The general GWR model is limited, in that it applies only one spatial scale. It considers only a single fixed bandwidth value in the analysis model. Thus, the model is vulnerable to multicollinearity. Additionally, each independent variable has global or local characteristics depending on the characteristics of the overall data. Therefore, considering the characteristics of the variables and the limitations of the GWR model, GWR analysis methods that apply a bandwidth suitable for each variable have been developed. Among such methods, mixed GWR separates global and local independent variables, and the multiscale GWR

(MGWR) sets the local coefficient value that has the optimal Akaike Information Criterion (AICc) value in the analysis model [52].

Thus, the best model is selected based on the AICc value. In this study, the MGWR model was applied using a backfitting algorithm (Figure 3). In general, the initial local coefficient of the MGWR model is based on the results of GWR analysis, and the subsequent local coefficients are estimated through corrections. The local coefficients are estimated repeatedly until they reach the desired levels, and the same method is repeated for all independent variables. *SOC-RSS* (Residual Sum of Squares) (2) are used as the iterative work termination criteria. The coefficient values are estimated using the proportionality of the residual sum of squares (RSS) and the *SOC-f* method (3), which corrects the GWR analysis results. Therefore, in this study, we used the *SOC-f* method. When the *SOC-f* value was less than 0.0005, the next independent variable was set. The adaptive kernel function was applied to each independent variable to select the bandwidth value. In addition, the model in which AICc attained the minimum value was selected by combining the bandwidth values [53].

$$SOC_{RSS} = \frac{|RSS_{new} - RSS_{old}|}{RSS_{new}} \tag{2}$$

$$SOC_f = \sqrt{\frac{\sum_{j=1}^{p} \frac{\sum_{i=1}^{n}\left(f_{ij}^{new} - f_{ij}^{old}\right)^2}{n}}{\sum_{i=1}^{n}\left(\sum_{j=1}^{p} f_{ij}{}^{new}\right)^2}} \tag{3}$$

where *SOC-RSS* is the proportional change in the residual sum of squares, and *SOC-f* is the change in the GWR smoother.

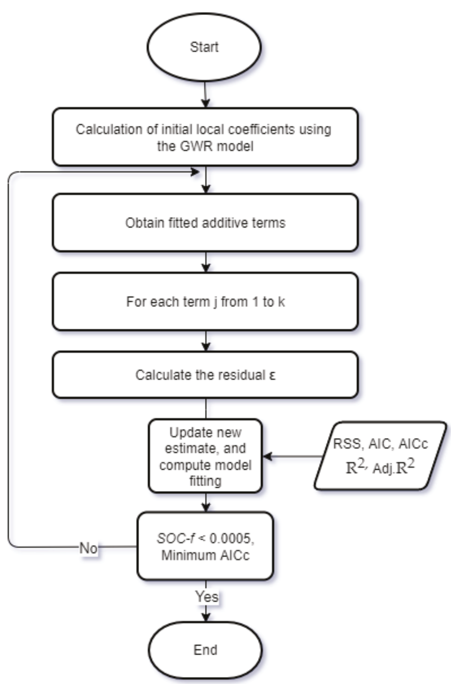

Figure 3. Data flow diagram of multiscale geographically weighted regression back-fitting calibration.

4. Analysis Results

4.1. Descriptive Statistics

The reliability of the data constructed for analysis is confirmed through basic statistical analysis. In addition, the basic statistics serve as a starting point for conducting spatial regression analysis by displaying data distributions and patterns in this study. The descriptive statistics of the independent variables used in the analysis and the electrical energy consumption of buildings by administrative dong, the dependent variable in this study, are as follows: first, the number of administrative dongs in Seoul, which is the analysis target, is 424; the administrative dong is the unit of analysis in this study. Because the existing distribution of electrical energy consumption does not exhibit a general linear form, it is converted to a linear form by taking its natural logarithm. Among seasonal temperatures, the temperatures in spring and autumn are similar, as can be observed from the overall statistical values. By contrast, the summer and winter temperatures are noticeably different. The temperature distribution used in this study reflects the seasonal characteristics of Korea, which has four distinct seasons. Based on the results reported in previous studies, we considered temperature a significant factor affecting the amount of electrical energy required for heating and cooling in buildings. The average number of floors in each administrative dong varied from 2 to 18. The average building age in each dong ranged from 5 to 55 years. Among the variables pertaining to each building type, the areas of detached houses and education and business facilities are zero in several administrative dongs because these dongs house densely populated buildings of the same type. Household income levels ranged from 1836 USD per month to 5714 USD per month, and the average household income was 2849 USD per month (Table 2).

Table 2. Descriptive statistics of variables.

Division	Variable	Minimum	Maximum	Mean	Standard Dev.	Variance	VIF
Dependent	Log of building electrical energy consumption	14.07	22.71	18.11	0.97	0.94	-
Independent	Living population	57106.00	1253928.00	298939.89	142864.43	20410244485.88	3.593
	One-person household	115.00	16971.00	4192.66	2457.34	6038503.79	2.968
	Two-person household	20.00	6152.00	2187.68	881.79	777547.92	2.318
	Three-or-more-person household	29.00	11217.00	3875.65	1848.23	3415942.81	2.298
	Household income	2230710.00	6945812.00	3460789.90	1019302.25	1038977085862.02	2.005
	Average number of floors	2.00	18.00	4.11	2.08	4.33	2.170
	Average building age	5.00	55.00	28.08	6.20	38.45	1.771
	Apartment area	527.00	28482642.00	803712.85	1707951.48	2917098242892.06	1.081
	Detached house area	0.00	560122.00	138281.46	104137.33	10844584450.76	2.384
	Commercial building area	2063.00	1340807.00	161112.39	148799.38	22141254757.75	2.312
	Education building area	0.00	1766866.67	83258.86	156400.18	24461015913.75	1.193
	Office building area	0.00	4472947.89	156292.92	404878.90	163926920148.92	2.057
	Spring temperature	13.58	21.27	17.98	1.38	1.91	4.701
	Summer temperature	19.56	28.50	24.08	1.59	2.53	1.365
	Fall temperature	14.15	19.92	17.40	1.06	1.12	4.801
	Winter temperature	−1.56	2.75	1.24	0.67	0.45	1.451
	Green cover and water areas	548.24	3834250.60	126512.09	314705.56	99039587845.58	1.220

4.2. Evaluation of Model

According to the literature [18–21], there exists a spatial effect on the consumption of electrical energy in buildings. Therefore, a GWR analysis considering spatial autocorrelation was conducted. Before spatial regression analysis, the dependent variable, that is, the electrical energy consumption of each administrative dong, was examined to identify spatial autocorrelations. Moran's index was calculated by performing Moran's I analysis of ArcGIS to examine global spatial autocorrelations and spatial distribution patterns. A Moran's index value of 0.1153, which represents a significant level, was obtained in the analysis. This indicated a positive spatial autocorrelation. Furthermore, the Z-Score value indicated that the degree of clustering was 6.249, meaning that the spatial pattern was extremely clustered (Table 3). Moran's Index was calculated using the MGWR residual to determine whether the spatial autocorrelation was controlled by the MGWR model. The value of Moran's Index was −0.0278, which was lower than the Moran's Index value obtained using the OLS model. In addition, the probability for spatial autocorrelation of the MGWR model was not significant, meaning that spatial autocorrelation was controlled.

Table 3. Analysis of spatial autocorrelation.

Criteria	OLS	MGWR
Moran's Index	0.1153	−0.0278
Expected Index	−0.0023	−0.0023
Variance	0.0003	0.0003
Z-score	6.2490	−1.3575
p-value	0.000 0	0.17461

Subsequently, the fits of three models were compared, namely, the global OLS, spatial GWR, and MGWR models, considering various criteria. In this study, the residual sum of squares (RSS), AIC, AICc, R^2, and adjusted R^2 were considered to identify the most suitable model. The RSS, AIC, and AICc values decreased gradually in the order of OLS, GWR, and MGWR. This indicates that MGWR had the best model fit. In addition, the R^2 of the OLS model was 0.555. However, the R^2 of the GWR model was 0.661, R^2 of the MGWR model was 0.74, and adjusted R^2 of the MGWR model was 0.685. Thus, it can be concluded that the MGWR model had the highest explanatory power. Consequently, iterative work was performed to determine the optimal model fit and bandwidth of the MGWR model. Through iteration, the model with the lowest AICc was selected as the final model. In this study, 36 iterations were performed to determine the final model (Table 4).

Table 4. Model fit summary of OLS, GWR, and MGWR models.

Criteria	OLS	GWR	MGWR
RSS	186.38	143.92	109.671
AIC	894.76	863.36	784.07
AICc	899.06	882. 88	818.87
R^2	0.5 55	0.661	0.74 0
Adj. R^2	0.536	0.607	0.685
No. of iteration	-	-	36

In general GWR analysis, the adjusted R^2 value indicates the explanatory power of the entire global model, and the local R^2 value representing each variable locally is presented separately. In this study, the adjusted R^2 value of the MGWR analysis model was 0.685. The region with the lowest local R^2 value of 0.63 was located toward the northeast and southeast of Seoul. The region with the highest explanatory power was the southwestern region. Note that the closer it is to the region, the higher is its explanatory power. The region with the strongest explanatory power had an R^2 value of 0.78, indicating the existence of regions with explanatory powers higher than 0.685, which was the overall explanatory power of the model (Figure 4).

4.3. Result of Spatial Analysis

In this study, the bandwidth value applied to each independent variable in the MGWR model differed from that in the GWR model. According to the spatial distribution of the data of each variable, iterative work was performed using an appropriate bandwidth value. As mentioned above, a total of 36 operations were performed. Variables representing 423 of the bandwidth values that appeared had the characteristics of global variables rather than local variables. Other variables included variables with strong local characteristics, such as summer temperature, winter temperature, households with three or more people, green and water-covered areas, average building age, average apartment area, average educational facility area, and average business facility area (Table 5).

Figure 4. Local R^2 values of multiscale geographically weighted regression.

Table 5. Optimal bandwidth of each parameter in GWR and MGWR analyses.

Division	Variable	Bandwidth	
		GWR	**Multiscale GWR**
Intercept	Intercept	264	58
Population and household factors	Living population	264	423
	One-person household	264	423
	Two-person household	264	423
	Three-or-more-person household	264	103
Socioeconomic factors	Household income	264	423
Building characteristic factors	Average number of floors	264	423
	Average building age	264	418
	Apartment area	264	314
	Detached house area	264	423
	Commercial building area	264	423
	Education building area	264	145
	Office building area	264	334
Environmental factors	Spring temperature	264	423
	Summer temperature	264	235
	Fall temperature	264	423
	Winter temperature	264	78
	Green and water areas	264	109

The analysis results obtained using the global OLS model and the MGWR model were compared and reviewed. Firstly, the analysis results were reviewed centering on the variables significantly derived from OLS. The summer temperature exhibited a significant influence at 0.111, and the winter temperature exhibited a significant influence at −0.106. In the MGWR analysis, the average values of the local coefficients of these two variables had a positive influence. However, in terms of the minimum, median, and maximum values of winter temperature, there were regions with local negative and positive effects. In the OLS analysis results, living population had a significant positive influence, and in the MGWR results, it also had a positive influence globally. This finding is consistent with the results of previous studies, which indicated that the larger the population in an area, the greater the electrical energy consumption. Next, green and water areas had a significant positive influence. In general, green and water areas play a significant role in alleviating the urban heat island phenomenon. Furthermore, they have a negative influence on electrical energy consumption for cooling. However, note that green and water areas alone do not reduce the heat island phenomenon. The heat island phenomenon is additionally affected by the permeability, density, and surrounding environment of an area [42]. However, the OLS results obtained in this study showed their positive effect, which is contrary to the results obtained in a previous study. This can be attributed to the factors other than green and water areas that significantly reduced electrical energy consumption.

In terms of building area, significant positive results were observed for apartments, education buildings, and business buildings. According to the OLS and MGWR analysis results, the building areas of apartments and business buildings had a global positive effect. Regarding the area of educational buildings, the OLS result was positive, but the MGWR results found regions with a negative influence. In addition, both the OLS and MGWR analyses showed the significant positive influence of household income (Table 6).

Table 6. Factors affecting the consumption of electrical energy in buildings: OLS and MGWR analysis results.

Division	Variable	OLS	Multiscale GWR				
			Mean	Standard Deviation	Min	Median	Max
-	Intercept		−0.023	0.161	−0.394	0.001	0.342
Population and household factors	Living population.	0.388 ***	0.411	0.005	0.399	0.411	0.421
	One-person household	0.036	0.033	0.004	0.024	0.033	0.042
	Two-person household	−0.023	−0.027	0.013	−0.054	−0.022	−0.009
	Three-or-more-person household	−0.011	0.005	0.08	−0.158	−0.003	0.204
Socioeconomic factors	Household income	0.156 ***	0.215	0.001	0.212	0.216	0.217
Building characteristic factors	Average number of floors	0.028	−0.024	0.01	−0.044	−0.025	0.002
	Average building age	0.030	0.042	0.004	0.034	0.041	0.052
	Apartment area	0.107 ***	0.1	0.045	0.044	0.08	0.169
	Detached house area	−0.055	−0.077	0.009	−0.086	−0.082	−0.053
	Commercial building area	0.066	0.089	0.004	0.08	0.088	0.102
	Education building area	0.215 ***	0.199	0.104	−0.015	0.2	0.404
	Office building area	0.094 *	0.14	0.02	0.098	0.144	0.169
Environmental factors	Spring Temperature	0.031	0.091	0.007	0.079	0.089	0.108
	Summer Temperature	0.111 ***	0.071	0.071	−0.043	0.054	0.225
	Fall Temperature	0.015	0.01	0.014	−0.006	0.003	0.039
	Winter Temperature	−0.106 ***	−0.101	0.119	−0.481	−0.086	0.163
	Green and water areas	0.076 *	0.103	0.142	−0.105	0.085	0.363

* $p < 0.1$, *** $p < 0.01$.

The local results of the variables that appear significantly in the MGWR analysis results are as follows. Summer temperature had significant positive effects in most of the regions. These results were similar to those of the related studies in which MGWR was used, and the higher the summer temperature, the stronger the influence on energy consumption [54]. Electrical energy consumption due to cooling is high in summer. Therefore, it was identified to have a positive effect across the city [45]. The bandwidth used for summer temperature was 235. Therefore, summer temperature was shown to be a variable that influenced a large area of the city. This indicates that the summer temperature across administrative dongs in Seoul was similarly high overall. In addition, it was observed that the closer a region was to Gangnam, the more significant the effect of summer temperature on energy consumption in that region. Notably, this result confirmed that the influence of summer temperature was weaker in regions closer to Mt. Bukhan, which is in the northern part of Seoul. This reflects the spatial characteristics of a region with small building areas and large mountainous areas (Figure 5a). Winter temperature also had significant positive effects. However, it had a negative influence on the CBD areas, Gangnam, and Jongro. The bandwidth used for winter temperature was 78. Thus, winter temperature had a smaller bandwidth than summer temperature, indicating a regional temperature difference, and we can conclude that the energy used for heating increases as the temperature outside buildings in a region decreases (Figure 5b). These results suggest a relationship between seasonal temperature and energy usage, and it was confirmed that energy usage differs depending on the region owing to the temperature differences stemming from the heat island effect or density [31].

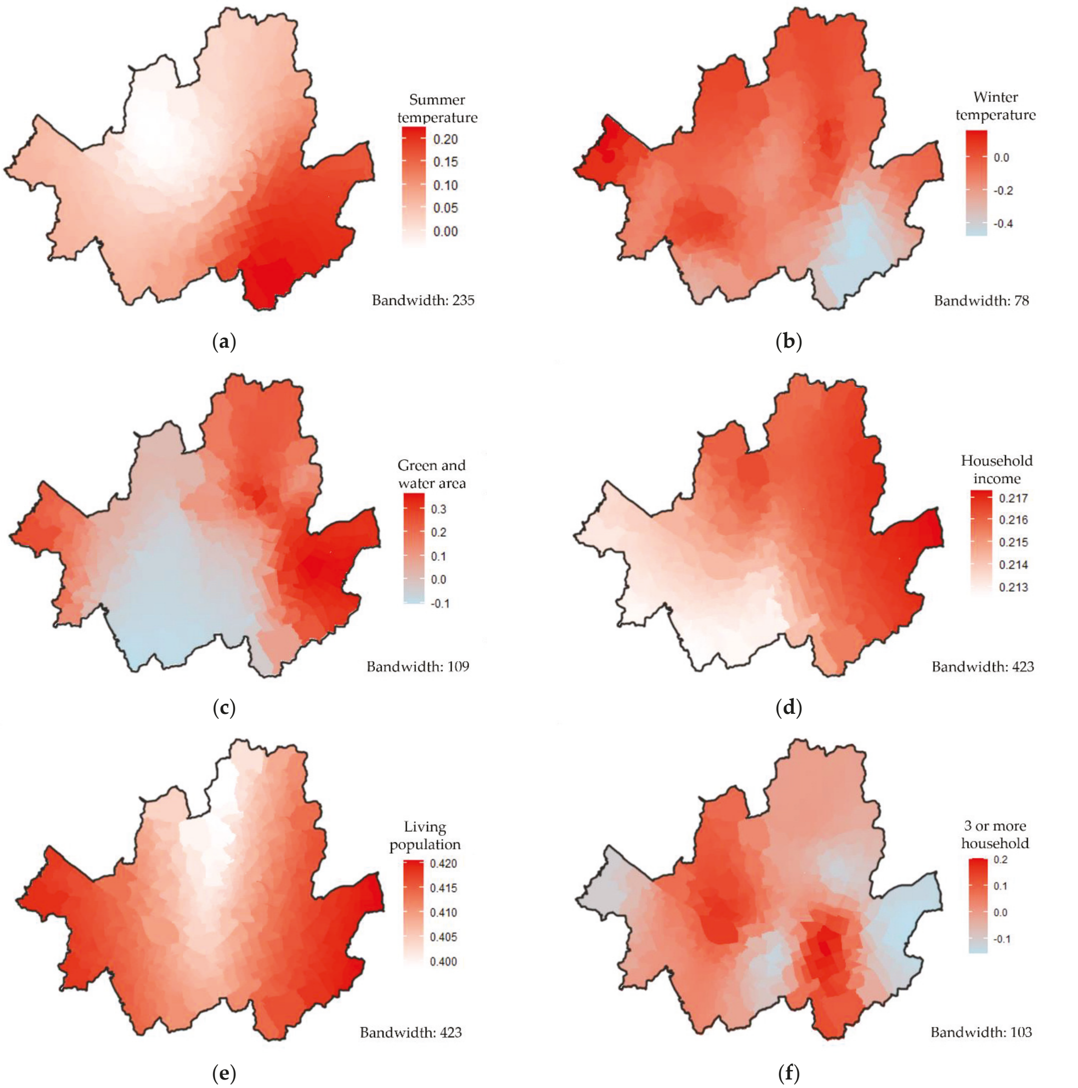

Figure 5. Multiscale geographically weighted regression results of local coefficients: (**a**) summer temperature; (**b**) winter temperature; (**c**) green and water area; (**d**) household income; (**e**) living population; (**f**) three-or-more-person household.

Previous studies have reported that green and water areas alleviate the urban heat island phenomenon and reduce electrical energy consumption by maintaining the temperature in the city at a comfortable level [42]. However, in contrast to the results of previous studies, the analysis results of this study confirmed that the average coefficient value had a positive influence on electric energy consumption. A related study using MGWR confirmed that all variables related to green areas had positive effects, unlike the analysis results of this study [54]. By contrast, we assumed that green areas may have local effects depending on the region and that there may be differences in influence depending on the area, as mentioned in the Introduction. In addition, by checking the local coefficient of green and water areas, it can be inferred that the green and water areas had a weak negative influence on Seoul overall. However, strong positive effects were observed in the Gangnam and Gangseo areas (Figure 5c). The bandwidth of the green and water area variable was 109. Thus, the effect of green and water areas in Seoul is more local than city-wide. Therefore, it can be concluded that a strong positive influence was observed for a high average local coefficient value. This result can be attributed to the high building density and high electrical energy consumption, despite the large-scale green and water areas. The Gimpo Airport (8.63 km^2) in Gangseo consumes the highest amount of electrical energy among all of the administrative dongs in Seoul. In the Jamsil district, which corresponds to the Songpa area, there are large green areas, such as Seokchon Lake and Olympic Park. In addition, many high-rise buildings, such as the Jamsil Lotte Tower and Lotte World, are located in this area. However, Eunpyeong and Gwanak, the regions in which Mt. Bukhan and Mt. Gwanak are located, respectively, and Yeongdeungpo and Yongsan, which are close to Mt. Gwanak and the Han River, were found to be negatively affected. We assumed that the green and water areas in these regions reduced the use of electrical energy by maintaining the temperature at a relatively comfortable level. These results show that superficial green and water areas alone cannot significantly affect energy reduction, as mentioned in previous studies (Figure 6).

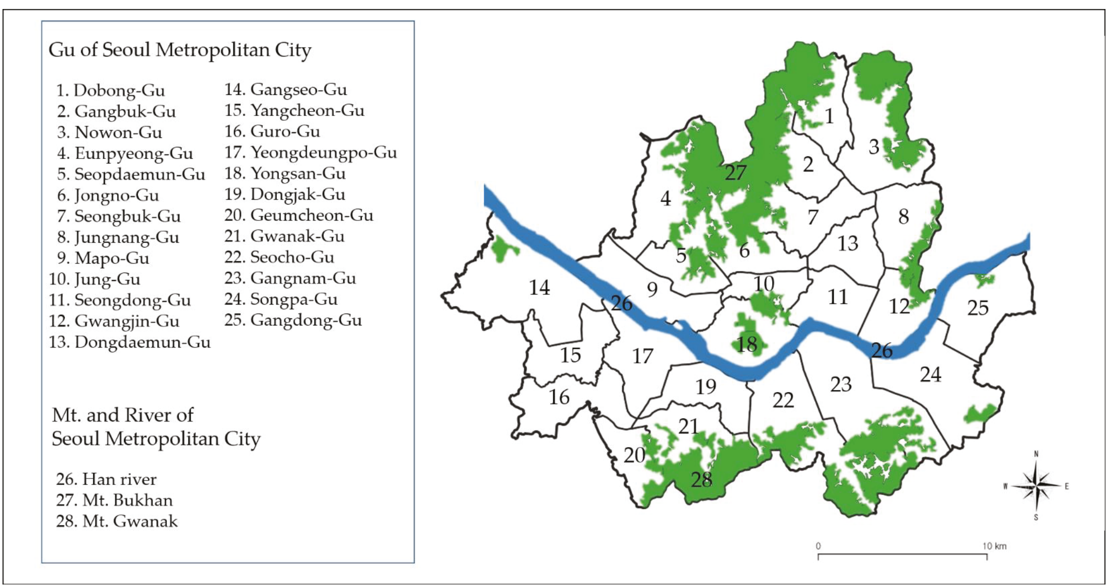

Figure 6. Administrative boundary of Gu, and mountains and rivers of Seoul.

In the case of household income, significant positive effects were confirmed in all regions except Gangseo. A study conducted using GWR yielded the same results as the present study, with a positive impact across the city [55]. This result is consistent with the social belief that high-income people use more electrical energy than low-income people. This was confirmed by the fact that a greater amount of electrical energy was consumed in Gangdong and Gangnam in 2020, where the average household income is relatively high, compared to that in Gangseo, where the average household income is relatively low. In a related study conducted using MGWR, energy consumption increased as income increased across the city. Moreover, as the interregional income difference increased, the influence increased, as reported in a previous study [56] (Figure 5d).

Living population had no significant influence on the Gangbuk region around Mt. Bukhan. However, the closer a region was to Gangnam and Gangseo, the more significant the positive influence. This is consistent with the results of previous studies, in which it was demonstrated that the electrical energy consumption of buildings increases in areas with a high density of buildings and more floating populations than that in mountainous terrain [3,4]. In another study conducted using MGWR, the effect of population differed depending on the region, but it was found to have a positive effect overall. This is consistent with the general conclusion that the higher the population density, the higher is the energy consumption [57]. In addition, the analysis results indicated that the impact of living population on Seoul is large (Figure 5e). In addition, various local factors affect households with three or more persons in Seoul. The bandwidth used for households with three or more persons was 103. In other studies conducted using MGWR, the influence of regional differences was different from that in the present study. Previous studies have mentioned households as an important variable. Moreover, the previous studies reported consistent results throughout the city with no regional differences [54,58]. Unlike previous studies, we identified differences in influence due to the regional characteristics mentioned in the introduction. Living population had a positive influence in the Gangnam, Yeouido, Mapo, and Yongsan regions. Thus, it can be inferred that in these areas, the higher the number of households with three or more persons, the higher the electricity consumption. This was validated by the fact that these regions have households with relatively high income levels in Seoul. Therefore, they possibly use a large amount of electrical energy. By contrast, a negative influence was observed in Gangseo, Jungnang, Gwanak, Gangdong, and the entire city, meaning that the higher the number of households with three or more people, the lower the electrical energy consumption. These results indicate that as the number of household members increases, the amount of energy consumed by one person per unit area in a building decreases. Moreover, previous studies have demonstrated that an increase in the number of household members leads to a decrease in energy consumption because it increases the population density [38]. Thus, it can be concluded that in general, an increase in the number of household members leads to a reduction in energy consumption (Figure 5f).

Among building types, apartment buildings had a significant positive influence in the Gangdong and Gangbuk regions, but no significant effect in the Gangseo region. In the case of apartment buildings, given that multiple households reside in one building, the amount of electrical energy used by the building is higher than that used in other types of housing. This claim was validated by the results of the present study (Figure 7a). By contrast, detached houses had a negative influence. Unlike apartments, a detached house is often inhabited by a single household. Hence, compared to an entire apartment building, the amount of energy consumed is lower because the total floor area of a detached house is lower than that of an apartment building (Figure 7b). Educational buildings had a significant positive influence, except in the Gangnam, Eunpyeong, and Mapo regions. The bandwidth used for educational buildings was 145. In the Gwanak region, where Seoul National University is located, educational buildings had the strongest influence. This indicates that universities consume a large amount of electrical energy (Figure 7c). Among educational buildings, the amount of energy used by each school level was different, but university buildings used large amounts of energy [59]. Furthermore, it was found that building age had a significant positive effect. OLS analysis did not yield any significance, but MGWR analysis yielded some significance in the city center, which houses relatively old buildings. Thus, as reported in a previous study [60], the results of this study confirmed that building age affects the insulation and energy consumption of buildings. Therefore, old buildings should be repaired to reduce electrical energy consumption and increase energy efficiency (Figure 7d).

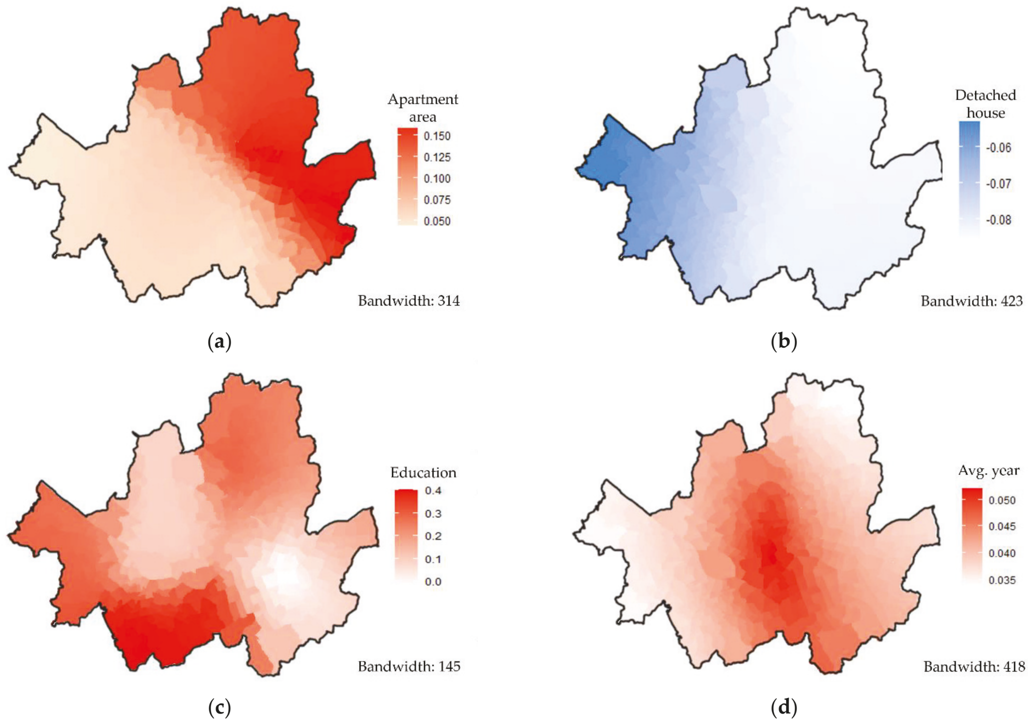

Figure 7. Multiscale geographically weighted regression results of local coefficients: (**a**) apartment; (**b**) detached house; (**c**) education; (**d**) average building age.

5. Discussions

In this study, we conducted an MGWR analysis to identify the factors affecting electrical energy consumption, especially the factors that were not detected in OLS analysis. The analysis results confirmed that the influence of the factors considered here may differ across regions. Therefore, we propose several suggestions for reducing the electrical energy consumption of buildings based on the analysis results.

We found that the outdoor temperature during winter and summer has a significant effect on electrical energy consumption. In summer, electricity consumption increases throughout the city because of an increase in cooling demand. This is consistent with the results of previous studies [10,38,54]. By contrast, several regions consumed more electrical energy during winter to maintain a relatively comfortable temperature in the building. This result confirmed the existence of regional differences in electrical energy consumption used for heating in winter, which did not appear in other studies. The area with the highest electrical energy consumption had a high density of buildings. It was found that this area used plenty of electrical energy for heating and cooling to maintain comfortable temperatures inside buildings. Thus, the application of technology that maintains indoor temperatures can reduce the electrical energy required for heating and cooling in winter and summer, respectively.

Furthermore, the OLS analysis results indicated that the green and water areas have a positive influence. However, the MGWR results show that the degree of influence differs across regions. This indicates that green and water areas do not necessarily affect the electrical energy consumption within a city. However, in some regions, green and water areas can somewhat influence electrical energy consumption. Even in the areas with plenty of green areas and water bodies, we found areas with high temperatures depending on solar orientation. Likewise, even in areas with a high density of green areas, some patches may not be significantly influenced by green cover. Therefore, a novel method is required for assessing the relationship between energy consumption and the density and degree of influence of green and water areas.

In the case of the influence of population, the analysis results showed that the higher the absolute population, the higher the energy consumption; this result is consistent with the existing perception that a compact city is more suitable for reducing energy consumption.

Studies have reported that older buildings consume more electrical energy, which is consistent with our analysis results. Therefore, the insulation effect of old buildings should be improved through repair and reconstruction. The Jongro region of Seoul has many aging buildings, and their energy efficiency is low. Hence, active redevelopment and repair work is required in Seoul to increase the electrical energy efficiency of these buildings.

6. Conclusions

In this study, characteristic urban factors affecting the energy consumption of buildings were analyzed across the administrative districts in Seoul in 2020. The local influences of variables were determined using the MGWR model, a local spatial regression model. This model was used to consider the spatial autocorrelations of the electrical energy consumption of buildings by applying a backfitting algorithm to the GWR model. Consequently, the resulting model confirmed that the influences of the factors affecting electrical energy usage varies by region.

Moreover, the analysis results confirmed that summer and winter temperatures affect the electrical energy consumption of buildings. In addition, they confirmed that in some regions, green and water areas reduce electrical energy consumption by alleviating the heat island phenomenon, as reported in previous studies. However, in regions with large-scale facilities or buildings, the influence of large green areas or water areas was not significant. Hence, the relationship between green and water areas and electrical energy consumption warrants further investigation. In the case of population and households, the analysis results showed that the number of household members had a significant effect on the use of electrical energy. An increase in the number of household members reduced electrical energy consumption. In addition, electricity consumption varied according to building type. Furthermore, it was confirmed that the influence of building type on electrical energy consumption differed across regions.

Variables with different influences across regions were identified using the MGWR model. The variables with differing influence across regions were winter temperature, green and water areas, and households with three or more members. This result did not appear in previous studies, and it could not be confirmed by the results of OLS analysis. Therefore, it is reasonable to use the MGWR model, which can reflect the spatial distribution characteristics of variables.

The present work is significant as a fundamental study for reducing the energy consumption of buildings by analyzing various factors that affect their electrical energy consumption. However, this study has a few limitations. First, this case study targeted Seoul, a city with an annual gross regional domestic product (GRDP) of 360 billion US dollars and one of the most active global economic centers. Moreover, Seoul is a densely populated metropolis with approximately 10 million inhabitants. In terms of natural environment, the city has large natural green areas, and Han River runs from east to west across the city. In addition, the built-up areas house numerous high-rise buildings. It is difficult to generalize the results of this study to all cities in the world because of the peculiar spatial characteristics of Seoul. Second, we did not consider indoor temperature, unlike previous studies, owing to data limitations. Because approximately 82% of the buildings in Seoul are made of reinforced concrete, we did not consider building materials as a variable. These are different from other previous studies in this study. Therefore, subsequent studies will be able to generate superior results by adopting a variety of variables depending on their unique situations.

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Developing a Conceptual Partner Selection Framework: Digital Green Innovation Management of Prefabricated Construction Enterprises for Sustainable Urban Development

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Abstract: Digital green innovation management activities are the core of low-carbon intelligent development of prefabricated construction enterprises (PCEs) for sustainable urban development. PCEs have to seek joint venture partners to avoid the financial risk of digital green innovation projects. The purpose of this study is to develop a conceptual partner selection framework for the digital green innovation management of prefabricated construction towards urban building 5.0. In this study, first, symbiosis theory and six analysis methods were integrated to innovatively build a 3W1H-P framework system for the joint venture capital partner selection of digital green innovation projects. Second, the dual combination weighting method was innovatively proposed to avoid subjective and objective deviation in attribute weight and time weight. Finally, empirical research was carried out to verify the scientific nature, reliability, and practicability of the framework system and selection model. The results of this study show that the framework system and selection model proposed can be used to assist PCEs to select joint investment partners of digital green and innovative projects for sustainable urban development.

Keywords: prefabricated construction; digital green innovation management; venture capital; project partners

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1. Introduction

In 2020, China announced at the UN Climate Conference that its carbon dioxide emissions would peak by 2030 and become carbon neutral by 2060. The carbon emissions from buildings account for more than 40% of the total carbon emissions in the whole cycle [1–3]. Housing is one of the top four sources of carbon emissions in Europe, accounting for a significant share of the total carbon emissions in society [4]. Carbon emissions run through all aspects of the construction industry. There is plenty of room to reduce carbon emissions in building materials and construction [5,6]. In the context of carbon peak and carbon neutral, it is very important to reduce the carbon emissions of the construction industry. Prefabricated construction enterprises (PCEs) need to transfer a large number of operations in traditional construction methods from the construction site to the construction factory. These constructs and fittings are installed to construct the building through reliable connections [7]. The goal of carbon peak and carbon neutrality promotes the development of PCEs towards green digital innovation [8].

The construction industry can be developed by accelerating the transformation of traditional construction methods. First, the traditional construction industry is based on on-site manual work. This approach has problems, such as low resource utilization efficiency and construction safety [9]. The parts of prefabricated buildings are made in a factory and assembled on site with reliable connections. As a result, this approach has the characteristics of standardized design, factory production, construction and prefabricated, integration of decoration, management information, intelligent application, and so on [10]. Second, in the past few decades, the progress of the cast-in-place concrete building model has benefitted from China's abundant labor resources. However, with the gradual disappearance of the demographic dividend and the rapid increase in labor costs, labor-intensive production mode will be unsustainable. At the same time, it not only accelerated the upgrading of the traditional construction industry to the industrialization of construction but also promoted the overall progress of the construction industry [11,12]. Third, the traditional construction industry has caused great damage to the ecology and environment, mainly reflected in the carbon emissions [13]. The modular, industrial production of prefabricated components can also minimize the discharge of construction waste, save consumables, and reduce air, noise, and other pollution. Therefore, it can reduce carbon emissions over the life of the building [14–18]. If prefabricated buildings can replace conventional buildings on a large scale in the future, carbon emissions will be greatly reduced.

However, the development of PCEs in China is still facing great challenges. The first is that PCEs are increasingly demanding carbon reduction [19]. At present, many developed countries have decoupled carbon emissions from economic development, but China is still in the stage of increasing carbon emissions and has not reached the peak [20]. As one of the industries with high carbon emissions, carbon emission reduction means that the production mode, technological level, material selection, and business model in the industry will face innovation. The goal of carbon peak and carbon neutrality puts forward new requirements for the traditional construction industry. It also means that PCEs have higher requirements for carbon reduction [21,22]. The second is the low degree of intelligent PCEs [23]. In the prefabricated building industry, chain technology, prefabricated shear wall structure connection, site installation and construction and acceptance methods, and other key technologies are not yet mature. In addition, related technical standards, norms, and construction methods cannot keep up, resulting in varying degrees of constraints on its development [24]. In the degree of standardization, the modular production and standardization of building components are relatively low. General components are used less. These conditions result in low construction efficiency and a high cost of prefabricated buildings. It is difficult to give full play to the advantages of industrialization [25].

In the face of the above problems, PCEs solve them through green digital innovation projects. In recent years, promoting the development of PCEs through research and development projects has become a hot spot of scholars' research [26–29]. Many companies are also carrying out this activity. In April 2021, the Yunnan Kunming Steel Construction Group Co., Ltd. Green Prefabricated Building Innovation Studio was established. The green prefabricated building design research and development innovation group, green and intelligent manufacturing innovation group, and green building construction and installation method innovation group were set up. They promote advanced concepts and technology to solve the technical bottleneck of production and operation. In May of the same year, the Hubei Provincial Intelligent Construction Science and Technology Innovation Consortium was established. In addition, in order to empower the transformation and upgrading of the construction industry in Hubei Province, all the member units will jointly summarize and form a list of key technologies of intelligent construction.

As the spillover effect of technological innovation becomes more and more prominent, how to effectively conduct digital green innovation activities has become a very important problem in the development of PCEs. In the process of promoting the development of PCEs, they have to face huge financial and risk pressure. In addition, other PCEs are also searching for methods. In the market, there is more cooperation between PCEs, which provides a way to solve this dilemma. However, it also involves the issue of partner selection [30]. At present, many systematic approaches provide ideas for choosing joint investment partners, but there are still some shortcomings.

In recent years, many scholars have studied partner selection in terms of the methods and index system [31–39]. The research methods mainly include the partner evaluation method, the attribute weighting method, and the weighting method. As for the partner evaluation method, analytic hierarchy process (AHP) and data envelopment analysis (DEA) methods were adopted before, while some new methods and combined methods were adopted in recent years [31–35]. This research is mainly committed to considering all kinds of complex factors. With respect to the attribute weighting method, there are mainly linear programming models, methods for minimum and maximum entropy values, membership, and non-membership methods. Regarding the weighting method, there are mainly techniques for the order preference by similarity to an ideal solution (TOPSIS) method, coefficient of variation method, and ideal point method [36–39]. In terms of the index system, some scholars proposed that innovation has an important impact on partner selection [31–33]. Some scholars believed that technology plays a non-negligible role in partner selection [34–36]. Many scholars expressed their views in choosing methods and systems, but there are still some shortcomings [37–39]. In the selection of methods, most previous studies have focused on a single subjective or objective weight. However, there are fewer studies of intuitive fuzzy weights and their combination with objective weights. There is a lack of a certain degree of combing and summary in the construction of the system, which cannot explain the level of digital green innovation projects carried out by PCEs under the goal of double-carbon. It is not conducive to the evaluation of the implementation and a full grasp of its situation.

To solve the above problems, the purpose of this research is to build a research system to select joint investment partners and select scientific methods to promote the digital green innovation development of PCEs. Firstly, a new fuzzy entropy comprehensive evaluation formula is proposed based on the entropy method and TOPSIS method. Second, combined with the existing research index system, this paper divides the joint venture capital partners of PCEs into risk indicators and resource indicators under the dual-carbon goal. This study builds a research system of PCEs choosing joint investment partners in the investment activities of digital green innovation projects. This study expounds the relevant theory and proposes the fusion method.

The rest of this paper is as follows. Section 2 is a literature review and frame system. The methodology is elucidated in Section 3. Section 4 is the empirical study. Conclusions and future prospects are presented in Section 5.

2. Literature Review and Theoretical Framework

2.1. Literature Review

2.1.1. Digital Green Innovative and Joint Venture Investment

(i) Digital green innovation. In recent years, some scholars have conducted in-depth research on digital green innovative management. They thought that digital green innovative management of enterprises is particularly important [40,41]. Khin & Ho (2018) put forward that digital technology can significantly improve the sales revenue and reduce the operating cost rate of enterprises [40]. Li et al. (2020) believed that, in the era of the digital economy, the application of digital technology can significantly promote the improvement of enterprises' capabilities. The capability improvement effect of digital technology application can be more fully reflected in enterprises with a poor resource base and high dynamic capability [41]. Meanwhile, many scholars put forward their views on green innovation management [42–44]. Kaluarachchi (2021) believed that ecological and green development in the field of architectural design in China are promoted through the integration of digital technology and green building design [42]. Jiang (2021) believed that it is necessary to achieve high-quality fusion of digital economy and green economy development. The research of the green economy sustainable paradigm shift must consider the digital tools in environmental sustainability. Changing the thinking mode of environmental governance should not only attach great importance to the use of digital solutions but also cannot ignore the digital economy accountability of the carbon footprint [43]. Chaker et al. (2022)

believed that the value of digital technology capability is beyond doubt, but its value potential is conditional. Digital technology enterprises must make further use of business model innovation to give full play to the potential value of digital technology [44].

(ii) Joint venture investment. Many scholars have discussed the motivations of joint venture investment [45–57]. Pence [45] (1982) and Perez [46] (1986) argued that venture capitalists are motivated to co-invest by obtaining a second opinion, which double-checks their investments using the views of other investment partners. It can not only prevent the deficiency of their own screening and management skills but also prevent the adverse selection problem caused by information asymmetry. This is supported by the empirical study conducted by Lerner [47]. The empirical results of Altintig et al. (2013) also supported both drivers [48]. Tykvova and Schertler (2014) examined the joint drivers of multinational venture capital. They found that joint investment was more conducive to obtain investment opportunities, improve risk allocation, and reduce information costs, thus indirectly proving both drivers [49]. Manigart and Lockett (2006) argued that risk diversification drivers and access to trade flow factors are more important than screening and appreciation drivers. In the early investment stage, there will be a stronger value-added motivation, and the motivation of joint investment with investors is to obtain the screening and value-added skills of leaders [50]. Lockett and Wright (2001) formally classified previous studies into risk diversification and resource accumulation. Resource accumulation motivation is more important for early-stage investment at least [51]. Brander et al. (2002) summarized joint venture capital factors as risk dispersion hypotheses for diversification of the portfolio, screening hypotheses for acquiring pre-investment screening skills, and value-added assumptions for managing post hoc investments. The study found more support for the value-added hypothesis [52]. Verwaal et al. (2010) tended to support access to transaction flow factors [53]. Ferrary (2010) believed that the motivation of a joint venture is the accumulation of resources [54]. Hopp and Rieder (2011) believed that the motive of venture capital association is not to diversify the asset portfolio but to disperse risks [55]. Lerner (1991) believed that venture capital institutions would engage in window dressing. Window dressing is the practice of quarterly performance reviews of fund managers in which market performance is a noisy indicator and investors also look at portfolios at the end of each quarter. As a result, fund managers are likely to buy shares in companies with good quarterly results and sell shares in companies with poor quarterly results [56]. Admati and Pfleiderer (1994) believed that the lead investor may deliberately overestimate the security price of the follow-up financing by using this information advantage to seek the interests of the co-investor. To prevent this opportunistic behavior, co-investors often invest together so that the lead investor must maintain a constant share [57].

(iii) Based on the above literature review, it is summarized as follows. Many scholars only conducted research on digital innovation management or green innovation management. Few scholars put forward opinions on the integration of digital innovation management and green innovation management. According to the existing literature, the motivations of joint venture investment can be divided into risk dispersion motivation, resource accumulation motivation, and collusion motivation. Venture capital institutions have the need to reduce investment risk. Co-investing in one area can diversify a portfolio away from systemic risk. More importantly, it possesses the specific nature of a syndicate to improve the ability of investment against risk. Much of the literature supports the idea of risk diversification drivers [45–50]. According to the research of resource accumulation motivation, the main motivation of joint venture investment lies in the acquisition of pre-investment screening resources and post-investment management resources, as well as the acquisition and exchange of transaction flows [51–55]. The main motivation of venture capitalists' association is to prevent the opportunistic behavior and window dressing behavior of leading investors [56,57]. It can be seen from the above literature that the existing studies tend to support the motivation of resource accumulation.

2.1.2. Criteria for Venture Capital Partner Selection and Characteristics of Preference

(i) Criteria for venture capital partner selection. In much of the literature on partner selection, different scholars have proposed different criteria for partner selection [58–63]. Zhu et al. (2010) built the green technology innovation of the enterprise environmental evaluation index system from the two dimensions of the enterprise internal environment and the external environment [58]. Bi et al. (2013) built an evaluation index system of green process innovation performance from the three aspects of economic performance, social performance, and ecological performance [59]. Ghisetti and Rennings (2014) measured green innovation efficiency, selected 92 indicators of energy consumption and environmental pollution, and made a distinction between energy efficiency innovation and environmental beneficial innovation based on the two aspects [60]. Salamat et al. (2018) established a partner selection index system for the international strategic alliance [61]. Dedehayir et al. (2018) studied the role of innovation leadership, direct value creation, value creation support, and the entrepreneurial ecosystem in the innovation ecosystem. They point out that organizational culture, partners, and technological level are important factors for the long-term development of the innovation ecosystem [62]. Yin et al. (2020) measured the four dimensions of regional green innovation input capacity, green innovation output capacity, green innovation environment capacity, and green diffusion input capacity [63].

(ii) Characteristics of preference. As for the characteristics of co-investment partners that venture capital institutions should or prefer to choose, scholars have studied as follows [64–67]. Du (2016) found that venture capital institutions are more inclined to unite with investment partners with similar experience [64]. Gompers et al. (2016) examined the impact of the individual-level characteristics of venture capitalists on the selection of joint investment partners. The study found that venture capitalists preferred to choose partners who had attended the same university and were of the same race and gender [65]. In terms of experience level, Lerner (1994) believed that experienced venture capitalists in the first round of investment tend to associate with investors with a similar experience level and generally do not choose smaller or junior partners. Casamatta and Haritchabalet (2007) theoretically believed that experienced venture capitalists would choose more experienced partners to unite [66]. In terms of capital scale and heterogeneous resource endowment, Hochberg et al. (2015) conducted a combined study and believed that risk diversification is not the main driving force for joint investment partner selection. By selecting partners with much resource endowment and specific heterogeneous resources, resource superposition and complementarity can be realized [67].

(iii) Based on the above literature review, it is summarized as follows. Many scholars expressed their opinions on the selection of evaluation indicators. However, the lack of a certain degree of summary is not conducive to the evaluation and implementation and a comprehensive grasp of the situation [58–63]. Based on the existing literature, there are two views on what characteristics venture capital institutions prefer to select as co-investment partners. The first view holds that venture capital institutions tend to form syndicates with partners with similar characteristics or types. The reason is that this type of syndicate also has lower agency costs and information asymmetry, making the investment risk lower. There is much literature supporting the selection of similarity partners [64,65]. The second view holds that venture capital institutions tend to form syndicates with partners with different characteristics or types and the same level of resource endowment. The reason is that joint investment with venture capital institutions with the same level of heterogeneity or resource endowment can obtain the heterogeneous resources of the other side, which is conducive to resource superposition, complementarity, and exchange to achieve cumulative advantages. There are two ways to combine venture capital to accumulate resources. One is to select partners with the same level of resource endowment for resource superposition. The other is to select partners with different characteristics or types for resource complementarity and exchange. With regard to supporting the view of selecting resource accumulation partners, the existing literature examines the effects of experience level, capital size, and heterogeneous resource endowment [66,67].

2.1.3. Approaches for Venture Capital Partner Selection

In terms of partner selection methods, Nikghadam et al. (2016) have proposed partner selection methods based on fuzzy target optimization [68]. Chen and Han (2018) constructed linear planning models for the case of incomplete attribute information [69]. For the case where the weight information is completely unknown, Gao et al. (2016) proposed methods based on minimum and maximum entropy values [70]. Yin et al. (2018) proposed methods that considered membership and non-membership [71]. Liang & Chong (2019) proposed the gray model and the DEA method [72]. In terms of the weighting method, Zhang et al. (2021) used the TOPSIS method to solve the optimal capacity configuration of the system [73]. Zhao and Yu (2021) used the coefficient of variation method to comprehensively evaluate the indicators through the corresponding weight combination [74]. Liu et al. (2021) used the ideal point method to construct the evaluation model [75]. Liu (2021) used the ideal point method to optimize the hierarchical analysis method, entropy weight method, and excessive weighting method [76]. Lin and Bai (2021) used the TOPSIS method to construct a weighted standard matrix and evaluated the advantages and disadvantages of each power plant [77]. Chen et al. (2021) established a combined weight optimization method based on the Gini coefficient method and excessive weighting method [78]. Chou et al. (2022) proposed a combined weight method based on MOEAD [79].

Numerous studies provide methods and ideas for partner selection. On the level of partner selection and weighting, many opinions and ideas have been provided by predecessors [68–79]. In terms of evaluation methods, there are methods such as the comprehensive index method, grey correlation method, grey fuzzy comprehensive evaluation method, AHP, combination weight, and so on. However, the combination evaluation and in-depth analysis with other evaluation methods are rarely carried out, and there are some problems, such as a lack of consistency in the evaluation results. Regarding the determination of weights, the subjective weighting method may be highly subjective and arbitrary, influenced by the decision-maker's lack of knowledge or experience. Objective weighting ignores the subjective information of decision-makers. The algorithm complexity of the combination weighting method is generally high. Each of these methods has advantages and disadvantages.

2.2. Theoretical Framework

2.2.1. Theoretical Model of Joint Investment Partner Selection

Digital green innovation projects usually occur in the process of enterprise change. Digital green innovation plays an important role in improving the performance of PCEs. It is regarded as one of the key factors affecting the green competitive advantage and strategic selection of PCEs. However, PCEs have to face significant investment pressure for innovative activities in many digital green R&D projects. More and more PCEs are choosing joint partners to spread risks and share resources when conducting digital green innovation activities. This practice has helped the construction industry to some extent. Problems related to the selection of joint partners by prefabricated construction firms can be solved by constructing joint venture capital networks. The specific theoretical model is shown in Figure 1.

In the joint venture network, PCEs and joint venture partners are the two main subjects of digital green innovation projects. The exchange of green knowledge and digital innovation technologies between construction firms and joint venture partners helps to promote business development and technological progress because this kind of cooperation not only combines heterogeneous partners but also combines heterogeneous knowledge. In the process of knowledge and technology exchange, PCEs and joint venture partners gradually form a mutually beneficial symbiotic relationship. The two share more and more complementary resources on digital green innovation. Whether PCEs can choose appropriate joint venture partners is directly related to the development of mutualistic symbiosis. In the joint venture capital network, it is particularly important to select one or more joint venture partners for PCEs to carry out digital green innovation activities.

However, this selection is a complex decision-making process. This paper addresses this issue.

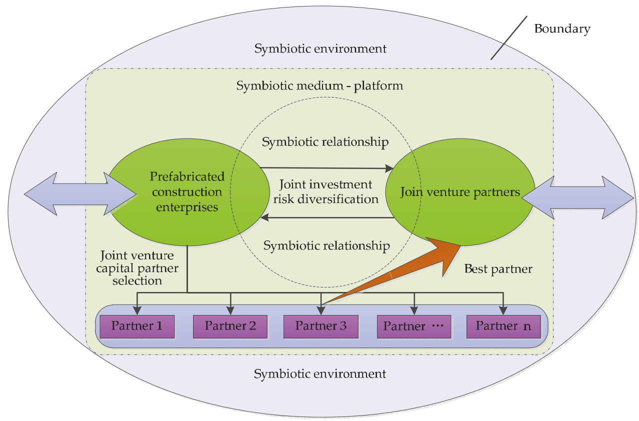

Figure 1. Theoretical model of PCEs choosing joint venture capital partners.

2.2.2. Framework System of Joint Investment Partner Selection

By systematically sorting out and summarizing the five aspects of the knowledge of alliance motivation (why), partner selection (who), situation influence on alliance (where), alliance process (how), and alliance investment influence on the performance of PCEs, it can be found that there is a certain logical relationship between them.

First, motivation affects partner selection, which, in turn, affects firm performance. Namely, PCEs choose joint venture partners based on the risk diversification motivation to carry out digital green innovation projects to promote the enterprise venture investment performance. In this mechanism, PCEs are in different situations, leading to different joint motivations and partner selection behaviors. The impact on performance will be different, and the play of the mechanism will present heterogeneity.

Secondly, partner selection and the impact on the performance of PCEs is to analyze the process of the black box of joint venture investment. PCEs carry out digital green innovation projects to carry out joint venture investment, which is the process of joint venture capital partners investing in PCEs. In this process, joint venture partners and PCEs will play against each other based on the principle of maximizing their own interests.

Finally, it can be seen that PCEs' selection of joint investment partners is a process of investment behavior. The motivations of joint venture, partner selection, and game behavior in the process of a joint venture are bound to be affected by the situation of joint venture partners and PCEs.

Based on the above analysis and the idea of six analysis methods, this paper integrated the above logical relations. The activity of PCEs choosing joint venture partners in digital green innovation projects innovatively puts forward a research framework of joint venture capital, 3W1H-P, as shown in Figure 2.

Many scholars have emphasized the importance of partner selection criteria [58–63]. Partner selection should be based on the level of environmental protection [60,63]. Innovative leadership, direct value creation, and value creation support are considered when selecting strategic alliance partners [62]. Scholars have put forward their own views on the environmental, economic, social, and ecological aspects [59]. At the same time, organizational culture, partners, and other factors cannot be ignored [62]. This paper established a research system for PCEs to select joint venture partners when carrying out digital green innovation projects, as shown in Figure 3.

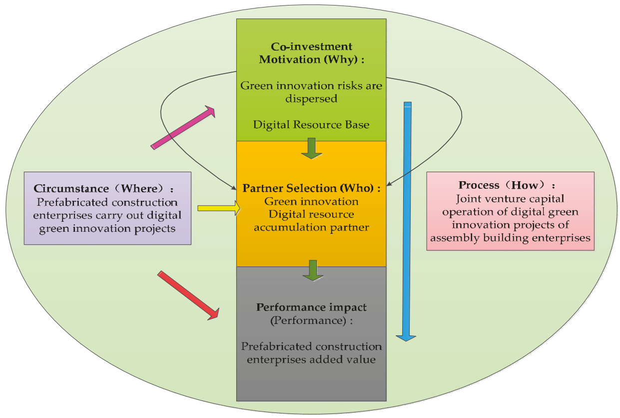

Figure 2. PCEs choose the joint investment partner 3W1H-P research framework.

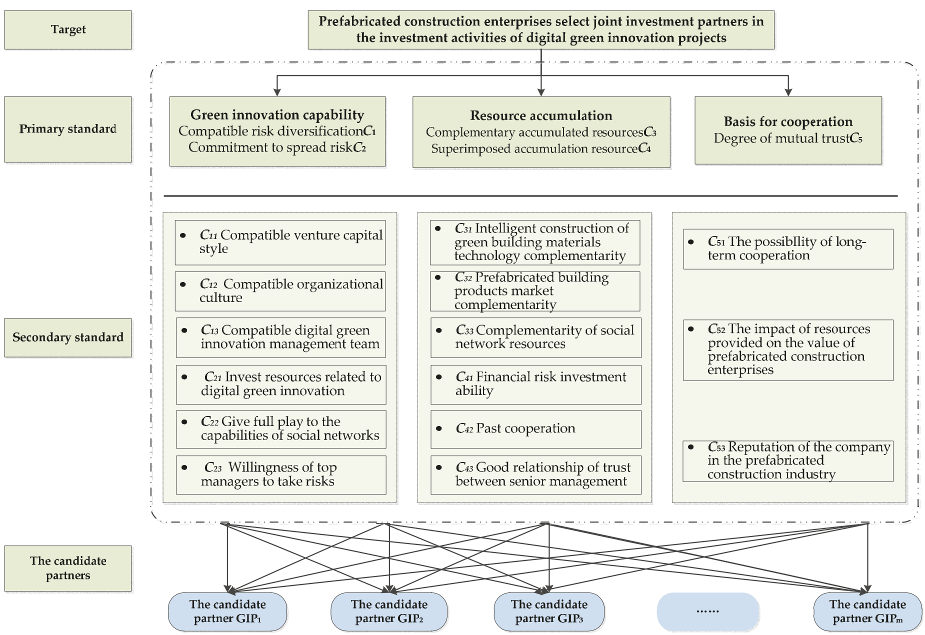

Figure 3. Criterion framework for PCEs to select joint venture partners when carrying out digital green innovation projects.

3. Methodology

3.1. Methodological Framework

In this study, a selection method was proposed. It is an integrated approach based on fuzzy prospect theory and vise kriterijumska optimizacijai kompromisno resenje (VIKOR). The running logic of this method is shown in Figure 4.

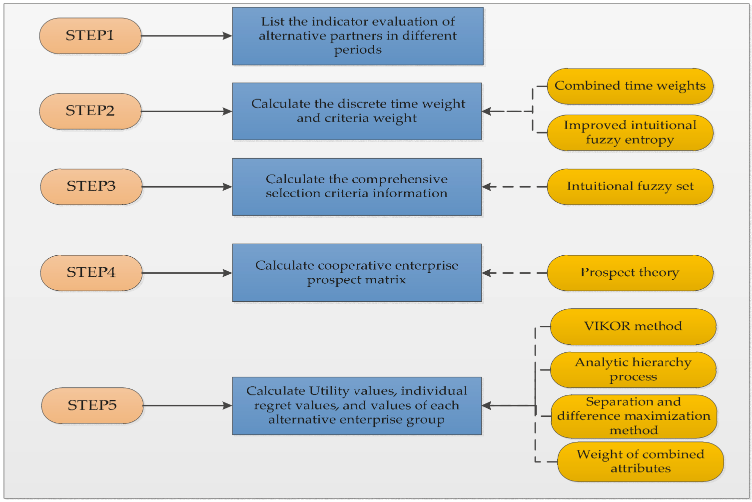

Figure 4. Methodological framework of choosing digital green innovation partner for PCEs.

Figure 4 illustrates the process used by PCEs to dynamically select digital green innovation partners. The main steps are as follows. Step 1: List the indicator evaluation of alternative partners in different periods. Step 2: Calculate the discrete time weight and criteria weight. Step 3: Calculate the comprehensive selection criteria information. Step 4: Calculate cooperative enterprise prospect matrix. Step 5: Use VIKOR and attribute weight method to calculate utility values, individual regret values, and values of each alternative enterprise group.

3.2. *Preliminary*

3.2.1. Intuitional Fuzzy Set

The definitions regarding intuitive fuzzy set are shown in Appendix A [80–82].

3.2.2. AHP

AHP is a subjective weighting method with strong applicability and operability. This method can better represent each factor and their correlation degree [83]. AHP method is adopted in this study. First of all, each element under the same criterion layer is compared in pairs with the expert consultation method and the relevant literature using 1–9 scale method, and the judgment matrix is constructed. Secondly, the consistency of the judgment matrix is tested. Finally, w, the weights of each factor layer and criterion layer, are calculated. The specific decision-making process of AHP is shown in Appendix B.

3.2.3. Separation and Difference Maximization Method

The deviation maximization method is an objective method, which has the characteristics of focusing on the relationship between the information while ignoring the relationship between the information itself [84]. Appendix C shows the specific calculation steps.

3.2.4. Weight of Combined Attributes

Index weight w_j under the comprehensive AHP method and index weight ω_j under the deviation maximization method are introduced to determine the comprehensive weight of the index [85,86].

The distance d between the two was determined by the Euclidean distance. The result is as follows:

$$d = \left(w_j, \omega_j\right) = \sqrt{\sum_{j=1}^{q}\left(w_j - \omega_j\right)^2} \quad (1)$$

The actual weight $w\prime$ after correction is represented by two parameters. The result is as follows:

$$w_j\prime = \alpha w_j + \beta \omega_j \quad (2)$$

In Formula (A2), α and β represent the weight preference coefficient of AHP method and deviation maximization method, respectively, and the following constraints are satisfied:

$$\begin{cases} d^2\left(w_j, \omega_j\right) = (\alpha - \beta)^2 \\ \alpha + \beta = 1 \\ \alpha \geq 0, \beta \geq 0 \end{cases} \quad (3)$$

3.2.5. Prospect Theory

The prospect theory was proposed in 1979 and expanded by Tversky and Kahneman in 1992. Prospect theory is an effective tool to reflect the utility of intuitive perception and has been widely used to solve various decision-making problems. In this study, fuzzy prospect theory is introduced to help PCEs to avoid similar risks blindly and make the decision more reasonable and effective. Based on the above analysis, the following definitions are made in this paper. Definitions related to prospect theory are given in Appendix D.

3.3. Fusion Approaches

3.3.1. Combined Time Weights

In the process of PCEs choosing joint investment partners in the investment activities of digital green innovation projects, the weight vector of time series reflects the preference degree of PCEs to time, and time degree $\lambda(t) = \left(\widetilde{a}(t_1), \widetilde{a}(t_2), \ldots, \widetilde{a}\left(t_p\right)\right)^{\mathrm{T}}$ is crucial to obtain the weight of time and the selection result.

Subjective time weight based on time degree and ideal solution. Let $\varphi = \sum_{k=1}^{p} \lambda(t_k)(p-k)/(p-1)$ be a time vector, where $0 \leq \varphi \leq 1$. Time degree represents the attention degree and preference degree of decision-makers to different time information. When $\varphi = 0$, $\lambda(t)^+ = (0, 0, \ldots, 1)^{\mathrm{T}}$ is called the positive ideal time weight vector, and the decision-maker only pays attention to the current information. As φ increases, decision-makers shift from focusing only on current information to focusing on past information. When $\varphi = 1$, then $\lambda(t)^- = (1, 0, \ldots, 0)^{\mathrm{T}}$ is called the negative ideal time weight vector, indicating that decision-makers only pay attention to the past information. Let $d\left(\lambda^1(t_k), \lambda^2(t_k)\right)$ be the Euclidean distance $\lambda^1(t_k)$ and $\lambda^2(t_k)$ between the time weight vectors, and the distance can be expressed as:

$$d\left(\lambda^1(t_k), \lambda^2(t_k)\right) = \sqrt{\sum_{k=1}^{p} \left|\lambda^1(t_k) - \lambda^2(t_k)\right|^2} \quad (4)$$

Therefore, the Euclidean distance between the time weight vector and the positive ideal time weight vector $d\left(\lambda(t_k), \lambda(t_k)^+\right)$ and negative ideal time weight vector $d\left(\lambda(t_k), \lambda(t_k)^-\right)$ can be expressed as:

$$d\left(\lambda(t_k), \lambda(t_k)^+\right) = \sqrt{\sum_{k=1}^{p-1} \lambda(t_k)^2 + \left(1 - \lambda\left(t_p\right)\right)^2} \quad (5)$$

$$d\left(\lambda(t_k),\lambda(t_k)^-\right)=\sqrt{(1-\lambda(t_1))^2+\sum_{k=2}^{p}\lambda(t_k)^2} \tag{6}$$

The ideal time weight vector C is expressed as:

$$C=\frac{d\left(\lambda(t_k),\lambda(t_k)^-\right)}{d\left(\lambda(t_k),\lambda(t_k)^+\right)+d\left(\lambda(t_k),\lambda(t_k)^-\right)} \tag{7}$$

The model is then optimized based on the TOPSIS idea and the ideal solution. The model (M-1) is expressed as:

$$\begin{cases} \max C(\lambda)=\dfrac{\sqrt{(1-\lambda(t_1))^2+\sum_{k=2}^{p}\lambda(t_k)^2}}{\sqrt{\sum_{k=1}^{p-1}\lambda(t_k)^2+\left(1-\lambda\left(t_p\right)\right)^2}+\sqrt{(1-\lambda(t_1))^2+\sum_{k=2}^{p}\lambda(t_k)^2}} \\ s.t.\ \varphi=\sum_{k=1}^{p}\frac{p-k}{p-1}\lambda(t_k),\ \sum_{k=1}^{p}\lambda(t_k)=1,\lambda(t_k)\in[0,1],k=1,2,\ldots,p \end{cases} \tag{8}$$

Objective time weight $F(\lambda(t_k))$ can be shown as follows:

$$F(\lambda(t_k))=-\sum_{k=1}^{p}\lambda(t_k)\ln\lambda(t_k),k=1,2,\ldots,p \tag{9}$$

Then, the maximum entropy principle was used to solve the time weight of the information entropy to establish a nonlinear planning model. It is as follows:

$$\begin{cases} \max F(\lambda(t_k))=-\sum_{k=1}^{p}\lambda(t_k)\ln\lambda(t_k) \\ s.t.\ \varphi=\sum_{k=1}^{p}\frac{p-k}{p-1}\lambda(t_k),\ \sum_{k=1}^{p}\lambda(t_k)=1,\lambda(t_k)\in[0,1],k=1,2,\ldots,p \end{cases} \tag{10}$$

Based on subjective and objective comprehensive time weight. According to the principle of enriching the present and thinning the past, the greater the degree of relationship, the greater the degree of attention to the current decision information. It considers the influence of subjective preference and objective criterion information of PCEs and can make the results of joint investment partner selection more comprehensive, accurate, and reliable when PCEs carry out digital green innovation project investment activities. The model can be expressed as:

$$\begin{cases} \max G=\theta\dfrac{\sqrt{(1-\lambda(t_1))^2+\sum_{k=2}^{p}\lambda(t_k)^2}}{\sqrt{\sum_{k=1}^{p-1}\lambda(t_k)^2+\left(1-\lambda\left(t_p\right)\right)^2}+\sqrt{(1-\lambda(t_1))^2+\sum_{k=2}^{p}\lambda(t_k)^2}}+(1-\theta)\sum_{k=1}^{p}\lambda(t_k)\ln\lambda(t_k) \\ s.t.\ \varphi=\sum_{k=1}^{p}\frac{p-k}{p-1}\lambda(t_k),\ \sum_{k=1}^{p}\lambda(t_k)=1,\lambda(t_k)\in[0,1],k=1,2,\ldots,p \end{cases} \tag{11}$$

where θ is the equilibrium coefficient, $\theta\in[0,1]$.

3.3.2. Improved Intuitional Fuzzy Entropy

Let $\widetilde{A}=\left\{\left(x_i,\mu_{\widetilde{A}}(x_i),v_{\widetilde{A}}(x_i)\right)\middle|x_i\in X\right\}$ be an intuitionistic fuzzy set on domain $X=\{x,x_2,\cdots,x_n\}$, and let

$$E\left(\widetilde{A}\right)=\frac{1}{n}\sum_{i=1}^{n}\left(\left|\mu_{\widetilde{A}}(x),v_{\widetilde{A}}(x)\right|-1\right)^2\ln\left[e+\left|\mu_{\widetilde{A}}(x_i)-v_{\widetilde{A}}(x_i)\right|\left(1-\mu_{\widetilde{A}}(x_i)-v_{\widetilde{A}}(x_i)\right)\right] \tag{12}$$

be the entropy of intuitionistic fuzzy set $\widetilde{A}$.

Theorem 1. *$E\left(\widetilde{A}\right)$ is intuitional fuzzy entropy $\mu_{\widetilde{A}}(x_i) + v_{\widetilde{A}}(x_i) \in [0,1]$.*

Proof. First prove $E\left(\widetilde{A}\right) \in [0,1]$ because $E\left(\widetilde{A}\right) \in [0,1]$, $v_{\widetilde{A}}(x_i) \in [0,1]$, so $1 - \mu_{\widetilde{A}}(x_i) - v_{\widetilde{A}}(x_i) \in [0,1]$. Let $g(\alpha_i, \beta_i) = (\alpha_i - 1)^2 \ln(e + \alpha_i\beta_i)$, where $\alpha_i = \left|\mu_{\widetilde{A}}(x_i) - v_{\widetilde{A}}(x_i)\right|$, $\beta_i = 1 - \mu_{\widetilde{A}}(x_i) - v_{\widetilde{A}}(x_i)$ with respect to $g(\alpha_i, B_i)$; take the partial derivative with respect to α_i and there is

$$
\begin{aligned}
& g_{a_i}(\alpha_i, B_i) = 2(\alpha_i - 1)\ln(e + \alpha_i\beta_i) + (\alpha_i - 1)^2 \tfrac{\beta_i}{e+\alpha_i\beta_i} \\
& = (\alpha_i - 1)\left[2\ln(e + \alpha_i\beta_i) + \tfrac{\alpha_i\beta_i - \beta_i}{\alpha_i\beta_i + e}\right] \le (\alpha_i - 1)\left[2\ln e + \tfrac{\alpha_i\beta_i - \beta_i}{\alpha_i\beta_i + e}\right] \\
& = (\alpha_i - 1)\tfrac{2\alpha_i\beta_i + 2e + \alpha_i\beta_i - \beta_i}{\alpha_i\beta_i + e} \le 0
\end{aligned}
$$

Equals if $\alpha_i = 1$. So, $g(\alpha_i, \beta_i)$ is decreasing with respect to α_i. When $\left|\mu_{\widetilde{A}}(x_i) - v_{\widetilde{A}}(x_i)\right| = 1$, the minimum value is 0. $E\left(\widetilde{A}\right) \in [0,1]$ is true.

To illustrate the rationality and superiority of the entropy formula proposed in this paper in measuring intuitive fuzzy information and fuzzy information, two classical intuitionistic fuzzy entropy formulas are selected as follows:

$$E_1\left(\widetilde{A}\right) = \frac{1}{n}\sum_{i=1}^{n}\left(1 - \mu_{\widetilde{A}}(x_i) - v_{\widetilde{A}}(x_i)\right) \tag{13}$$

$$E_2\left(\widetilde{A}\right) = \frac{1}{n}\sum_{i=1}^{n}\left(1 - \left(\mu_{\widetilde{A}}(x_i) + v_{\widetilde{A}}(x_i)\right) e^{1-\left(\mu_{\widetilde{A}}(x_i) + v_{\widetilde{A}}(x_i)\right)}\right) \tag{14}$$

□

Example 1. *Suppose $\widetilde{A}_1 = \{(x, 0.1, 0.7)\}$, $\widetilde{A}_2 = \{(x, 0.4, 0.4)\}$, and $\widetilde{A}_3 = \{(x, 0.8, 0.2)\}$ are the three intuitionistic fuzzy sets in domain $X = \{x\}$and calculate intuitionistic fuzzy set by entropy formula E, E_1, and E_2, respectively. The calculated results are shown in* Table 1.

Table 1. Comparison of the calculation results.

	$\widetilde{A}_1$	$\widetilde{A}_2$	$\widetilde{A}_3$
$E\left(\widetilde{A}\right)$	0.1669	1.0000	0.1600
$E_1\left(\widetilde{A}\right)$	0.2000	0.2000	0.0000
$E_2\left(\widetilde{A}\right)$	0.2290	0.2290	0.0000

The new intuitionistic fuzzy entropy shows that, when the hesitancy degree is the same, the smaller the absolute deviation between membership degree and non-membership degree, the larger the intuitionistic fuzzy entropy is $E\left(\widetilde{A}_1\right) < E\left(\widetilde{A}_2\right)$. When the absolute deviation between membership degree and non-membership degree is the same, the greater the hesitation degree, the greater the intuitive fuzzy entropy, such as $E\left(\widetilde{A}_1\right) > E\left(\widetilde{A}_3\right)$, which is consistent with the actual situation. However, although the hesitancy of element x belonging to $\widetilde{A}_1$ and $\widetilde{A}_2$ is the same, the absolute deviation between the membership degree of x belonging to $\widetilde{A}_1$ and the non-membership degree is greater than that of x belonging to $\widetilde{A}_2$, so the uncertainty of $\widetilde{A}_1$ should be less than that of $\widetilde{A}_1$. Using entropy formulas $\widetilde{A}_1$ and $\widetilde{A}_1$, $E_1\left(\widetilde{A}_1\right) = E_1\left(\widetilde{A}_2\right)$, $E_2\left(\widetilde{A}_1\right) = E_2\left(\widetilde{A}_2\right)$ can be obtained, which is not true.

Example 1 shows that E_1 and E_2 cannot accurately capture the difference of intuitionistic fuzzy entropy caused by absolute deviation of membership degree and non-membership degree (fuzzy information) in intuitionistic fuzzy set with the same hesitation degree (intuitive information). The formula proposed in this paper considers intuitionistic information and fuzzy information contained in intuitionistic fuzzy sets more comprehensively. Therefore, when describing the entropy of intuitionistic fuzzy sets, formula E proposed in this paper is more reasonable.

Set $\omega_j(t_k)$ as the target attribute weight of t_k periods and establish the optimization model of the target attribute weight of a sequence as follows:

$$\begin{cases} \min \sum\limits_{j=1}^{n} (\omega_j(t_k))^2 E_j(t_k) \\ s.t \sum\limits_{j=1}^{n} \omega_j(t_k) = 1 \end{cases} \tag{15}$$

The Lagrangian function $L(\omega_j(t_k), \lambda)$ was constructed according to the above formula:

$$L(\omega_j(t_k), \lambda) = \sum_{j=1}^{n} (\omega_j(t_k))^2 E_j(t_k) + 2\lambda(\sum_{j=1}^{n} \omega_j(t_k) - 1) \tag{16}$$

Take the partial derivative of $\omega_j(t_k)$ and λ, respectively, and make the partial derivative function equal to 0; then:

$$\begin{cases} \frac{\partial L(\omega_j(t_k),\lambda)}{\partial \omega_j(t_k)} = 2\omega_j(t_k)E_j(t_k) + 2\lambda = 0 \\ \frac{\partial L(\omega_j(t_k),\lambda)}{\partial \lambda} = 2(\sum\limits_{j=1}^{n} \omega_j(t_k) - 1) = 0 \end{cases} \tag{17}$$

Solving the above formula, the target attribute weight $\omega_j(t_k)$ is

$$\omega_j(t_k) = \frac{(E_j(t_k))^{-1}}{\sum\limits_{j=1}^{n} (E_j(t_k))^{-1}} \tag{18}$$

3.3.3. VIKOR Method

The methodological steps for the VIKOR method are shown in Appendix E.

4. Empirical Study

4.1. Empirical Background

Tianfeng Green Prefabricated Group was founded in 1997. It has been committed to the green intelligent prefabricated industry, building an industrial ecological chain of steel structure prefabricated buildings, cluster intelligent prefabricated buildings, modular prefabricated houses, energy-saving plates, intelligent equipment, new energy, steel logistics, and distribution. The company has undertaken a number of torch programs of the Ministry of Science and Technology, major provincial and municipal science and technology projects, and obtained more than 200 national patents. Therefore, how to reduce the carbon emissions of building materials, improve green competitiveness, and profit are important issues. Therefore, Tianfeng will be committed to the development and practice of digital green and innovative projects to innovate green products and provide green building materials as the development goal.

Tianfeng is about to launch a digital green innovation project. The main body of the project is a cluster intelligent prefabricated building. A cluster intelligent prefabricated building is a prefabricated steel structure with an ultra-low energy consumption building system that adopts new construction technology and green building materials. Moreover, the cluster prefabricated building structure system has the characteristics of light weight, manual handling, convenient installation, and strong and durable structure, which is very suitable for application in mountainous areas and scenic spots. Tianfeng customized the program design and housing construction and committed to close cooperation with a number of enterprises, gathering wisdom development, creating a win–win situation. At present, the enterprise needs to select a matching joint venture partner from some enterprises to carry out the project.

In recent years, seven enterprises have carried out digital green and innovative activities. Prefab construction company Tianfeng needs to select one of them as a partner to carry out digital green innovation activities, and these companies are willing to work with them. Tianfeng has some experience in the selection of partners, but how to choose the best digital green innovation partner from multiple enterprises is still a difficult problem.

4.2. Empirical Elements

4.2.1. Development of Evaluation Criteria

In different scenarios, enterprises choose different methods for partners. In view of the current situation, PCEs need to develop in the direction of digitalization, greening, and innovation. The current systems and methods cannot satisfy Tianfeng to choose the best risk joint investment partner. In order to evaluate the suitability of joint investment partners for PCEs to carry out digital green innovative project investment activities, this paper innovatively proposes a research framework of joint venture investment 3W1H-P in the evaluation index system. This theory has a solid theoretical basis, and the research system of PCEs to choose joint investment partners in the investment activities of digital green innovative projects is constructed. This system can meet the requirements of Tianfeng to select joint investment partners. The evaluation criteria of the research system for enterprises to choose joint investment partners usually come from the green innovation ability, resource accumulation, and degree of overlap of cooperation foundation. In the digital green innovation system of enterprise cooperation and collaboration, green innovation capability is divided into compatible risk diversification and commitment risk diversification, including compatible venture investment style, organizational culture, digital green innovation management team, investment in digital green innovation resources, social network capability, and risk investment willingness of senior managers. Resource accumulation can be divided into complementary accumulation resources and superposition accumulation resources, including technological complementarity, market complementarity, social network resource complementarity, financial risk investment ability, past cooperation, and good mutual trust between senior managers. The basis of cooperation is the mutual trust degree of both parties, including whether the cooperative enterprise has the possibility of long-term cooperation with the PCEs, the influence of the resources provided by the cooperative enterprise on the value of the PCEs, and the reputation of the cooperative enterprise in the prefabricated construction industry. The established evaluation system is shown in Figure 3.

4.2.2. Data and Scenarios

Tianfeng is a construction enterprise with professional construction qualifications. At present, the concept of green building is gradually being taken seriously, and the government has set carbon emission reduction targets for PCEs. Construction companies face hefty fines if their total carbon emissions exceed the limits set by the government. How to reduce the carbon emissions of construction projects and improve green competitiveness and profits is an important issue. In this case, Tianfeng needs to select the best joint investment partner from a large number of alternative enterprises in the construction project. The standards and methods proposed in this paper are suitable for PCEs to select joint investment partners in the development of digital green innovative project investment activities. The reason is that managers and participants understand that the weight of partner selection criteria for digital green innovation is in a vague state. After preliminary screening, seven digital green innovation initiatives have been shortlisted by co-investment partner $P_i = \{P_1, P_2, P_3, P_4, P_5, P_6, P_7\}$.

4.3. Results and Discussion

4.3.1. Results

Step 1: List the indicator evaluation of alternative partners in different periods. Tianfeng needs to select the best partner from the seven major co-investment partners according to the suggested standards and methods. The potential co-investment partners mentioned above are evaluated according to the compiled co-investment partner selection criteria, as shown in Figure 3, including five main criteria and fifteen sub-criteria. In this process, this paper selects time series set $t_k = (t_1, t_2, t_3, t_4,)$ of different periods in recent 4 years. For the sake of simplicity, this paper only gives the calculation of five main criteria, denoted as attribute set $C_k = (C_1, C_2, C_3, C_4, C_5)$. Tables 2–5 list the evaluation of indicators of seven alternative partners in four different periods.

Table 2. Original evaluation criteria information matrix at the moment t_1.

	C_1	C_2	C_3	C_4	C_5
P_1	[0.5,0.3]	[0.3,0.5]	[0.5,0.3]	[0.6,0.3]	[0.1,0.7]
P_2	[0.2,0.7]	[0.2,0.5]	[0.7,0.2]	[0.5,0.3]	[0.6,0.2]
P_3	[0.2,0.4]	[0.5,0.3]	[0.6,0.4]	[0.8,0.2]	[0.6,0.3]
P_4	[0.4,0.6]	[0.8,0.2]	[0.4,0.6]	[0.3,0.6]	[0.3,0.5]
P_5	[0.7,0.2]	[0.7,0.3]	[0.6,0.4]	[0.3,0.5]	[0.5,0.2]
P_6	[0.5,0.1]	[0.3,0.1]	[0.3,0.5]	[0.5,0.2]	[0.2,0.6]
P_7	[0.3,0.6]	[0.6,0.2]	[0.7,0.2]	[0.2,0.7]	[0.5,0.4]

Table 3. Original evaluation criteria information matrix at the moment t_2.

	C_1	C_2	C_3	C_4	C_5
P_1	[0.3,0.2]	[0.5,0.3]	[0.1,0.5]	[0.3,0.5]	[0.2,0.4]
P_2	[0.5,0.4]	[0.5,0.1]	[0.6,0.2]	[0.1,0.3]	[0.3,0.5]
P_3	[0.4,0.5]	[0.6,0.2]	[0.5,0.4]	[0.4,0.5]	[0.6,0.2]
P_4	[0.3,0.4]	[0.5,0.2]	[0.4,0.3]	[0.3,0.7]	[0.6,0.1]
P_5	[0.5,0.2]	[0.6,0.4]	[0.3,0.6]	[0.7,0.2]	[0.6,0.2]
P_6	[0.8,0.2]	[0.3,0.7]	[0.4,0.3]	[0.6,0.4]	[0.3,0.6]
P_7	[0.4,0.3]	[0.5,0.4]	[0.5,0.4]	[0.4,0.6]	[0.3,0.5]

Table 4. Original evaluation criteria information matrix at the moment t_3.

	C_1	C_2	C_3	C_4	C_5
P_1	[0.2,0.3]	[0.3,0.6]	[0.4,0.5]	[0.3,0.5]	[0.3,0.5]
P_2	[0.5,0.3]	[0.6,0.2]	[0.2,0.5]	[0.6,0.4]	[0.5,0.2]
P_3	[0.6,0.2]	[0.3,0.4]	[0.3,0.4]	[0.3,0.6]	[0.4,0.5]
P_4	[0.5,0.3]	[0.5,0.4]	[0.6,0.3]	[0.3,0.5]	[0.3,0.7]
P_5	[0.4,0.5]	[0.3,0.5]	[0.4,0.5]	[0.4,0.2]	[0.6,0.3]
P_6	[0.4,0.6]	[0.4,0.5]	[0.3,0.6]	[0.2,0.5]	[0.3,0.4]
P_7	[0.6,0.3]	[0.2,0.6]	[0.6,0.2]	[0.5,0.4]	[0.6,0.4]

Step 2: Calculate the discrete time weight and criteria weight. It is according to the original evaluation criteria information matrix of joint venture capital partner selection, which contains only venture capital partner $P_i = \{P_1, P_2, P_3, P_4, P_5, P_6, P_7\}$. Based on consultation with relevant experts, we take $\theta = 0.5$. φ is the time vector; $\varphi = 0.3$. According to Equations (4)–(11), it can be known that the weight of comprehensive time degree based on subjective and objective can be solved. According to Equation (12), the criterion weight based on improved intuitionistic fuzzy entropy can be obtained. Specific values can be seen from Table 6.

Table 5. Original evaluation criteria information matrix at the moment t_4.

	C_1	C_2	C_3	C_4	C_5
P_1	[0.5,0.2]	[0.6,0.4]	[0.3,0.4]	[0.3,0.5]	[0.5,0.3]
P_2	[0.3,0.6]	[0.3,0.6]	[0.3,0.6]	[0.5,0.4]	[0.4,0.5]
P_3	[0.3,0.3]	[0.6,0.2]	[0.5,0.4]	[0.1,0.6]	[0.2,0.6]
P_4	[0.2,0.5]	[0.3,0.5]	[0.3,0.6]	[0.2,0.5]	[0.3,0.6]
P_5	[0.5,0.4]	[0.5,0.2]	[0.4,0.5]	[0.3,0.5]	[0.3,0.5]
P_6	[0.3,0.5]	[0.3,0.5]	[0.6,0.3]	[0.5,0.1]	[0.5,0.2]
P_7	[0.5,0.4]	[0.4,0.5]	[0.3,0.5]	[0.3,0.6]	[0.3,0.6]

Table 6. Discrete time weight and criteria weight.

	$\lambda(t)$	$C(t_1)$	$C(t_2)$	$C(t_3)$	$C(t_4)$	$C(t_5)$
t_1	0.1109	0.2036	0.2018	0.182	0.2114	0.2013
t_2	0.1731	0.1698	0.2171	0.179	0.2006	0.2335
t_3	0.2211	0.1961	0.2011	0.202	0.1974	0.2034
t_4	0.4949	0.1761	0.2042	0.1839	0.2242	0.2117

Step 3: Calculate the comprehensive selection criteria information. According to Appendix A, the weighted IFNs' decision matrices of different periods are assembled by using dynamic intuitionistic fuzzy weighted geometric operators. These five criteria are combined into a set of criteria information of cooperative enterprise selection matrix of four periods, as shown in Table 7.

Table 7. Comprehensive selection criteria information.

	C_1	C_2	C_3	C_4	C_5
P_1	[0.0835,0.7664]	[0.1222,0.8458]	[0.0606,0.8541]	[0.0805,0.8553]	[0.0806,0.8293]
P_2	[0.0768,0.8880]	[0.0911,0.8373]	[0.0772,0.8694]	[0.1057,0.8104]	[0.1096,0.8244]
P_3	[0.0773,0.8164]	[0.1370,0.7547]	[0.1086,0.8428]	[0.0500,0.8788]	[0.0807,0.8573]
P_4	[0.0599,0.8657]	[0.1056,0.8262]	[0.0865,0.8757]	[0.0583,0.8811]	[0.0849,0.8767]
P_5	[0.1176,0.8326]	[0.1276,0.7872]	[0.0910,0.8812]	[0.0958,0.8157]	[0.1108,0.8111]
P_6	[0.0928,0.8573]	[0.0762,0.8663]	[0.1064,0.8402]	[0.1125,07410]	[0.0946,0.8066]
P_7	[0.1113,0.8405]	[0.0932,0.8585]	[0.0993,0.8368]	[0.0847,0.8883]	[0.0951,0.8707]

Step 4: Calculate cooperative enterprise prospect matrix. This study can make the enterprise decision-making more reasonable and effective. It helps PCEs to blindly avoid similar risks. Using the Appendix D of prospect value function, the prospect matrix is obtained, as shown in Table 8.

Table 8. Cooperative enterprise prospect matrix.

	C1	*C2*	*C3*	*C4*	*C5*
P1	−0.1989	−0.0813	−0.0998	0.0287	−0.0668
P2	0.0289	−0.0362	−0.0672	−0.1420	0.0000
P3	−0.1234	−0.1478	0.0057	0.0000	0.0308
P4	−0.0746	0.0000	0.0328	0.0113	0.0463
P5	0.0240	0.0357	0.0373	−0.1324	−0.0335
P6	0.0000	0.0366	0.0000	−0.2632	−0.0744
P7	0.3226	0.0302	−0.0272	0.0398	0.0416

Step 5: Use VIKOR and attribute weight method to calculate utility values, individual regret values, and values. Based on Appendices B and C, Equations (1)–(3) and combination weight method $j_k = (0.2118, 0.1948, 0.1647, 0.1922, 0.2365)$, this paper obtains the combination weight. VIKOR method and Equation (A18) were used to obtain positive ideal

points and negative ideal points of attributes. By using Equation (A19), group utility value S_i and individual regret value R_i are calculated. Take the compromise coefficient $\theta = 0.5$ and use Equation (A20) to calculate the value Q_i. Specific values are shown in Table 9.

Table 9. Utility values, individual regret values, and values.

	S_I	R_I	Q_{I1}	Q_{I2}	Q_I	Ranking
P_1	0.7297	0.2216	0.5000	0.4531	0.9531	1
P_2	0.5279	0.1256	0.3414	0.1512	0.4925	4
P_3	0.4695	0.1948	0.2955	0.3688	0.6642	3
P_4	0.2234	0.1613	0.1021	0.2635	0.3656	6
P_5	0.3878	0.1563	0.2313	0.2478	0.4791	5
P_6	0.6045	0.2365	0.4016	0.5000	0.9016	2
P_7	0.0935	0.0776	0.0000	0.0000	0.0000	7

Finally, the value of each potential partner in the construction project is determined as follows:

$$P_i = (P_1, P_2, P_3, P_4, P_5, P_6, P_7)$$
$$= (0.9531, 0.4925, 0.6642, 0.3656, 0.4791, 0.9016, 0.0000)$$

The seven potential partners were rated as worthy in order of priority $P_1 > P_6 > P_3 > P_2 > P_5 > P_4 > P_7$. Therefore, the joint venture investment partner of digital innovation activities of Tianfeng is determined as P_1. Based on the above evaluation and selection, the joint venture partner P_1 is the best joint venture partner of Tianfeng. In fact, P_1 has become a preferred co-venture partner. In addition, joint venture partner P_6 is recommended as a reserved venture partner.

Based on the case of Tianfeng's selection of joint venture investment partners in carrying out digital green and innovative activities, the above study indicates the selection process of joint venture investment partners from the perspective of digital green innovation customers. This process is also for the PCEs to carry out the digital green innovation process. The above analysis further verifies that the key influencing factors for PCEs to choose joint venture investment partners in digital green and innovative activities include compatible risk diversification, commitment to risk diversification, complementary accumulation of resources, overlapping accumulation of resources, and mutual trust degree. In addition, the time preference of cooperative enterprises also has an important impact on the digital green innovation activities of PCEs.

4.3.2. Discussion

(i) Managerial implications. This study has two important management implications for PCEs in the selection of joint investment partners. The practical management significance of this study is as follows:

This paper constructs a theoretical model of a joint venture capital network. PCEs and joint venture partners are two main bodies of digital green and innovative projects. The exchange of green knowledge and digital innovation technologies between construction firms and joint venture partners helps to promote business development and technological progress. In the process of knowledge and technology exchange, PCEs and joint venture partners gradually form a mutually beneficial symbiotic relationship. The two share more and more complementary resources on digital green innovation. Whether PCEs can choose appropriate joint venture partners is directly related to the development of mutualistic symbiosis. The theoretical model based on the joint venture capital network can be applied to the selection of partners in PCEs, which can make the decision more theoretical and scientific.

In this study, the logical relationship is integrated with the idea of six analysis methods. This study innovatively proposes a 3W1H-P research framework of joint venture capital. First, motivation affects partner selection, which, in turn, affects firm performance. PCEs choose joint venture partners based on risk diversification motivation to carry out digital green innovative projects to promote enterprise venture investment performance. Secondly, this study comprehensively analyzes the motivations, partner selection, and the impact on performance. The joint venture investment behavior of PCEs in carrying out digital green innovation projects is the process of joint venture investment partners to invest in PCEs under certain motivation. In this process, joint venture partners and PCEs will play against each other based on the principle of maximizing their own interests. Finally, the selection of joint venture partners by PCEs is a process of investment behavior, and its joint motivation, partner selection, and game behavior in the process of joint venture partners are bound to be affected by the situation of joint venture partners and PCEs. Based on the research framework of 3W1H-P, the research system is constructed in this study, which can meet the requirements of PCEs to select joint investment partners in the investment activities of digital green innovation projects. The evaluation criteria of research systems for enterprises to choose joint investment partners usually come from green innovation ability, resource accumulation, and the degree of overlap of the cooperation foundation. Green innovation capability is divided into compatible risk diversification and commitment risk diversification, including the compatible venture investment style, organizational culture, digital green innovation management team, investment in digital green innovation resources, social network capability, and risk investment willingness of senior managers. Resource accumulation can be divided into complementary accumulation resources and superposition accumulation resources, including technological complementarity, market complementarity, social network resource complementarity, financial risk investment ability, past cooperation, and good mutual trust between senior managers. The basis of cooperation is the mutual trust degree of both parties, including whether the cooperative enterprise has the possibility of long-term cooperation with the PCEs, the influence of the resources provided by the cooperative enterprise on the value of the PCEs, and the reputation of the cooperative enterprise in the prefabricated construction industry. For managers, the use of the 3W1H-P research framework and the newly built research system can enable PCEs to select joint investment partners in the development of digital, green, and innovative project investment activities, which is more efficient and accurate, thus reducing the management costs and promoting the efficient operation of enterprises.

(ii) Theoretical implications. This study is based on the case of Tianfeng's joint venture investment partner in digital green and innovative activities. This study first listed the time series set $t_k = (t_1, t_2, t_3, t_4,)$, attribute set $C_k = (C_1, C_2, C_3, C_4, C_5)$, alternative partner set $P_i = \{P_1, P_2, P_3, P_4, P_5, P_6, P_7\}$ in different periods, and the evaluation of indicators of seven alternative partners in four different periods. Secondly, this study used the combined time weight to solve the subjective and objective comprehensive time weight and obtained the criterion weight according to the improved intuitionistic fuzzy number entropy. Then, this study used dynamic intuitionistic fuzzy weighted geometric operators to assemble the weighted intuitionistic fuzzy decision matrices of different time periods and combined these five criteria into a set of criteria information of a cooperative enterprise selection matrix including four time periods. Furthermore, this study helps PCEs to blindly avoid similar risks, making decision-making more reasonable and effective. Using the formula of prospect value function, the prospect matrix is obtained. The combined weight set is obtained by using the combined weight method. The VIKOR method was adopted to obtain the positive ideal points and negative ideal points of attributes and calculate the group utility value S_i and individual regret value R_i and value Q_i. Finally, the evaluation value of partners is prioritized to obtain the best partner. The theoretical process can be applied to other PCEs in the process of choosing joint venture capital partners. In this way, enterprises have sufficient theoretical support when choosing partners and can produce more realistic and effective selection results.

5. Conclusions and Enlightenment

5.1. Conclusions

With the background of carbon peak and carbon neutrality, it is very necessary for the construction industry to carry out digital green and innovative activities. It has gradually become an inevitable trend for PCEs to adapt to the new era, create new models, and develop healthily and long-term by choosing joint investment partners in the development of digital green innovative project investment activities. First, in this study, a theoretical model for PCEs to select joint investment partners in digital green innovative project investment activities was constructed. Second, with the help of the idea of six analysis methods, this study innovatively proposed a research framework of joint venture capital 3W1H-P by integrating logical relations. Third, on this basis, the research system of selecting joint investment partners was constructed. Fourth, intuitionistic fuzzy set, intuitionistic fuzzy number aggregation operator, and intuitionistic fuzzy entropy were expounded. The combined theoretical knowledge of combined time weight, improved intuitionistic fuzzy number entropy, and the VIKOR method is proposed. This practice brings positive enlightenment to other PCEs when they choose joint investment partners to make decisions in the investment activities of digital green innovative projects.

The results are drawn as follows. This study constructed a theoretical model of PCEs selecting joint investment partners. This study proposed the research framework of 3W1H-P. This study constructed a research system for the selection of joint investment partners. The research system includes green innovation capacity indicators, cooperation basic indicators, resource accumulation indicators, etc. This study indicates that the joint venture investment network theoretical model, the joint venture investment 3W1H-P research framework, research system, and applied theory can enable Tianfeng to select the optimal partner. Further, this approach can be applied to the selection of joint investment partners by global PCEs in the development of digital green innovative project investment activities.

5.2. Implications

This study has important management implications. This study not only constructed a theoretical model in the joint venture investment network but also innovatively proposed a 3W1H-P research framework of joint venture investment by integrating logical relations with the idea of six analysis methods. On this basis, a research system for PCEs to select joint investment partners in the investment activities of digital green innovative projects was constructed. The theoretical model, research framework, and research system can be used to assist PCEs to select joint investment partners in the investment activities of digital green innovative projects. This study has important theoretical implications. In this study, intuitionistic fuzzy set, intuitionistic fuzzy number aggregation operator, intuitionistic fuzzy entropy, AHP, deviation maximization method, combinatorial attribute weight, and prospect theory were theoretically expounded, and the theoretical knowledge of combination time weight, improved intuitionistic fuzzy number entropy, and the VIKOR method was proposed.

5.3. Deficiencies and Future Prospects

There are still some limitations in this study that deserve further attention. Artificial intelligence (AI) technology is gradually applied to decision-making problems, and the combination of resource complementarity and AI plays an important role in future enlightenment. In addition, only one case study was conducted in this study, and future studies may include large sample sizes from many PCEs to verify the correctness of the theoretical models, frameworks, systems, and use of theoretical knowledge. PCEs can be classified according to the scale of R&D or enterprise size.

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Appendix A

Definition A1. *Let X be a non-empty-theoretic domain, and the intuitive fuzzy set on X be defined as* $\widetilde{A} = \left\{ \left(x, \mu_{\widetilde{A}}(x), v_{\widetilde{A}}(x)\right) \middle| x \in X \right\}$ *, where* $\mu_{\widetilde{A}}(x)$ *is the membership function of the element X for the set* $\widetilde{A}$*.* $v_{\widetilde{A}}(x)$ *is a non-membership function for the element x for the set* $\widetilde{A}$*.* $\mu_{\widetilde{A}}(x), v_{\widetilde{A}}(x)\, X \to [0,1]$ *relative to* $\forall_x \in X$ *,*$0 \leq \mu_{\widetilde{A}}(x) + v_{\widetilde{A}}(x) \leq 1$*.* $\beta_{\widetilde{A}}(x) = 1 - \mu_{\widetilde{A}}(x) - v_{\widetilde{A}}(x)$ *is called the intuitionistic ambiguity of the set* $\widetilde{A}$*,* $0 \leq \beta_{\widetilde{A}}(x) \leq 1$*. Intuitionistic fuzzy sets over a non-empty field X are collectively denoted as* $IFS(X)$*.* $\widetilde{\alpha} = (\mu, v)$ *is an intuitionistic fuzzy number (IFN).*

Definition A2. *Set* $\widetilde{\alpha}_j (j = 1, 2, \cdots, n)$ *as a group of IFNs; then:*

$IFWA(\widetilde{\alpha}_1, \widetilde{\alpha}_2, \cdots, \widetilde{\alpha}_n) = \omega_1\widetilde{\alpha}_1 \oplus \omega_2\widetilde{\alpha}_2 \oplus \cdots \oplus \omega_n\widetilde{\alpha}_n = \overset{n}{\underset{j=1}{\oplus}} \omega_j\widetilde{\alpha}_j$ *is called intuitionistic fuzzy weighted average operator, and its calculation formula is*

$$IFWA(\widetilde{\alpha}_1, \widetilde{\alpha}_2, \cdots, \widetilde{\alpha}_n) = \left(1 - \prod_{j=1}^{n} \left(1 - \mu_j\right)^{\omega_j}\right) \tag{A1}$$

Definition A3. *Set* $\widetilde{\alpha}_j (j = 1, 2, \cdots, n)$ *as a group of intuitionistic fuzzy numbers, and then* $IFWG(\widetilde{\alpha}_1, \widetilde{\alpha}_2, \cdots, \widetilde{\alpha}_n) = \widetilde{\alpha}_1{}^{\omega_1} \otimes \widetilde{\alpha}_2{}^{\omega_2} \otimes \cdots \otimes \widetilde{\alpha}_n{}^{\omega_n} = \overset{n}{\underset{j=1}{\otimes}} \widetilde{\alpha}_j{}^{\omega_j}$ *is called intuitionistic fuzzy weighted geometric operators, and its calculation formula is*

$$IFWG(\widetilde{\alpha}_1, \widetilde{\alpha}_2, \cdots, \widetilde{\alpha}_n) = \left(\prod_{j=1}^{n} \mu_j{}^{w_j}, 1 - \prod_{j=1}^{n} \left(1 - v_j\right)^{\omega_j}\right) \tag{A2}$$

Definition A4. *Let* $\widetilde{A} = \left\{ \left(\mu_{\widetilde{A}}(x_i), v_{\widetilde{A}}(x_i)\right) \middle| x_i \in X \right\}$ *and* $\widetilde{B} = \left\{ \left(\mu_{\widetilde{B}}(x_i), v_{\widetilde{B}}(x_i)\right) \middle| x_i \in X \right\}$ *be two intuitionistic fuzzy sets, and call function* $E : IFS(X) \to [0,1]$ *intuitionistic fuzzy entropy if it satisfies the following criteria.*

Criterion A1. $E\left(\widetilde{A}\right) = 0$ *if and only if* $E\left(\widetilde{A}\right) = 0$ *is a clear set for* $\forall x_i \in X$*; there is* $\forall x_i \in X v_{\widetilde{A}}(x_i) = 0$ *or*$\mu_{\widetilde{A}}(x_i) = 0$*,* $v_{\widetilde{A}}(x_i) = 1$*.*

Criterion A2. $E\left(\widetilde{A}\right) = 1$ *if and only if* $E\left(\widetilde{A}\right) = 1$; *there is* $\mu_{\widetilde{A}}(x_i) = v_{\widetilde{A}}(x_i)$.

Criterion A3. $E\left(\widetilde{A}\right) = E\left(\widetilde{A}^c\right)$.

Criterion A4. $E\left(\widetilde{A}\right) \le E\left(\widetilde{B}\right)$ *for* $\forall x_i \in X$. *When* $\mu_{\widetilde{B}}(x_i) \ge v_{\widetilde{B}}(x_i)$, *there are* $\mu_{\widetilde{A}}(x_i) \ge \mu_{\widetilde{B}}(x_i)$ *and* $v_{\widetilde{A}}(x_i) \le v_{\widetilde{B}}(x_i)$; *when* $\mu_{\widetilde{B}}(x_i) \le v_{\widetilde{B}}(x_i)$, *there are* $\mu_{\widetilde{A}}(x_i) \le \mu_{\widetilde{B}}(x_i)$ *and* $v_{\widetilde{A}}(x_i) \ge v_{\widetilde{B}}(x_i)$

Criterion A5. *For* $\forall x_i \in X$, *when* $\left|\mu_{\widetilde{A}}(x_i) - v_{\widetilde{A}}(x_i)\right| = \left|\mu_{\widetilde{B}}(x_i) - v_{\widetilde{B}}(x_i)\right|$ *and* $\beta_{\widetilde{A}}(x_i) < \beta_{\widetilde{B}}(x_i)$, *there is* $E\left(\widetilde{A}\right) < E\left(\widetilde{B}\right)$.

Appendix B

(i) Construct the comparative judgment matrix. Using AHP method, the comparative judgment matrix of digital green innovation development level evaluation index of PCEs is constructed as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & L & a_{1n} \\ a_{21} & a_{22} & a_{23} & L & a_{2n} \\ a_{31} & a_{32} & a_{33} & L & a_{3n} \\ M & M & M & M & M \\ a_{n1} & a_{n2} & a_{n3} & L & a_{nn} \end{bmatrix} = \{a_{ij}\} \tag{A3}$$

In the evaluation index system of digital green innovation of PCEs, a_{ij} is the importance of the $i-th$ index relative to the j index. $a_{ij} > 0$, and, obviously, $a_{ii} = 1$; $a_{ij} = {a_{ji}}^{-1}$; $(i = 1, 2, \cdots, n; j = 1, 2, \cdots, n)$. As for the value of a_{ij} in the comparative judgment matrix, saaty1–9 contrast scale is used in this paper to measure the comparison of importance among indicators. The contrast scale is shown in Table A1.

Table A1. Saaty's contrast ruler.

Contrast Scale	Implication
1	The evaluation index C_i has the same importance as the evaluation index C_j
3	The evaluation index C_i is slightly more important than the evaluation index C_j
5	The evaluation index C_i is significantly more important than the evaluation index C_j
7	The evaluation index C_i is strongly more important than the evaluation index C_j
9	The evaluation index C_i is absolutely more important than the evaluation index C_j
2, 4, 6, 8	The results of evaluation index C_i and evaluation index C_j are in the middle position
Count backwards	The importance comparison result of evaluation index Ci and evaluation index C_j is the reciprocal of evaluation index C_j and evaluation index C_i

(ii) Calculate the weight set and conduct consistency test.

The weight set is calculated by the weight judgment matrix of the development level evaluation index of digital green innovation of prefabricated building enterprises, and the consistency test is carried out.

Multiply the elements in each row of the comparison judgment matrix, namely:

$$M_i = \prod_{j=1}^{n} a_{ij},\ i = 1, 2, \cdots, n \tag{A4}$$

$$\overline{W_i} = \sqrt[n]{M_i},\ i = 1, 2, \cdots, n \tag{A5}$$

$$w_i = \frac{\overline{W_i}}{\sum\limits_{i=1}^{n} \overline{W_i}},\ i = 1, 2, \cdots, n \tag{A6}$$

where a_{ij} is the element in row i and column j of the weight comparison judgment matrix of the development level evaluation index of digital green innovation of PCEs. W_i is the weight of the first indicator to the upper indicator in the development level evaluation system of digitalization, greening, and innovation of PCEs. It is concluded that $W = (w_1, w_2, \cdots, w_n)$ is the relative importance of the next layer to the upper layer, that is, the weight value of the index of the next layer to the upper layer. Consistency check is as follows:

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \quad (A7)$$

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \quad (A8)$$

$$CR = \frac{CI}{RI} \quad (A9)$$

where $\lambda_{\max}$ is the largest characteristic root of the judgment matrix of the development level evaluation index of digital green innovation of PCEs. CI is the consistency index of the index weight comparison and judgment matrix in the digital, green, and innovative development level evaluation system of PCEs. In n, the larger the CI, the worse the consistency (and vice versa). Since CI is an error of randomness, it is compared to the stochastic consistency index RI. CR is the random consistency ratio of index weight comparison judgment matrix in the evaluation system of digital green innovation development level of prefabricated building enterprises. RI values are shown in Table A2.

Table A2. RI values table.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.96	1.12	1.24	1.32	1.41	1.45	1.49

The basis of consistency test is that, when $CR < 0.1$, it means that the judgment matrix of development level risk evaluation of digital green innovation of prefabricated building enterprises is consistent. Otherwise, it is necessary to readjust the judgment matrix to meet the requirements of $CR < 0.1$.

Appendix C

Under the condition that normalization and weight constraint principles are satisfied, $\text{dev}\left(b_{ij}, b_{kj}\right)$ is set to represent the deviation between partner b_i and other partners for indicator b_j. b_{ij} and b_{kj} are the j-th index value of the i-th and k-th partner, respectively. ω_j is the weight of the first evaluation index of j. The deviation maximization method was used to calculate its weight, and the objective function was calculated as follows:

$$\text{dev}(\omega_j) = \sum_{i=1}^{m} \sum_{k=1}^{n} \text{dev}\left(b_{ij}, b_{kj}\right)\omega_j \quad (A10)$$

The determination of index weight is based on the principle of maximizing the total deviation of all partner evaluation indexes, and the following linear programming model is established T. The result is as follows:

$$T : \text{lop}\begin{cases} \text{maxdev}(\omega) = \sum\limits_{j=1}^{q} \sum\limits_{i=1}^{m} \sum\limits_{k=1}^{m} \text{dev}\left(b_{ij}, b_{kj}\right)\omega_j \\ \text{s.t.} \sum\limits_{j=1}^{q} \omega_j^2 = 1, \omega_j \geq 0 \end{cases} \quad (A11)$$

It is solved using the Lagrangian function T. The result is as follows:

$$L(\omega_j, \xi) = \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{m} \text{dev}\left(b_{ij}, b_{kj}\right)\omega_j + \frac{1}{2}\xi\left(\sum_{j=1}^{n}\omega^2 - 1\right) \quad \text{(A12)}$$

The partial derivatives of ω_j and ξ were taken, respectively, to obtain the optimal solution ω^* of the model. The result is as follows:

$$\omega^* = \frac{\sum_{i=1}^{m}\sum_{j=1}^{q} \text{dev}\left(b_{ij}, b_{kj}\right)}{\sqrt{\sum_{j=1}^{q}\left[\sum_{i=1}^{m}\sum_{k=1}^{m} \text{dev}\left(b_{ij}, b_{kj}\right)\right]^2}} \quad \text{(A13)}$$

Norm-normalized ω_j is as follows:

$$\omega_j = \frac{\sum_{i=1}^{m}\sum_{k=1}^{m} \text{dev}\left(b_{ij}, b_{kj}\right)}{\sum_{j=1}^{q}\sum_{i=1}^{m}\sum_{k=1}^{m} \text{dev}\left(b_{ij}, b_{kj}\right)} \quad \text{(A14)}$$

Appendix D

If the candidate partner is odd, the median is used as the reference point. If it is an even number of alternative partners, the mean of the two middle fuzzy numbers is used as the reference point. Assume that the reference point of the criterion value of S_1 in the state of criterion c_1 is Y_{jh}, and the prospect value function can be determined based on the distance formula of the two fuzzy numbers and the comparison results:

$$v\left(y_{ijh}\right) = \begin{cases} \left[d\left(y_{ijh}, Y_{jh}\right)\right]^{\alpha} & y_{ijh} \geq Y_{jh} \\ -\lambda\left[d\left(y_{ijh}, Y_{jh}\right)\right]^{\beta} & y_{ijh} < Y_{jh} \end{cases} \quad \text{(A15)}$$

Among them, α, β is the risk attitude coefficient. $\alpha, \beta \in [0, 1]$. The higher the value, the more likely it is to take risks. When $\alpha = \beta = 1$, the decision-maker is regarded as risk neutral. Here, define $\alpha = \beta = 0.88$, λ as loss avoidance coefficient, and define $\lambda = 2.25$. Since the decision weight is closely related to the objective probability, the ratio of the weight of probability p to the deterministic weight is taken as the decision weight of gain and loss, which are, respectively:

$$\pi(p_j)\begin{cases} \pi^+(p_j) = p_j^{\gamma} / \left[p_j^{\gamma} + (1-p_j)^{\gamma}\right]^{1/\gamma} \\ \pi^-(p_j) = p_j^{\delta} / \left[p_j^{\delta} + (1-p_j)^{\delta}\right]^{1/\delta} \end{cases} \quad \text{(A16)}$$

Among them, γ is the risk–return attitude coefficient; δ is the risk–loss attitude coefficient, and $\gamma = 0.61$ and $\delta = 0.69$ are defined here. Then, the comprehensive prospect value is as follows:

$$v(a_{ij}) = \sum_{h=1, v(y_{ijh}) \geq 0}^{l} v\left(y_{ijh}\right)\pi^+(p_j) + \sum_{h=1, v(y_{ijh}) < 0}^{l} v\left(y_{ijh}\right)\pi^-(p_j) \quad \text{(A17)}$$

Appendix E

(i) Set f^+ as the positive ideal point of the attribute, f^- as the negative ideal point of the attribute; then:

$$\begin{aligned} f_j^+ &= \left\{ \max_i v(a_{i1}), \max_i v(a_{i2}), \cdots, \max_i v(a_{im}) \right\} \\ f_j^- &= \left\{ \min_i v(a_{i1}), \min_i v(a_{i2}), \cdots, \min_i v(a_{im}) \right\} \end{aligned} \quad \text{(A18)}$$

(ii) Calculate group utility value S_i and individual regret value R_i; then:

$$S_i = \sum_{j=1}^{l} w_j \left(\frac{f_j^+ - v(a_{ij})}{f_j^+ - f_j^-} \right),\ R_i = \max_j \left\{ w_j \left(\frac{f_j^+ - v(a_{ij})}{f_j^+ - f_j^-} \right) \right\} \quad \text{(A19)}$$

(iii) The value is calculated by the following formula:

$$Q_i = \theta \times \frac{S_i - \min_i S_i}{\max_i S_i - \min_i S_i} + (1-\theta) \frac{R_i - \min_i R_i}{\max_i R_i - \min_i R_i} \quad \text{(A20)}$$

where θ is the decision-making mechanism coefficient.

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buildings

Article

A Technical Proposal for the Implementation of Transfer of Development Rights (TDR) on Preserved Historic Buildings in Turkey

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Abstract: Buildings that have cultural and historical significance are very important elements of our living spaces and they must be protected by public authorities. However, the preservation of these buildings prevents their landowners from using their development rights and causes economic losses. If those losses are not compensated, it results in social injustice. Leaving this problem unsolved makes historic buildings a target for arson, facilitates the destruction of unregistered (unlisted) historic buildings for redevelopment with a higher density. The traditional methods, namely expropriation and property exchange, generally fail to compensate those development losses. However, the method of transfer of development rights (TDR) can be a good option for this task in Turkey as well. Although there have been some important legislative actions, an "implementing regulation" could not be enacted so far. In this study, we attempt to develop a step-by-step methodology for the implementation of a TDR program from the perspective of land management. The methodology introduced in this paper is also tested for its validity by interviewing 18 professionals from related sectors and all the interviewees agreed on them with minor suggestions. The results derived from this study could benefit not only property owners, but also overall preservation efforts in the country.

Keywords: transfer of development rights (TDR); land registry; land management; preservation of buildings; historic buildings; development restriction; development loss; floor area; Turkey

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1. Introduction

Buildings that have cultural and historical significance are very essential elements of our living spaces. Among many other benefits, they add value to urban development with aesthetics, and they also connect us to our past and provide us with a sense of communal or national continuity [1,2]. However, these valuable buildings are usually under the threat of demolition to be redeveloped to a higher density for an economic return, i.e., for development gain. This is not a surprise in the development business where profits can be extremely high. Therefore, cultural heritage must be protected by public authorities for the sake of public interest, instead of abandoning them to their fate (Figure 1).

In Turkey, historic buildings are registered (or listed) and preserved by the hands of the State [3]. The preservation process of cultural heritage in the country can be considered successful with its powerful legislation and uncompromising preservation boards. However, if we look at the situation from the perspective of the owners of these buildings, it is a problematic issue in Turkey and also worldwide [4]. Because in the current practice, after the decision of preservation, the property rights of landowners are restricted by public authorities without any compensation.

To better understand the current building preservation processes in Turkey, the situation can be explained in an example neighborhood. According to the development plan of this imaginary neighborhood, there is a maximum two-story building limitation. It means that the owner of a land parcel in this area can build up to a maximum of two-story.

However, one of the buildings in the neighborhood is registered as "historic landmark" by the Preservation Board and it is now under the protection of the law. The owner of this property can no longer demolish or rebuild it. Even minor improvements, such as a simple roof repair, must be asked for permission from the Preservation Board [3]. In this neighborhood, all the buildings, including the historic building, are two-story. However, the problems start when the municipality council changes the two-story density rule to three-story. This means that the landowners are now allowed to build up to three-story on their lots (Figure 2).

Figure 1. A deteriorated historic building in Turkey.

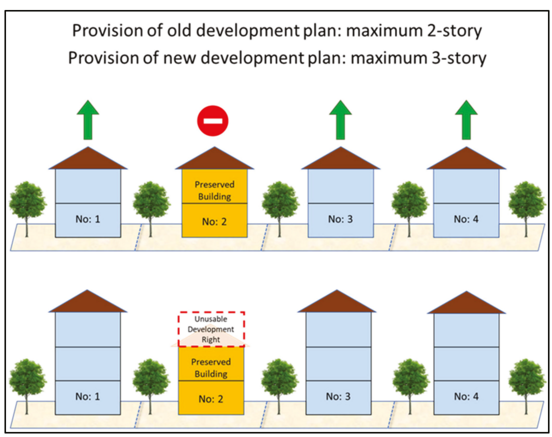

Figure 2. Unequal effects of restriction.

Now, all the landowners can benefit from this density increase by constructing larger buildings and enjoy the large profit stemming from the development gain, except the owner of the restricted building. This is obviously unfair. If there is no compensation for this loss, the landowner of the historic building is subject to injustice [5,6]. Unfortunately, conventional compensation methods generally do not work in Turkey [7–10]. This compensation problem must be solved, because firstly the current practice gives an inconvenient message that the landowners of these buildings are punished by the public authorities for not demolishing their buildings earlier than the preservation decision of the Boards. Secondly, the owners of unregistered (or unlisted) heritage buildings that are not restricted yet should hurry up to demolish them before Preservation Boards restrict them. In addition to it, because of such economic reasons, those buildings can also be neglected by their owners and be left for deterioration until they are demolished themselves or they are subject to incidents of arson with the hope that the property may be taken out of the list and become unrestricted again. Leaving this problem unsolved obviously damages the whole preservation effort.

As a candidate to solve the problem and end this injustice to support the overall preservation attempts, the transfer of development rights (TDR) method is analyzed in this article which has been used in many different countries for a few decades [11–14]. A technical and procedural methodology is proposed in the following sections for the implementation of TDR according to the specifications in Turkey, and it can be an example for other countries worldwide that have similar land management problems.

The paper is structured as follows: After the introduction section, the overall TDR concept and its background is explained by giving examples of economic losses of restricted property owners in Alanya, Antalya, Turkey in Section 2. Insufficient compensation methods of today which do not solve the problem are explained in Section 3. An introduction of the method of transfer of development rights (TDR) with a comprehensive literature review are given in Section 4. Previously enacted laws and regulations about TDR in Turkey that still lack an "implementation regulation" are explained in Section 5. The proposed implementation methodology for TDR is given in Section 6 with detailed technical steps. The interviews with professionals from relevant sectors regarding the applicability of the methodology in Turkey are discussed in Section 7, and finally the discussions and conclusions are provided in Section 8.

2. Examples of Economic Loss Due to Uncompensated Restrictions

In order to picture the contradiction, the development and economic loss of some real-life example properties in Alanya County of Antalya Province in Turkey are shown below.

Example 1:

Area: Saray Neighborhood (Coordinates: 36°32′55.8″ N; 31°59′33.5″ E) (Figure 3).

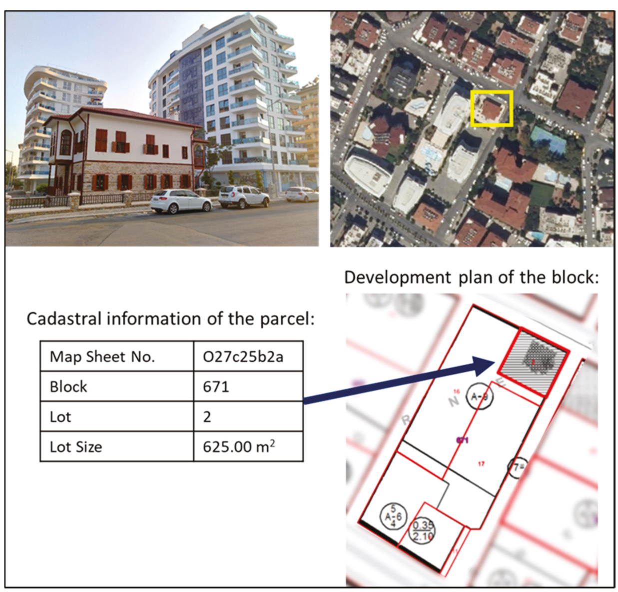

Figure 3. Example of a historic private residence in Alanya. Top left: A side-view of the building (June 2019); top right: A satellite image of the neighborhood; bottom right: development plan of the block; bottom left: cadastral information of the parcel. (For further information, please see Data Availability Statement section).

The historic building is located in the parcel No. 671/2 (meaning Lot 2 of Block 671) with the size of 625.00 m^2 in the northeastern part of the block (Figure 3). The building is listed as "cultural heritage" by the Preservation Board and the preservation decision was applied on the development plan by marking the lot with parallel lines. With this decision, the building cannot be demolished, and the lot cannot be redeveloped.

In order to calculate the economic loss caused by the restriction decision, the development rights of the other lots in the same block should be taken into account which the owner of the restricted land cannot use equally. According to the development plan, lots on the southern part have five-story building permission, with a floor-area-ratio (FAR) of "2.10". It means that the owner of the parcel can construct a building with a density calculated by multiplying the size of the parcel by "2.10". If there was no restriction, this "2.10" FAR would normally be applied to the restricted lot as well.

Therefore, if we copy this development rule (five-story, FAR: 2.10) for the parcel of the historic building, the parcel would normally have had 625.00 m^2 $\times$ 2.10 $\approx$ 1313 m^2 (results are generally rounded for simplicity in this paper) total building density in a five-story building. However, the total floor area used in the current historic building and its height are fewer than those. The historic building is a three-story building. To calculate the current total floor area of this building, the basement coverage of the building is measured from a satellite image and multiplied by the number of floors, which is three in this example. It should be noted that the total floor area of the historic building can be determined much more precisely, however this study focuses on the TDR method, rather than determining the most precise calculation of the total floor area of a building. Therefore, a rounded number is sufficient for the purpose of this research. According to this, the total floor area of the building is ~495 m^2. Now, if this current usage (~495 m^2) is subtracted from the development potential of the lot as calculated above (~1313 m^2), we can find the unusable/restricted/blocked floor area on the lot: the landowner is deprived of approximately 1313 − 495 = 818 m^2 of floor area.

In order to calculate the economic value of this unusable floor area of 818 m^2, an internet search for the sales prices of similar real estate in the neighborhood was undertaken. The prices per m^2 (Turkish Liras/m^2) in the area start from 5000 up to 14,000 Turkish Liras (TL) according to their luxurious features (December 2020 conditions). If we approach it extremely moderately and choose the bottom value of only 5000 TL, the market value of the restricted floor area of the lot would be 818 m^2 $\times$ 5000 TL = 4,090,000 TL. However, this figure is not the direct economic loss of the landowner, it should be adjusted by subtracting the construction costs. If we calculate the construction cost of a building of 818 m^2 according to the 2020 average construction costs table published by the Ministry of Environment and Urbanization [15] which is 1450 TL/m^2 for residential buildings, we reach approximately 818 m^2 $\times$ 1450 TL = 1,186,100 TL for the building. When we subtract it from the market value that we calculated earlier, 4,090,000 TL − 1,186,100 TL = 2,903,900 TL (~$380,590; USD/TL: 7.63) is found. This means that the owner of the historic building is deprived of almost 3 million Turkish Liras. An overview of these calculations can be seen in Table 1. This is a very large amount of money for a municipality to be paid for only one landowner. In addition, there are many of them.

Table 1. Overview of the calculations of Example 1.

(a) Parcel Size		625.00	m^2
(b) FAR		2.10	
(c) Total Development Right (a $\times$ b)	Approx.	1313	m^2
(d) Current Total Floor Area of Hist. Building	Approx.	495	m^2
(e) Restricted Floor Area (c − d)	Approx.	818	m^2
(f) Average Market Value per m^2	Approx.	5000	TL/m^2

Table 1. *Cont.*

(g) Market Value of Restr. Floor Area (e × f)	Approx.	4,090,000	TL
(h) 2020 Average Construction Cost (ACC)		1450	TL/m^2
(i) ACC of Restricted Floor Area (e × h)	Approx.	1,186,100	TL
(j) Owners' Total Economic Loss (g − i)		2,903,900	TL
(l) (j) in US Dollars (US/TL: 7.63)	Approx.	380,590	USD

Example 2:
Area: Kadıpaşa Neighborhood (Coordinates: 36°32′54.8″ N; 31°59′40.5″ E) (Figure 4).

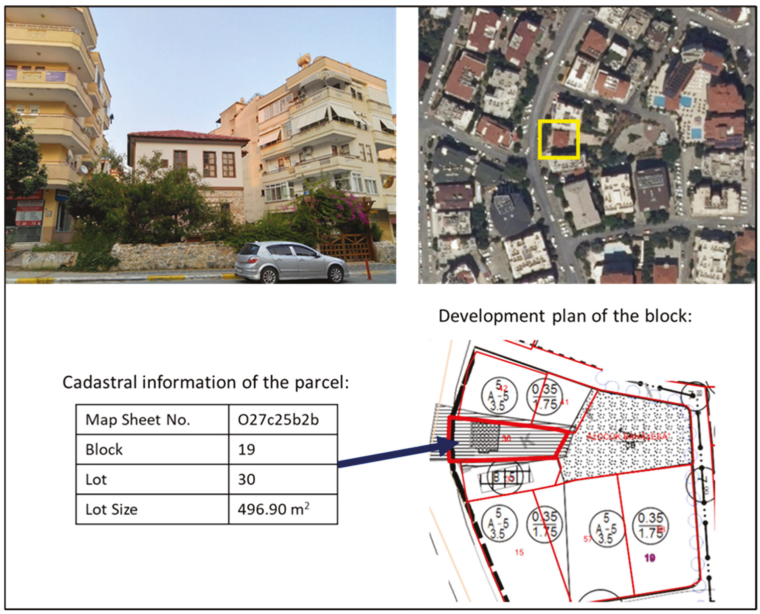

Figure 4. The second example of a historic building. Private residence (photographed in June 2019).

This historic building is located on the parcel No. 19/30. The construction rule for the block is maximum five-story and FAR: "1.75". The size of the restricted lot is 496.90 m^2 and marked by parallel lines in the development plan (Figure 4). The current historic building has approximately 184 m^2 total floor area (determined as explained in the first example above). If it was not restricted, the total development right (total floor area) of the parcel would be 496.90 m^2 × 1.75 ≈ 870 m^2. Therefore, the landowner is not allowed to use approximately 870 − 184 m^2 = 686 m^2 of floor area on the lot.

According to the real estate sales prices in the area, the market value is minimum 5000 TL/m^2. If we accept this minimum number again, the market value of the restricted floor area of 686 m^2 is worth 686 m^2 × 5000 TL = 3,430,000 TL. The construction cost of the specified floor area would be around 686 m^2 × 1450 TL/m^2 = 994,700 TL. If this number is subtracted from the market value, the total economic loss of the landowner is approximately 3,430,000 TL − 994,700 TL = 2,435,300 TL (~$319,174; USD/TL: 7.63), listed in Table 2.

Table 2. Overview of the calculations of Example 2.

(a) Parcel Size		496.90	m^2
(b) FAR		1.75	
(c) Total Development Right (a × b)	Approx.	870	m^2
(d) Current Total Floor Area of Hist. Building	Approx.	184	m^2
(e) Restricted Floor Area (c − d)	Approx.	686	m^2
(f) Average Market Value per m^2	Approx.	5000	TL/m^2
(g) Market Value of Restr. Floor Area (e × f)	Approx.	3,430,000	TL
(h) 2020 Average Construction Cost (ACC)		1450	TL/m^2
(i) ACC of Restricted Floor Area (e × h)	Approx.	994,700	TL
(j) Owners' Total Economic Loss (g − i)		2,435,300	TL
(l) (j) In US Dollars (US/TL: 7.63)	Approx.	319,174	USD

Example 3:
Area: Şekerhane Neighborhood (Coordinates: 36°32′47.0″ N; 32°00′14.9″ E) (Figure 5).

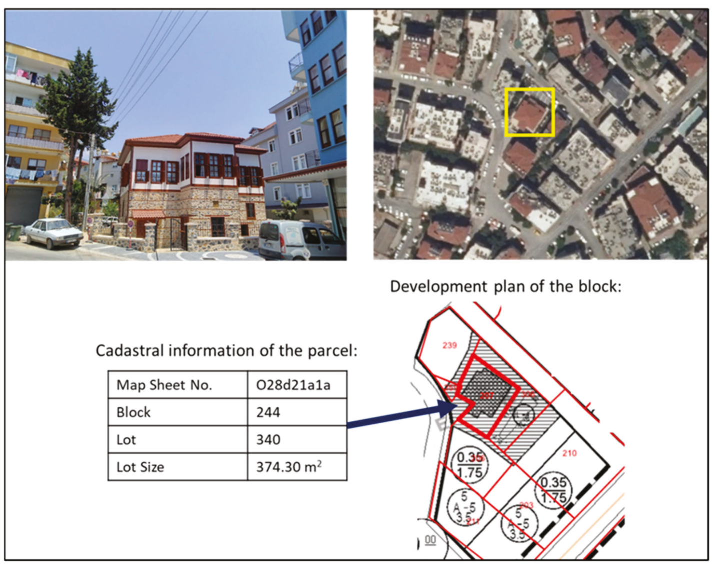

Figure 5. The third example of historic buildings. Private residence (photographed in July 2019).

The historic building is located on the parcel No. 244/340 and the size of the parcel is 374.30 m^2. The current building's total floor area is around 525 m^2. The FAR value for the block is "1.75" in the development plan (Figure 5). If there was no restriction, the lot would have 374.30 m^2 × 1.75 ≈ 655 m^2 total floor area potential. The restricted floor area of the landowner is approximately 655 m^2 − 525 m^2 = 130 m^2. The market value of a m^2 in the area is accepted as 5000 TL/m^2 like in the previous examples. The total market value of the unused floor area would be 130 m^2 × 5000 TL = 650,000 TL. The construction cost of the unusable floor area would be 188,500 TL (130 m^2 × 1450 TL/m^2). If we subtract it from the market value of the unused floor area, 650,000 TL − 188,500 = 461,500 TL (~$60,485; USD/TL: 7.63) is the total economic loss of the owner of the preserved building (Table 3). More examples can also be given; however, the above examples are sufficient to understand the overall situation.

Table 3. Overview of the calculations of Example 3.

(a) Parcel Size		374.30	m^2
(b) FAR		1.75	
(c) Total Development Right (a × b)	Approx.	655	m^2
(d) Current Total Floor Area of Hist. Building	Approx.	525	m^2
(e) Restricted Floor Area (c − d)	Approx.	130	m^2
(f) Average Market Value per m^2	Approx.	5000	TL/m^2
(g) Market Value of Restr. Floor Area (e × f)	Approx.	650,000	TL
(h) 2020 Average Construction Cost (ACC)		1450	TL/m^2
(i) ACC of Restricted Floor Area (e × h)	Approx.	188,500	TL
(j) Owners' Total Economic Loss (g − i)		461,500	TL
(l) (j) In US Dollars (US/TL: 7.63)	Approx.	60,485	USD

3. Insufficient Traditional Compensation Methods for the Economic Loss of Landowners

There are regular compensation methods for the economic loss of the landowners, namely *expropriation* and *property exchange*. Expropriation is a well-known and common approach. Basically, the real estate is purchased by a public authority by paying the market value of it [16]. However, since real estate prices are very expensive, the expropriation method is often out of question. In addition, it can be considered that the expropriation method may be used for only the restricted part, instead of buying the whole real estate. This way, the parcel and the building stay with the original owner, and the authority pays only for the economic loss arising because of the restriction (as calculated for the three buildings in the previous section). However, paying only for the restricted development rights of those buildings is very expensive as well. Even with the extreme minimization of the market values in this paper, the total economic loss for only these three examples alone is 5,800,700 TL (~$760,249; USD/TL: 7.63) in 2020 conditions. Since there are hundreds of restricted historic and cultural buildings in the town, the money to be paid is so large that public finances of any authority will have a problem at handling such an expense.

In addition to this, expropriation is the method of a public authority to purchase a real estate to "use" for public interest. In our case, if only the economic losses of the landowners are paid instead of purchasing the whole estate, that large amount of money would be used for something that does not provide a direct benefit for the public. In other words, those properties would not be owned by the public and could not be used as a park, green area, public facility, or something else. The money would be paid for something "invisible". We must admit that it is a politically discouraging situation. In fact, mayors or other decision-makers would like to use their limited annual budgets for the things that can be directly "used" by the citizens, rather than something made "out of thin air". Therefore, it is understandable that it is difficult for administrations worldwide to use the expropriation method for the restriction of development rights. Public finances usually cannot afford it. Even if they can afford, that money can be used in alternative ways that are more necessary and appreciated by citizens, such as roads, water systems, parks, or other social or physical infrastructure that people can directly benefit from. Spending limited public money on invisible "air rights" and complaining about the broken sewage system of the city would be ironic.

The second method is the property exchange. Basically, the State swaps unused public land for a private property. In this way the public authority does not pay any cash money. However, the downside is that it has the risk of impoverishing public authorities in terms of owning public lands because the lands that they exchange must be equal in value. Remembering that state lands are generally outside city centers and in rural areas, those lands are almost always cheaper than the urban lands. In order to reach the value of the urban lands, larger and larger sizes of rural lands must be allocated for the exchange. It can eventually cause the State to lose very large amounts of land. Therefore, this method is also ineffective in most cases. *Land readjustment* (LR) [7,17] could also be counted here. However, LR programs can be useful in vacant lands such as restricted archeological sites. With LR, the landowner can be freed from the restriction by shifting the landownership to a close-by unrestricted non-archeological area, and then the restricted archeological parcel can be transformed into a public area accordingly. However, LR cannot be used on restricted parcels with preserved buildings because buildings physically cannot be moved to somewhere else and the ownership of building and the ownership of the land beneath cannot be separated, principally. The building and the land parcel are strongly tied to each other.

However, there is a third option. It has been practiced in various countries, stood the test of time and can be a good option for Turkey as well: *transfer of development rights* (TDR, or in Turkish *imar hakkı transferi* or *imar hakkı aktarımı*). It is widely accepted that the TDR method has never been used in Turkey, or at least a recorded transfer case could not be found so far [18–22]. Therefore, this paper attempts to offer a step-by-step implementation procedure for TDR in Turkey in compliance with the legal, organizational, professional, and traditional specifications of the country.

From a wider perspective, there are many different areas to use the TDR method such as reducing urban sprawl [23,24], urban regeneration [25], preservation of agricultural areas [26,27], natural areas [28], historic sites and built heritage [18,29,30] which are all causing development restrictions for different reasons. However, the effort to evaluate TDR in all these areas in a single paper would eventually complicate the understanding. It is true that the TDR method is required in all the above-mentioned areas, however if it is a new approach in a country, which is the case in Turkey, it can be a better idea to evaluate it on a less complicated parcel-based field (a similar approach was taken in the US, New York's early TDR programs were implemented in small and defined areas [29] before going for larger areas). Thus, the preservation of historic buildings (parcel-based rather than area-based) is preferred as the case study in this paper. This choice is based on the following facts that, firstly, the economic and physical loss can easily be seen and calculable in this field. Secondly, we deal directly with the parcels one-by-one, rather than dealing with multiple parcels in large areas. Thirdly, the problem is very prevalent. A solution, which is the TDR method proposed in this study, can immediately find its place in the everyday life of people. In addition, it is probably not a coincidence that the modern TDR method was first introduced for the preservation of "landmark buildings" in the US [11,29].

4. Transfer of Development Rights (TDR) and the Literature Review

A "development right" can theoretically be explained as a government's license to build on a land parcel (governmental grant); or it is the government's restriction on a pre-existing right to develop a land (allowable density). Either way, it is simply the "right to build" on a land parcel [31]. Pizor (1986) explains it in another way as the difference between the existing use of a parcel and its "potential use". The latter explanation provides practical implications as it facilitates the idea of separating the land and its use in the TDR concept.

Development rights, by nature, provide a large amount of economic gain to their owners. Therefore, they should be implemented equally among landowners. For example, giving a three-story building permission for a parcel and completely forbidding building on the adjacent parcel without any reason will cause economic imbalance and results in social injustice. Normally, equal development potential should be allocated to everyone in the same zone by municipalities so then the development gain can be equalized [13]. However, some real estate owners are prevented by public authorities from using their development rights because of preservation decisions and the problems start right there. If there is no compensation for the loss (financially, or floor-area-wise), it results in unfairness. As explained in the previous section, the traditional compensation methods do not work properly. In order to solve this problem, the method of *transfer of development rights* (TDR, also called as *transferable development rights*) can be used. With TDR, the landowners of restricted parcels ("sending parcels") are allowed to transfer their unused/blocked/frozen development rights to be used on other land parcels ("receiving parcels") [4]. The sending and receiving parcels both can be owned by the same person or can be owned by different persons as well. It means that the restricted landowners can also sell their unused development rights to someone else [29,32]. When a development right is transferred on another parcel, the transferred amount is added on top of the original development right of the receiving parcel as a bonus density [33]. For example, if the receiving parcel normally has three-story building permission, an incoming TDR of one-story is added on top of it and make it a four-story building permission (Figure 6).

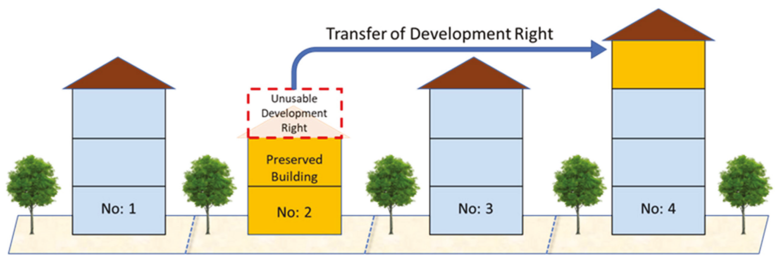

Figure 6. Transfer of restricted floor area onto another parcel (from building No: 2 to building No: 4).

It is widely accepted that TDR was first introduced in the United States and although it can be traced back to as early as 1916, a complete TDR process as understood today was first formalized in the 1960s for the preservation of historic buildings in New York City [13,29,34,35], which is in compliance with the title of this paper. Since then, together with the usage in different fields such as the preservation of agricultural lands and natural areas, large areas of land have been preserved in the US through TDR programs [11,36].

The US is not the only country where TDR has been implemented. The concept was also imported and used by other countries for various needs such as the creation of public service areas, urban regeneration and preservation of natural areas in Italy [13,37], reduction of urban growth in Germany [38], protection of agricultural landscape and forest expansion in the Netherlands [39,40], striking a balance between agricultural lands and urban development in China [5,6,41,42], and more [28,43].

In the study by Aliefendioğlu et al., (2017), the authors emphasize that conventional compensation methods do not work and they propose the TDR method for the depopulation of an area under disaster risk in Van City in Turkey. The paper analyzes the TDR method according to the real estate values in the area. Guzle et al., (2020) analyze the TDR method in a large preservation area (248 hectare) in the center of Izmir City in Turkey and examined a potential receiving area to make the transfers to. However, in our paper, TDR is analyzed for the conservation of parcel-based historic buildings, rather than large preservation sites. The authors think that it can be the starting point to implement TDR in a country because of pragmatic reasons, such that they can function as testing laboratories. It can be much easier to handle the processes in parcel-based programs; easier to spot, stop and correct mistakes and errors very locally without the risk of losing control and causing larger damages; on the other hand, successful applications can easily be transferred and employed in other programs and fields, such as in urban regeneration projects which is also a hot topic in the country [44].

When a restricted development right will be transferred, some valid concerns arise. One of the important questions is "where will the receiving area be?". Is it okay to transfer the development right to anywhere in the city, or should there be a specific transfer zone? Needless to say, the receiving area must have an infrastructural capacity for the incoming density and urban aesthetics should be cared for. Therefore, transferring "from where to where" is a valid question. A major principle is that the "sending area" and "receiving area" should be socio-economically compliant as much as possible. From this point of view, it is acceptable that the best fitting area for the sending area is the area itself. This means that it can be economically equal and environmentally logical to use the blocked development right in the same neighborhood. The development right of the restricted real estate can be transferred to a close-by parcel. It will not only equalize the prices and avoid dramatic value differences between the zones, but also the neighborhood will "consume" its own development potential. The other advantage is that if the right is used in the same neighborhood, the transfer can be made by the exact floor area. For example, if the landowner's blocked floor area is 200 m^2, this figure can directly be transferred onto another lot in the same neighborhood and be used there. It can avoid the complication of deciding where the receiving area should be and save a lot of time and effort for the authorities.

On the other hand, if the transfer needs to be made to another neighborhood/zone, then the economic equalization of the values will be required. Real estate appraisals will be needed for the "sending" and "receiving" areas. If we use the example of 200 m^2 floor area as mentioned above, and the market value in the "sending area" is, for example, 5000 TL/m^2, the economic value of the development right is 200 $m^2 \times$ 5000 TL = 1,000,000 TL. This way, the floor area in the "sending area" is turned into an economic value. Then, the average market value per square meter of the "receiving area" will also be appraised, for example it is 10,000 TL/m^2. The calculated "1,000,000 TL" in the "sending area" will be divided by this number, and the equivalent floor area in the "receiving area" is found as: 1,000,000 TL $\div$ 10,000 TL/m^2 = 100 m^2. This means that, the landowner's restricted 200 m^2 development right in the "sending area" will be economically equal to 100 m^2 development right in the "receiving area". The same mathematical approach is applied for the opposite scenario which is the sending area is more expensive than the receiving area. This way the transfer will not enrich or impoverish the landowner and the complaints will be minimized.

5. Legal Background of TDR in Turkey

If we look at the legal background of TDR in Turkey, there are few yet important legal arrangements in different laws in vague terms. Such as in the Article No.13 (2)a of implementing regulation of *Renewal of the Areas under Disaster Risk Act* (Implementation Regulation of 6306 (6306 Sayılı Kanunun Uygulama Yönetmeliği, Resmî Gazete Tarih: 15 December 2012, Sayı: 28498)) *No. 6306*, stating that "the administration can pay its debt to a person in cash, or by giving a vacant public land, or by transferring the development right to somewhere else"; in the Article No. 11 (1)d of the law of establishment of the Ministry of Environment and Urbanization (Çevre ve Şehircilik Bakanlığının Teşkilat ve Görevleri Hakkında Kanun Hükmünde Kararname, Resmî Gazete, Tarih: 4 July 2011, Sayı: 27984 Mükerrer) No. 644, it says "the Ministry is authorized to transfer development rights"; in the Temporary Article No. 6 of the *Expropriation Act* (Kamulaştırma Kanunu, Resmi Gazete, Tarih: 8 November 1983, Sayı: 18215) *No. 2942* "agreements can be made by property exchange, . . . , by permission for using the development right on somewhere else, . . . ". These are all vague statements and there is no explanation of how to do it. In addition, no information has been found in the literature or elsewhere about if they have ever been implemented so far.

Another law that outlines a better TDR concept and provides more technical information than the previously mentioned ones is an article that was enacted in 2004 in the *Protection of Natural and Cultural Assets Act* (Kültür ve Tabiat Varlıklarını Koruma Kanunu, Resmî Gazete, Tarih: 23 July 1983, Sayı: 18113) *No. 2863*, *Article 17*(*c*). This article clearly permits local authorities to implement TDR programs in case of development restrictions on properties because of preservation decisions, which is exactly in compliance with the purpose of this paper. However still, the article finalizes by a clause stating that the implementation of TDR can be made in terms of the "implementing regulation". However, this regulation has never been enacted. Therefore, in terms of *Act No. 2863*, it can be said that TDR has never been used in Turkey, or at least no official report or no information in the literature has been found so far [9,18–22]. Interestingly, it has been 17 years since the enactment of this TDR law, however no progress has been made in this regard. This might be mainly because people are unsure how to implement it technically. Therefore, in this paper, the step-by-step procedures are introduced in compliance with the institutional, professional, traditional, and legal preferences in the country, which is hoped to pave the way for the preparation of the first "implementing regulation" of TDR in Turkey.

6. Proposed TDR Methodology to Be Used in Turkey

The proposed TDR procedures can be exemplified in a scenario analysis as follows. According to it, the landowner is prevented from using 200 m^2 floor-area because of the restriction. The overall procedures are explained below step by step (Figure 7).

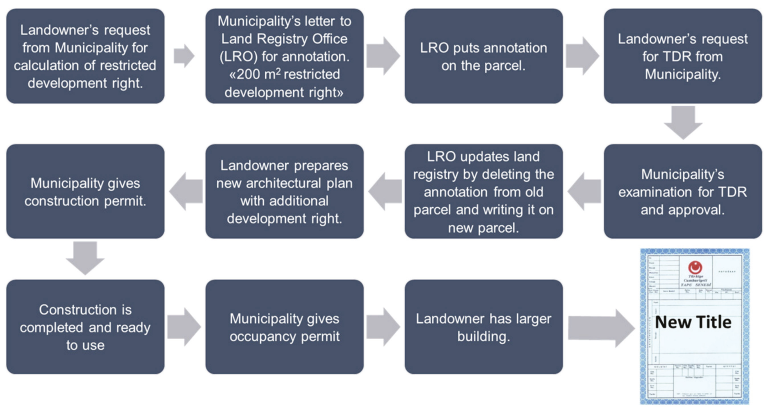

Figure 7. The overview of the proposed TDR process.

Step 1:

In order to talk about the transfer of a development right, first of all, it must be "recognized" by an authority that there is actually a development right which is blocked by a public decision without any compensation. Without it, this subject can only be an abstract philosophical discussion. The address for this recognition can be the municipalities (or local authorities). Because the municipality is the authority which handles all development issues. The municipality prepares development plans, accepts or refuses development requests, or changes any development decisions that were enacted earlier. If the municipality legally has full-control over the development subject, it should be the address to apply for TDR as well.

To obtain this recognition, the owner of the historic building will apply to the municipality that there is a restricted development right because of the preservation decision and there is an uncompensated development loss because of it. The owner applies to the municipality with a petition demanding technical research on how much floor area is unusable due to the preservation. The municipality then analyzes the application and calculates the development loss of the applicant. However, it is not enough. This information should be recorded somewhere, and the correct place to record this information is the title of the real estate in the land registry office. Therefore, in the same petition, the applicant also asks from the municipality to send the calculated amount of development loss (200 m^2 in our example) to the local land registry office to put an annotation on the title of the parcel. This way, the unused development right will automatically be secured and recognized by the State (Figure 8).

Date: …/…/…..

PETITION TO THE MUNICIPALITY OF …

I am the owner of the land parcel No. 101/5 in Saray Neighborhood. The development plan in my neighborhood permits a 4-story building. However, the current 2-story building on my parcel is decided to be registered as "historic and cultural property" and restricted by the Preservation Board, therefore I am not allowed to redevelop my lot to have a 4-story building. Therefore, I do have a loss of development right because of this preservation decision.

I hereby apply to request a technical investigation to calculate how many square meters of floor area that I am deprived of due to the restriction, and I also kindly ask you to send this information to the Directory of Land Registry to put an annotation on the title of my land parcel.

Name SURNAME
Signature

Figure 8. Petition from the landowner to the municipality for the recognition and registration of the unusable development right on land registry.

Step 2:

The municipality receives the petition, and the relevant department investigates the request and calculates the exact square meter of the restricted development right of the petitioner. After finding the number, this information is sent by the municipality to the local land registry office to put the annotation on the title accordingly (Figure 9).

MUNICIPALITY OF …

Department of Planning and Development

Subject: Putting annotation on the parcel No.101/5 for restricted development right. Date: …/…/….

TO THE DIRECTORATE OF LAND REGISTRY

Context: The petition of "Name SURNAME".

According to the development plan, the parcel No. 101/5 in Saray Neighborhood normally would have maximum of 400 m^2 building floor area (FAR:1.0, the size of the parcel: 400 m^2; 1.0 × 400 = 400 m^2). However, currently there is a preserved 2-story historic building which has 200 m^2 total floor area. Therefore, the landowner is not allowed to use 400 m^2 – 200 m^2 = 200 m^2 floor area due to the restriction.

I hereby request from you to put an annotation on the title registry of the above mentioned land parcel that "there is 200 m^2 restricted/unused development right because of the preservation decision".

Mayor
Signature

Figure 9. Letter from municipality to land registry for annotation.

Step 3:

When the official letter from the municipality arrives to the local land registry office, the registry personnel put the annotation on the title of the property in the land registry book. Even though today annotations are only recorded electronically on the *Land Registry and Cadaster Information System* (TAKBIS) since 2015 in Turkey [45,46], for a better read and simplicity, the classic book registry method is showed in the figures in this paper (Figure 10).

KÜTÜĞÜ (Land Registry)		
ULÜN NİTELİĞİ	BEYANLAR (Annotations)	
	This parcel has 200 m²	
	restricted development right	
	according to the current	
	development plan.	
	Municipal request,	
	12/05/2020, No.1246	

Figure 10. Putting annotation on the title in the land registry book (only the relevant part of the registry book is shown and the given date and registry number are random).

Step 4:

Once the restricted development right is registered on the title, this right is now officially recognized. From now on, by the request of the landowner, this right can be transferred to somewhere else (if approved by the authorities in terms of urbanization). The transfer does not have to be undertaken quickly. The owner may prefer to wait. Thus, it is up to the owner when to use it or not. In addition, putting such annotation on the title will automatically increase the market value of the property because the landowner now has the extra development right that can be used somewhere else or can be sold.

According to our scenario, the owner buys another lot in the same block and wants to transfer the restricted development right onto this new parcel. To do that, the owner applies to the municipality with a petition and requests to transfer the restricted 200 m^2 of development right onto this new parcel (Figure 11).

Date: …/…/…..

PETITION TO THE MUNICIPALITY OF …

I am the owner of the land parcel No. 101/5 in Saray Neighborhood. Because of the preservation decision, there is 200 m^2 restricted development right on my lot that I cannot use. I'd like to transfer this whole restricted floor area (200 m^2) to the parcel No.101/3 in the same block which is in my ownership as well. I hereby request to apply for the Transfer of Development Rights (TDR) program.

Name SURNAME
Signature

Figure 11. Petition of landowner to municipality for transfer of development right.

Step 5:

When the petition of TDR request arrives to the municipality, it will be analyzed if it is appropriate for the urbanization rules and principles. If the municipality finds no obstacles, the request will be approved. If it is found inappropriate for the urbanization of the city, the request will be declined. The decision-making body in the municipality in Turkey can be municipal board (in Turkish, *belediye encümeni*) or municipal council (*belediye meclisi*). However municipal council is preferred and suggested in this study. The request is firstly analyzed by the planning and development department of the municipality which mainly consists of planners, engineers and architects. After the initial research, the request and the technical opinion are sent to the municipal council for the final decision. According to our scenario, the request of TDR is approved (Figure 12).

MUNICIPALITY OF …

DECISION OF MUNICIPAL COUNCIL

Date: …/…/….

No: ..

The TDR application of "Name SURNAME" is discussed. The request of transferring 200 m^2 restricted development right from the land parcel No.101/5, to the parcel No.101/3 is found appropriate for the urbanization of the city. Therefore the TDR application is approved.

Mayor	Council Member	Council Member
Signature	Signature	Signature

Figure 12. Decision of municipal council for TDR request.

Step 6:

The TDR application is approved by the municipality. However, this is only an approval. To update the land registry records, the owner should apply to the land registry office with the approval decision of municipal council to cancel the old restriction annotation on the "sending parcel" No. 101/5, and then put a new annotation on the "receiving parcel" No. 101/3 stating that "the 200 m^2 development right is transferred from the lot No. 101/5 to the lot No. 101/3".

Putting this information on the title of the lots in land registry does not only mean the recognition of a right, but also it helps third parties to get informed about the current rights and responsibilities of the parcels if they want to buy them. In this way, if the "sending parcel" (together with the historic building on it) is to be sold to someone else, the buyer will clearly see that the restricted development right on this lot is transferred to somewhere else, so the buyer will be aware of that there is no more potential of development rights on the parcel. When the development right is transferred to another lot, the market value of the sending lot will decrease accordingly. On the other hand, if the "receiving lot" is subject to a sale, the potential buyer of it will be aware of, in addition to the original development right of the lot, that there is an extra development right on it that is coming from another parcel through TDR. This will increase the demand and accordingly increase the market value of the receiving lot. Essentially, recording TDR on the land registry is not only a recognition by the State, but it also serves to the publicity of the land registry information in order to protect the new buyers from misinformation.

The landowner applies to the local land registry office with a petition (together with the decision of approval of the municipal council attached) to make relevant changes on the titles for the transfer from the sending parcel to the receiving parcel (Figure 13).

MUNICIPALITY OF …

DECISION OF MUNICIPAL COUNCIL

…sed. The request of transferring …101/5, to the parcel No.101/3 is …e TDR application is approved.

Council Member

Signature

Date: …/…/…..

PETITION TO THE DIRECTORATE OF LAND REGISTRY

I am the owner of the land parcels No.101/5 and No.101/3. There is 200 m^2 restricted development right on the parcel No.101/5. I applied to the municipality to transfer my 200 m^2 restricted development right from the parcel No.101/5 to the parcel No.101/3 and my request has been approved by the Municipal Council. The decision of the Council is attached to this letter. I hereby apply to you to make the relevant changes on the land registry of the two parcels accordingly.

Name SURNAME

Signature

Attachments:

- Decision of the Municipal Council.

Figure 13. Landowner's application to land registry office for the update in land registry.

Step 7:

After the application of the landowner, the local land registry office will make the transfer on the land registry book by canceling/deleting the annotation on the sending parcel and putting a new annotation on the receiving parcel. The transfer is clearly referenced to each other on both titles (Figure 14).

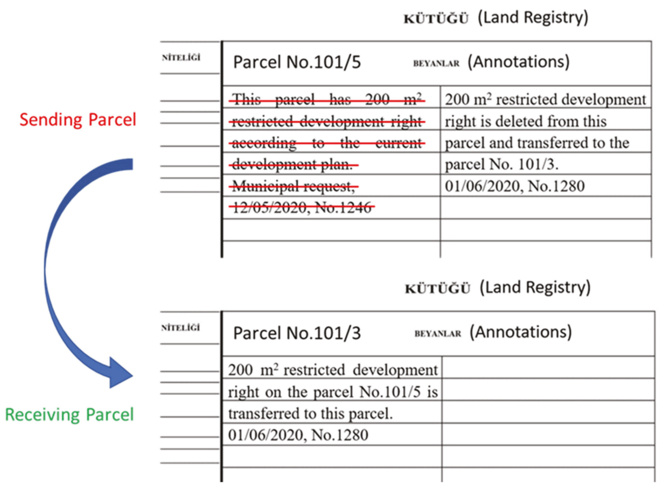

Figure 14. TDR update on land registry (only relevant part of the page of registry book is shown).

Step 8:

The transfer of development right is now "legally" made; however, it is not made "practically" yet. After this point, the owner will apply to the municipality to take a development sketch (in Turkish, *imar çapı*) for the receiving parcel together with its bonus density. In our scenario, the original right of the receiving parcel was 400 m^2, plus the incoming TDR of 200 m^2, the total floor area is now 600 m^2. The municipality will give a development sketch for 600 m^2 floor area. Then, the landowner will apply to an architect to prepare a building project which has 600 m^2 total floor area with an appropriate building height and width as implied by the municipality. After that, the landowner, together with the new architectural plan and other relevant documents, will apply to the municipality for a construction permit (in Turkish, *inşaat ruhsatı*). After the construction is completed and ready to use, the municipality will give the occupancy permit (in Turkish, *yapı kullanma izin belgesi*) [47,48]. At the end, the landowner will have a larger building and the restricted development right is completely consumed by the owner. As a result, the State did not need to spend any money and the injustice problem is solved by using the restricted development right of 200 m^2 on another land parcel (an overview of the procedures can be found in Figure 7).

7. Interviews with Sector Professionals

The implementation methodology proposed above is analyzed by interviewing 18 professionals from relevant sectors. The interviewees were found through personal contacts. All the participants reside in Antalya Province in Turkey. The interviews were conducted with open questions rather than a survey questionnaire and lasted around 45 min per participant. The meetings were held either in the workplaces of the participants (14 participants), or via video conference over the internet (four participants). The interviews were conducted with a PowerPoint presentation explaining the methodology and technical steps with aforementioned facts and figures.

The TDR concept is primarily in the field of construction, urbanization, and legal expertise. Accordingly, the interviewees were selected from these five professions: surveying engineering (also called geomatics or land surveying), civil engineering, architecture, urban planning, and lawyer profession with various educational and professional backgrounds from the private and public sectors. The careers of the participants are listed below (Table 4). The implementation steps were introduced to the interviewees, and they were asked what they think about the suggested procedures with the consideration of Turkish organizational, institutional, professional, legal, and traditional preferences.

Table 4. Careers of the interviewees.

	Profession	Degree	Sector	Experience (Year)
1	Architect	MSc	Academic	5+
2	Architect	MSc	Public	5+
3	Architect	BSc	Private	3+
4	Architect	MSc	Academic	3+
5	Architect	MSc	Academic	5+
6	Civil Engineer	PhD	Academic	25+
7	Civil Engineer	BSc	Private	5+
8	Lawyer	BSc	Private	15+
9	Lawyer	BSc	Private	10+
10	Lawyer	BSc	Private	20+
11	Lawyer	BSc	Private	15+
12	Surveying Engineer	MSc	Public	10+
13	Surveying Engineer	BSc	Private	10+
14	Surveying Engineer	BSc	Private	25+
15	Surveying Engineer	MSc	Public	25+
16	Urban Planner	MSc	Academic	3+
17	Urban Planner	BSc	Private	10+
18	Urban Planner	BSc	Private	15+

The "technical interviews" were made only with the focus on the technical steps introduced above. The interviews were performed with the same manner as explained in Section 6 step-by-step. After completing the presentation and explaining the implementation steps, the interviewees were asked the following two questions: "Q1: Is the introduced methodology technically applicable/appropriate in Turkey?" and "Q2: Do you have any suggestions to improve the methodology?". Since the introduced methodology is offered for the whole country, the answers of participants were not place-specific either. The overview of answers can be seen in Figure 15.

According to the interview results, all the participants agreed on the methodology and confirmed the implementation steps proposed in this study for their applicability in Turkey. There were minor suggestions by few participants. Only three participants suggested that "municipal boards" (in Turkish *belediye encümeni*, they meet at least once a week) or a specially formed "TDR board" can also be an option as the approval authority in the municipality, rather than "municipal councils" (in Turkish *belediye encümeni*, they meet at least once a month). They stated that these suggestions were made solely with the intention to decrease the workload of municipal councils. However, they also admitted that this is a minor suggestion and there is nothing wrong to go with the "municipal council" as well. In brief, the technical implementation steps suggested above are completely approved by the interviewed 18 sector professionals in terms of applicability in the land registry-development bureaucratic framework in Turkey.

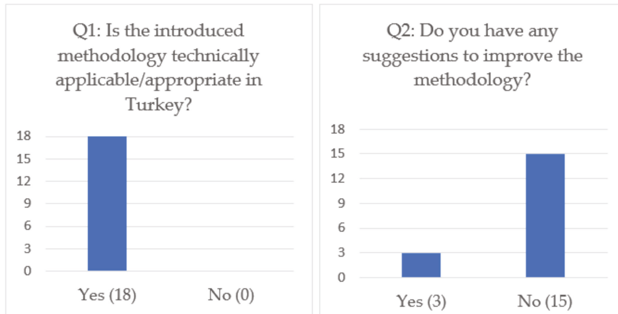

Figure 15. Interview results.

Together with the confidence provided by the positive feedback from the interviews, the authors believe that a successful TDR can help save our cultural heritage. For example, the historic building shown in Figure 16 no longer exists. The building somehow escaped from the net of the Preservation Board, so the owner(s) demolished this valuable landmark and redeveloped it with a modern multistory apartment building. With a successful TDR option, such historic buildings can be saved without causing unjust development restrictions which encourage landowners to find ways to demolish and redevelop their inheritance buildings.

Figure 16. An example of a destroyed and redeveloped historic building in Turkey (It was not listed as a "historic building" before the destruction. The construction started in December 2019).

8. Discussions and Conclusions

Since TDR is a new approach in Turkey and an implementing regulation (*uygulama yönetmeliği*) could not be enacted yet, this paper attempts to pave the way for the preparation of an implementing regulation. Although TDR legislations have been made as early as 17 years ago, the reasons for such a delay for the usage of TDR in Turkey can be analyzed in these two facts: (i) how to make the transfer technically is unknown, i.e., not knowing where to go, who to apply, which administration or agency does which part of the work and who will be responsible for what; and (ii) the fear of negative results of TDR, such as aesthetical concerns (causing high-rise buildings in wrong areas), physical concerns (putting excessive pressure on the infrastructure), social concerns (failing to avoid ill-intentioned people to abuse the system) and legal concerns (causing unforeseen legal consequences). These concerns are not invalid at all. However, this paper is based on the first part of the questions: how to make a transfer technically. The authors think that it is a better idea to divide these two questions and analyze them separately. After defining the processes and having a sense of direction, then it can be easier to talk about the potential bumps and holes on the road. Otherwise, the fear of failure will continue to keep the sector from taking any steps in this field.

Finally, with the confidence provided by the interviews with 18 related sector professionals, this paper confirms that the TDR process in Turkey can be handled between the "landowner", the "municipality" and the "land registry office" as explained in Section 6 "Proposed TDR Methodology to be Used in Turkey". The proposed methodology could help reduce the economic losses of landowners of restricted properties, support public finances by not spending limited public budgets for the compensation of development restrictions, make the "transfer process" completely transparent to public scrutiny, and finally support the overall preservation of historic buildings in the country.

However, a minor addition can still be made here. Although it is not mentioned in the methodology section above, local cadastral offices can take part between the municipality and the land registry office for the inspection of the technical calculations made by the municipality. Because land registry offices are unable to make those technical inspections. The *land registry agency* in Turkey is traditionally highly alert to potential errors and mistakes, so the agency may ask technical inspections of the sibling agency: the *cadaster office*. Since the *land registry* and *cadaster* offices are the arms of the same upper-authority, *General Directorate of Land Registry and Cadaster*, local cadastral offices can make the technical checks for the municipality's applications, and then send the application to the land registry office if there is no technical problem. If they find an error though, they can send it back to the municipality to make relevant corrections. This way the land registry office will have the confidence to keep the records as correct as possible.

There are few academic studies in this subject in the Turkish academia. Although the literature may provide some information about the need for TDR in various fields, it still lacks providing practical implementation methodologies. This paper is aimed to fill this gap by offering a step-by-step technical implementation of a TDR program. In addition, the usage of TDR in the field of preservation of cultural heritage could facilitate its usage in different areas such as protection of agricultural lands, or even urban regeneration projects. Therefore, the authors call for more academic work on this topic.

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New Direction of Sustainable Urbanization: The Impact of Digital Technologies and Policies on China's In Situ Urbanization

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Abstract: As part of the process of sustainable urban planning in China, digital technologies have led to major practical and academic concerns. However, few scholars have focused on the impact of digital technologies on in situ urbanization from a policy–technology perspective. This interdisciplinary work aims to analyze how digital policies and their technologies contribute to the transformation of in situ urbanization patterns. This study follows the structure of law and policy research regarding the path of phenomenon presentation–institutional analysis–limitation interpretation. First, the legislation and policies for digitalization of the countryside has drastically changed the logic of how traditional in situ urbanization works. The concept of in situ urbanization 2.0 is used to describe this new phenomenon. Second, historical legitimacy, performance legitimacy, and socially sustainable reproduction are three reasons why rural digitalization reform has triggered in situ urbanization 2.0. Finally, the double dilemma of overreliance on technological change in the in situ urbanization 2.0 process is pointed out; these dilemmas need to be addressed through legislation and policy adjustments. Four recommendations for action are proposed to address these dilemmas. The findings of this research contribute to the literature on sustainable urban planning and rural digitalization reform.

Keywords: sustainable urban planning; digital legislation and policy; rural digitalization reform; digital technology

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1. Introduction

Rapid urbanization is an enormous challenge to sustainable development [1–3]. The urbanization rate in China, the world's largest developing country, increased from less than 20% in 1978 to 60.6% in 2019, an average increase of one percentage point per year [4], which means that the sustainability challenges facing the country are extremely serious. In facing this challenge, scholars have advocated that digital technologies, along with digital policies, should be widely applied in rapid urbanization [5]. For example, ul Hussnain et al. point out that digital technologies can sustainably contribute to urban spatial planning. Sharif et al. [6] focus on the innovation of s-technology for intracity traffic management. Zhan et al. [7] focus on the great utility of data technology in urban climate regulation. Scott et al. [8] highlight the utility of digital technology in emergencies [9]. Moreover, digital technologies enable sustainable urban development in the commercial [10], industrial [11], and consumption sectors [12]. Despite these challenges, as an innovator of sustainable urban planning, digital technologies have received widespread attention in theory and practice [13].

The rapid urbanization model, transformed by digital technology, is a hot topic in academia at the moment. Surprisingly, however, few studies have focused on what digital technologies have brought to in situ urbanization, which is more characteristic of urbanization under Chinese planning than of metropolises [14]. Only a few studies have paid attention to this topic and those that do mention it only tangentially. For example, while some studies address the innovation of digital technologies on the path to in situ urbanization planning, the core topic is online services in China's rural transformation. Some studies [15] focusing on in situ urbanization have largely ignored digital technologies [16]. Considering the great sustainable potential of in situ urbanization [16], the focus on digital technologies is important for bringing innovation to in situ urbanization.

Regarding this topic, this study aims to analyze how digital policies and their technologies contribute to the transformation of in situ urbanization patterns. The innovation that digital policies and their related technologies bring to in situ urbanization and common paths of small city development have not been systematically clarified. This activity is thus the research objective of the article. The core argument of the article is that digital policy and its related technologies innovate a different path for in situ urbanization than before. This article develops a systematic argument from three sub arguments: innovation phenomena, institutional logic, and limitations of contemporary innovation, and proposes in situ urbanization 2.0 as a core concept for use in this field. The introduction of new concepts provides a possible path for future research. The study makes contributions to the contemporary literature. In addition, the research perspective is different from that of previous studies, which mostly used empirical methods to demonstrate the efficacy of data policies in the process of in situ urbanization. In contrast, this paper takes a normative research perspective to logically classify the changes that policies and their technologies bring to in situ urbanization. Such a method is rare in recent studies and can contribute to the literature.

The article follows three stages of research: describing phenomena, conducting institutional analysis based on a conceptual framework, and interpreting limitations to develop an argument. This is a common argumentation structure in law and policy studies. The typical study can support this argument structure. Specifically [17,18], this article comprises five parts. The second part examines in situ urbanization innovation phenomena under digital policies using four official indicators, arguing that the process of in situ urbanization 2.0 has begun. Building on the second part, the third part uses the theoretical framework of political economy to analyze the institutional logic of the Chinese government's promotion of in situ urbanization 2.0. Three types of logic—political, economic and social—not only form the motivation for the Chinese government to promote in situ urbanization 2.0, but are also the source of internal and external constraints in the process of in situ urbanization 2.0. The fourth part proposes two types of limitations of contemporary in situ urbanization 2.0 derived from the theoretical framework in the previous section. These limitations are concentrated in internal non-self-consistent dilemmas and external conflict risks. Based on the limitations analyzed in the fourth part, possible future responses are presented in the fifth part. The last part summarizes the article and presents the limitations of this study.

2. In Situ Urbanization Innovation under Digital Policy

2.1. In Situ Urbanization Effects of Rural Digitalization Reform: 1.0–2.0

The United Nations provides a fundamental definition of in situ urbanization: it occurs when a rural population reaches an urban standard of living without having to migrate to cities [19]. Although more specific definitions have been debated, the term in situ urbanization is mainly used to describe the process of moving from rural to urban areas [20], which is accompanied by a social process of farmers becoming urban residents [21]. The process usually begins with the transfer of the workforce from the agricultural sector to the nonagricultural sector [22]. There are two traditional drivers of in situ urbanization, namely, the development of industrial activity in rural areas and government-facilitated foreign investment [23]. These two drivers have led to different forms of in situ urbanization. In general, the process of in situ urbanization in China has contributed to changes in settlement patterns that have led to differences between villages and towns. Officials believe that the specific utility of in situ urbanization should be measured in terms of four areas: infrastructure development, agricultural industrialization, public service levels, and rural local governance [24].

Since 2019, a series of digital policies, such as digital platforms for rural development strategies and digital plans of action for rural development, have had an enormous impact on the path to in situ urbanization [25]. These impacts have been so great that they have mechanically changed the traditional process of in situ urbanization. Therefore, we call in situ urbanization under the digital reform of the countryside "in situ urbanization 2.0". Based on officially published criteria, we explain how digital reform has changed traditional in situ urbanization in terms of four aspects: infrastructure development, agricultural industrialization, public service levels, and rural local governance.

2.2. Construction of Digital Infrastructure

China's digital infrastructure in rural areas can be divided into two phases: physical infrastructure development and recent digital infrastructure development. The recent digital infrastructure development, supported by the rural digitalization reform policy, has comprehensively renewed rural digital facilities, which is a prerequisite for the realization of in situ urbanization 2.0.

In in situ urbanization 1.0, the construction of the interface end of Internet information facilities, as physical infrastructure construction, is the main digital infrastructure task. This construction was largely completed in the 1.0 period. By the end of 2021, the proportion of administrative villages with access to both fiber optics and 4G nationwide exceeded 99%. Broadband networks are gradually being extended to key areas such as rural population clusters and production operation areas and along major transport routes. The scale of rural broadband users continues to expand and the penetration rate of the fixed broadband population exceeds the average level of member countries of the Organization for Economic Co-operation and Development. By the end of 2021, the total number of rural broadband access users had reached 158 million, a net increase of 15.81 million over the end of 2020. Physical infrastructure development has largely transformed the basic rural landscape, driving in situ urbanization 1.0.

In recent times, digital infrastructure, a fully upgraded version of physical infrastructure construction, has comprehensively updated digital technologies in the process of in situ urbanization 2.0. Digital infrastructure refers to the internet base, internet user base, and technical base necessary for digital development by means of internet technology. The popular concepts of network communication, big data, cloud computing, blockchain, artificial intelligence (AI), quantum technology, the internet of things, and the industrial internet all need to be based on digital infrastructure. As the basis of in situ urbanization 2.0, digital infrastructure offers the opportunity to urbanize production and life in the countryside in a completely different way from the traditional path. Notably, because of the rapid nature of China's development and the high rate of iteration of digital technologies on the internet, some villages that have not yet entered the traditional process of in situ urbanization have made the leap.

For example, basic industries in certain rural areas have skipped straight to physical infrastructure construction and moved directly from the traditional development model to a digital infrastructure-based rural e-commerce platform. This kind of leap is an example of how digital infrastructure development has been widely promoted and practiced in rural areas. Additionally, in Chengdu, the installation of video surveillance systems is the main security measure in public safety construction in rural areas [26]. However, with the advancement of video surveillance technology, security measures have received significant technological enhancements in terms of software. The storage capacity of traditional communication devices and the ability to analyze video content have been greatly enhanced by AI and big data cloud storage technology, which in turn has brought about efficient public security governance.

2.3. Digitalization of the Agricultural Industry

Chinese agriculture is characterized by a small amount of land per capita; thus, the mainstay of agricultural production remains the small family farm, with an average of approximately ten acres of land [27]. For small family farms, the labor force, cultivation technology, and funds for investing in machines are the main constraints on production [28]. Therefore, in in situ urbanization 1.0, the agricultural industry has been upgraded mainly around mechanization and cultivation techniques. However, breaking with the traditional logic of industrial upgrading, in situ urbanization 2.0 has reshaped the whole system of agricultural production by means of digital technology.

First, the revolution of in situ urbanization 2.0 as part of agricultural industrialization is mainly driven by digital technologies used to enhance agricultural production capacity. In recent years, digital technology has comprehensively changed the logical production of industries such as agriculture, forestry, animal husbandry, fishery, agricultural and side-line product processing, industrial product manufacturing, and leisure tourism. In production activities, digital technology enables artificial intelligence to control automated agricultural production and management processes. For example [29], new digital technologies such as sensor technology, geo-information technology, mobile computing processing technology, and AI technology can comprehensively collect all kinds of data in the agricultural production process and perform dynamic task planning and planting management based on this technology. The results undoubtedly greatly enhance the efficiency of agricultural production.

Second, the agricultural digital ecosystem is reconstructed by rural digitalization reform. In terms of the sale of agricultural products, digital technology has reconstructed the ecological chain of the production, purchase, and sale of agricultural products [30]. On the production side, a digital agricultural production system based on technical equipment that ensures production and is supported by data algorithms is formed. On the retail side, a system of blockchain traceability, AI quality grading, and comprehensive logistics that ensures product quality is constructed. On the sales side, a system for ensuring the product sales of all-channel production and for marketing docking and regional public brands is improved. The efficiency of the agricultural ecosystem reconfigured by digital technology is enhanced.

Finally, traditional specialty industry clusters, which are an important pillar of in situ urbanization, are being reshaped by digital technologies. In the late modern period, through specialized manufacturing, a large number of rural areas gained economic power, which promoted in situ urbanization. However, as the demographic dividend declines and labor costs rise, in situ urbanization slows as the economic growth rate declines. The digitalization of rural areas has brought new economic growth points. Some regions are seizing the opportunity for digital development to accelerate the transformation through the upgrading and innovative development of clusters. For example, Guangdong's rural areas have initiated the digital transformation of specialty industry clusters. The industrial internet system constructed through digital technology collects data from multiple links, such as branding, production, processing, and material supply. The data collection and coproduction model based on this system has greatly improved local production efficiency, providing a new impetus for local economic development and in situ urbanization.

2.4. Digitalization of Basic Public Services

The large-scale application of digital technology is an important feature of the national basic public service system to be established during the period of the 13th Five-Year Plan We summarize the digital government construction plans for each province in China for 2022; see Appendix A Table A1, which reflects the general investment of governments across China in the digitalization of basic public services. This feature intuitively reshapes the basic public services of in situ urbanization. This reshaping is reflected in two ways. After digitalization, the threshold for the construction of basic public services is significantly lowered. Scholars point out that basic public services are a difficult aspect of in situ urbanization because the construction of basic public services involves high demands on finance, technology, human resources, and the quality of citizens. In situ urbanization 1.0 policies, such as new rural cooperative medical services, have also focused on basic public services such as education, healthcare, and social security, but they have had poor results [31]. However, this reality has been reshaped by data technology. Through digitalization, such as the construction of a unified online administrative service platform, digital technology has enabled the reshaping of the way in which power operates, and the cost of running administrative power has been significantly reduced [32]. Currently, through the organizational hierarchy of the administrative bureaucracy, digital technologies and their public service models are beginning to be transmitted to rural areas that are not endowed with digital technologies. The elements of finance, technology, human resources, and citizenship are also being empowered by digital technology in rural areas. This means that basic public service provision, as part of in situ urbanization, is made much less difficult.

The digital reengineering of public services creates public service parity. In addition to infrastructure provision, the most important public services are education and healthcare. With these public services being widely covered by digital technology and its infrastructure enhancement, quality educational resources and medical resources are digitally accessible to urban and rural people on a near-parity basis. In 2018, the proportion of multimedia in rural primary and secondary schools reached more than 50%. There are 2843 county-level centers for digital cultural services, 32,179 grassroots service points in townships, 32,719 public electronic reading rooms in townships, 14,136 digital cultural stations, and cell phone applications that provide farmers with more accurate science and technology services, skills services, etc. [33]. Overall, by reducing factor costs, digital technologies have dramatically reduced the difficulty of public service provision, which indirectly accelerates in situ urbanization 2.0.

2.5. Digitalization of Rural Governance

The top-level design of rural digitalization, such as the Law of the People's Republic of China on the Promotion of the Revitalization of Rural Areas and the Outline of the Digital Village Development Strategy, has also changed the logic of rural local governance. Digitalization policies divide the governance of in situ urbanization into public administration, public security, and public service, and revolutionize the logic of governance through the large-scale use of digital technologies.

Public management and public services include local government services, rural party construction, and village public affairs governance, which are almost fully reliant on digital technology. In Chinese Communist Party (CCP) construction projects [33], digital technology has been used to build several sets of governance programs, such as "Internet and party construction", "smart party construction", "online party branches", and "online village (residents) committees". These systems have changed the model of offline CCP construction and strengthened the party's control over rural areas. In addition, through the digital platform, local government services and village public affairs governance have been moved online, which has greatly improved the efficiency of governance. Rural public administration has been transformed by digital technologies in terms of the organizational structure and forms of content.

The governance logic of public security, which mainly includes social security management and public health governance, has been completely changed by digital technology. At present, the digital technology-led "Snow Bright Project" has basically replaced the traditional social security management model. The "Snow Bright Project" is an extension of the digital security management model in metropolitan areas called the "Skynet Project" in the process of in situ urbanization, which manifests in the installation of real-time surveillance systems in almost all public areas of a city without blind spots to effectively combat crime. Unlike the traditional model of human patrolling, digital technology can transmit and analyze video data in real time to efficiently monitor and manage the security of a city and rapidly act to prevent and combat crime. In place of traditional methods, the digital technology-led "Snow Bright Project" has yielded excellent results in practice. One example is the adoption of the "Snow Bright Project + Grid" governance model in Sichuan Province, which has resulted in a significant reduction in muggings and burglaries in towns [26].

Additionally, digital technology, which differs from traditional governance methods, has greatly improved the efficiency of public health governance [30]. For example, the traditional offline model has been abandoned, and the digital platform of government-enterprise cooperation directly helps residents learn about epidemic prevention and conduct health self-examinations online to help with prevention, control, and monitoring activities. Similarly, village organizations use new methods for enhancing epidemic prevention activities and to monitor compliance, efficiently realizing public health prevention and control efforts simultaneously.

The above compendium shows the innovation of rural digitalization reform based on in situ urbanization from four key perspectives. Digital infrastructure construction has revolutionized the trend of infrastructure construction; the digitalization of the agricultural industry has realized the transformation and upgrading of rural industrial clusters; the digitalization of public services has enhanced the supply capacity of public services; and the digitalization of rural governance has completely changed the traditional logic of rural governance. These corrections are undoubtedly efficiency enhancing. The development of the digital economy can directly reduce the income gap between urban and rural areas and can also promote the return of the labor force [34]. The digitalization of public services and rural governance will further enhance people's quality of life. As a result, a perhaps unexpected picture is presented: digital technology facilitates the rapid development of in situ urbanization along an unconventional path. Digital reform-based development paths and the development outcomes of digital urbanization are compatible with traditional in situ urbanization. Traditional in situ urbanization, particularly in China, developed along a single path in the late 1990s; large cities needed to accelerate their urbanization by better coordinating with smaller surrounding cities and towns [35]. This means that the path of in situ urbanization is large city–peri-urban–rural, which has significant spatial concomitance. However, digital reforms have altered this path. Under the new path, the extent of digital reform in rural areas, rather than the distance from large cities, is one of the key elements influencing in situ urbanization. In addition, traditional in situ urbanization involves four aspects: infrastructure development, agricultural industrialization, public service levels, and rural local governance. In terms of development outcomes, a number of scholars have pointed out that digital urbanization has greatly accelerated the efficiency of these indicators [15]. Based on the differences in development paths and outcomes between the old model and new model, this phenomenon is called "in situ urbanization 2.0". Thus, the different paths and accelerated efficiency of in situ urbanization 2.0 are the features that distinguish it from urbanization 1.0.

3. The Institutional Logic of In Situ Urbanization 2.0

The current digital reform of the countryside could create an unconventional phenomenon of in situ urbanization called "in situ urbanization 2.0". A logical question arises: why is rural digitalization reform being pushed by the state? We argue that the official formulation recognizes the irreplaceable political and economic significance of the digital reform of the countryside as a process of legitimacy reproduction. In addition, the in situ urbanization 2.0 triggered by rural digitalization reform can bring important social benefits. These three reasons constitute the institutional logic behind the official promotion of rural digitalization reform and, thus, in situ urbanization 2.0.

3.1. Politics: The Reproduction of Historical Legitimacy

The Marxist theory of communism, which is the foundation of the Chinese governance, defines the development of the countryside as one of the measures of the reproduction of legitimacy. Marxists have argued that human society goes through three stages: the unification of urban and rural areas without any distinction, the separation and conflicting interests of urban and rural areas, and the integration of urban and rural areas. This means that the Marxist conception of the Kingdom of Heaven on Earth includes a commitment to the equal development of urban and rural areas. The advancement of in situ urbanization logically becomes the process of fulfilling this promise and completing the reproduction of legitimacy.

This process of legitimacy reproduction has been followed in this country and written into the constitution. Article 1 of the Constitution of the People's Republic of China explicitly states that the masses are important allies in governance. Article 1 of the Constitution of the People's Republic of China states: The People's Republic of China is a socialist state governed by a people's democratic dictatorship that is led by the working class and based on an alliance of workers and peasants. Given the specificity of the state system as defined in Article I of the Chinese Constitution, it is imperative that the CCP consider the development of the countryside to protect the interests of its ruling allies. The CCP has placed rural development in a strategic position. Officials have argued that the CCP's practical exploration of the "three rural issues" embodies the mission of changing historical tasks [36]. The exploration of this issue is an important component of the internal logic of balancing urban and rural development in the process of national modernization. Due to the CCP's strong reliance on the legitimacy production process, the regime has been actively practicing legitimacy reproduction through rural reform for a long time. This practice is evident in various important programs across different eras. It is clear from the narrative of official documents that the digital reform of the countryside can be seen as a process of legitimacy production in the digital age. Officially, the digital reform of rural areas connects the "rural revitalization strategy" and the "digital China strategy". The construction of the digital countryside is the main method of rural revitalization in the digital era, and it is also a key feature of digital China. Digital village construction can be very useful for rural areas in China seeking to solve the problems of in situ urbanization and sustainable development, and thus to realize rural revitalization. Therefore, in terms of ideology, the digital reform of the countryside is an indispensable and timely strategy for continuing the reproduction of certain ideologies.

3.2. The Economy: Reproduction of Performance Legitimacy

In the economic sphere, rural digitalization reform is seen as the solution to many performance legitimacy challenges. This perception is shaped by the fact that rural China has long been seen as providing fuel for sustainable urbanization. Means of production and productivity dispossession has become a dominant mechanism of Chinese urbanization [37]. Specifically, based on the criteria for identifying urbanization [16], the markers of urbanization are mainly seen in the development of the industrial economy and job growth.

At the moment, rural digitalization is the response chosen to ensure sustainable urban planning and the continuation of the legitimacy of economic performance. The current model of urbanization is predicted to be unsustainable, and in situ urbanization is a natural development. After four decades of development, the process of urbanization is now slowing down [38]. To ensure continued economic development, industrial migration and consumer markets will radiate to surrounding towns and cities, and in situ urbanization is an inevitable choice to avoid triggering enormous risks to the decades of progress made under sustainable economic growth brought about by urbanized development. However, the process of developing industrial migration and consumer markets is not without obstacles. This development can be accomplished with low attrition only if the countryside is close to the city in all aspects of infrastructure. By promoting in situ urbanization 2.0 through rural digitalization reform, rural infrastructure has been greatly developed, which significantly reduces attrition in developing industrial migration and consumer markets and increases the sustainability of urbanization and economic development.

In addition, rural digitalization is a response to ensure sustainable rural development to perpetuate performance legitimacy. During the first 40 years of modern urbanization, the low cost of absorbing labor from the countryside was one of the main tools of traditional urbanization. For example, in 2011, there were 230 million migrant workers, approximately 80% of whom came from the countryside [21]. As a result of this massive and continuous siphoning, the economic and social functions of rural China have been completely degraded. Traditional patterns of production and life have been completely disrupted by traditional urbanization [31]. However, the labor absorption capacity of cities is not unlimited. As the Lewis turning point approaches, the declining countryside will have to absorb the surplus labor that has not yet been siphoned off by cities [39]. Moreover, as the urban economy transforms and large cities become saturated by development, some of the displaced labor will have to be accepted by the declining countryside. Unless there is massive reform, there will not be enough infrastructure and jobs in the decaying countryside to support and utilize this workforce. Rural digitalization offers a path to reform for the countryside. The recasting of rural economic and social functions through rural digitalization and other rural revitalization policies can change the industrial and employment structure of the countryside, which means that the capacity of surplus and eliminated labor can be more fully stimulated. Additionally, with the policy's enhancement of rural public services and public administration, the reshaped countryside will begin to have a siphoning effect on labor from other regions. This virtuous circle will further unleash rural productivity for sustainable rural development. Thus, by promoting in situ urbanization 2.0 through digital rural reforms, the government can free up more resources for sustainable rural development, which implies a reproduction of performance legitimacy.

3.3. Society: A Realistic Driver of Sustainable Development

Urbanization aims to promote citizenization, under which people's social needs must be sustainably satisfied [40]. In situ urbanization 2.0 offers great social sustainability utility through rural digitalization reforms. According to the EU definition, social sustainability generally encompasses poverty eradication, healthcare, education, labor structure optimization, and digitalization [41]. In situ urbanization 2.0 has a significant impact on these areas.

For labor structure optimization, in situ urbanization 2.0 is significant. This phenomenon has been corroborated by the digitization of rural areas abroad [42]. Through digital infrastructure construction, new technologies are introduced and used to transform and empower the promotion of the cultivation of competitive digital agriculture industries. These new industries change the structure of the local workforce, opening up employment space for local and foreign top talent and causing them to stay in the local area. In addition, the supply of basic public services such as distance education and online training has facilitated the reproduction of local top talent. All of these measures directly change and optimize the local labor structure and achieve sustainable human resource development.

In poverty eradication, if governments enable agricultural markets to function well, supply the necessary financial and technological support, and create the necessary public infrastructure, large agricultural productivity and growth gains can be reaped [43]. In situ urbanization 2.0, as an effect of rural digitalization reform, can accelerate the upgrading of industries, help farmers become rich, and help them efficiently connect to the market. In particular, the development of rural e-commerce can help improve the solution to the information asymmetry disadvantage of traditional agricultural markets. In situ urbanization 2.0 has strongly developed local industries and increased jobs and income for local farmers, helping to further consolidate the results of poverty eradication and prevent farmers from returning to poverty.

In situ urbanization 2.0 also makes a unique contribution to healthcare and education. Digital infrastructure construction objectively reduces the cost of public services and public administration, especially healthcare and education. Currently, low-cost digital infrastructure platforms and telemedicine platforms are widely used by farmers. In addition, electronic reading rooms and libraries are widely opened to meet the differentiated educational needs of farmers.

Finally, as the most fundamental element, digitalization directly changes the overall logic of rural governance. Party construction and social security, the two most important concerns of the CCP for rural governance, have been completely transformed by digitalization. On the other hand, the traditional model has been abandoned. Currently, in rural governance, digital technology has demonstrated its disruptive nature in terms of organizational, technological, and institutional innovation. Through digital reform, rural governance undergoes practical and institutional innovation to strengthen government leadership in rural areas and to enhance the efficiency of grassroots governance.

4. Dilemmas and Risks of In Situ Urbanization 2.0

The phenomenon of in situ urbanization 2.0 at scale has forced researchers to investigate its institutional causes. Based on the theoretical framework of political economy, the institutional logic of the Chinese government's promotion of in situ urbanization 2.0 has been analyzed above from three institutional perspectives: political, economic, and social. However, a legitimate question that immediately follows is whether in situ urbanization 2.0 can be soundly developed based on the current institutional logic.

The answer is not optimistic. It is true that reformers have a strong incentive to advance digital reforms to promote in situ urbanization 2.0 for the three reasons mentioned above, but this does not mean that the institutional logic desired by reformers is thoroughly implemented in institutional designs. UN research has pointed out that as with many of China's reforms, the institutional design of in situ urbanization in China has been largely top-down and led by the central government [35]. Empirical research has shown that the top-down reform model in China has several general limitations, such as authority–responsibility distribution and fiscal dilemmas [44–47]. Political economy usually develops institutional analysis from the conceptual framework of endogenous and exogenous causes. Based on this conceptual framework, the article argues that there are *internal non-self-consistent dilemmas* and *external conflict risks* in the current in situ urbanization 2.0 regime.

4.1. The Internal Non-Self-Consistent Dilemma of In Situ Urbanization 2.0

Although the four scenarios of in situ urbanization 2.0 described above are currently seeing success, this does not mean that this process is free from dilemmas and risks. The logical starting point of the internal dilemma of digital reform is the tension between the traditional and digital systems. Based on the perspective of policy construction, the dilemmas of the transition period are a topic that must be considered. For example, in terms of the subject of promotion, are the financial and administrative powers of reformers sufficient to support reform? In terms of the target implementers, is the grassroots governance model compatible with digital reform? In terms of the content of promotion, does the specific content of digital reform meet the current requirements of in situ urbanization 2.0? These and other questions warrant specific analysis.

4.1.1. The Reformer's Dilemma: Ambiguous Authority and Responsibility and Fiscal Dependence

In the process of in situ urbanization 2.0, reformers face the twin dilemmas of fiscal dependence and ambiguous authority and responsibility. The blurring of authority and responsibility is caused by the incomplete top-level design of the system. At present, the overall planning of agricultural and rural digitalization, such as that described in the Outline of the Digital Countryside Development Strategy and Digital Countryside Construction Guide 1.0, does not provide a planning design from the top level to the bottom level, which leads to overall confusion regarding authority and responsibility. Specifically, since China's political structure is a "strip–block (Tiao–Kuai)" model [48–50], the confusion regarding authority and responsibility disrupts the "strip–block" relationship. This confusion has caused problems in both the "strip–strip" and "block–block" structures.

In the "strip–strip" structure, the confusion regarding powers and responsibilities at the top has led to a conflict between the universality and specificity of administrative operations. The current master plans for the digitalization of agriculture and rural areas, such as the Outline of Digital Village Development Strategy, have only national guidelines and do not consider the realities of each region. In provincial development, there are varying roles of rural development within the overall development of the country. This is widely present in the context of the second part: "digitalization of the agricultural industry". For example, in provinces on the southeastern coast and in the plains, rural areas may play the role of a major food-producing region. In contrast, in hilly provinces, rural industries may be better suited to the development of specialty agriculture, such as the forestry, fruit, and tea industries. The top-level design should empower local governments with sufficient autonomy, which can help them build digital facilities, adjust agricultural industry, digitalize basic public services, and develop rural governance and other construction based on regional characteristics. However, the current abstract and universal top-level design does not give clear authority or guidance to local governments. This issue causes problems such as an unclear development direction and ambiguous development authority for local governments, which ultimately creates many difficulties for in situ urbanization 2.0.

In the "block–block" structure, there is no comprehensive top-level plan to regulate what different levels should be responsible for in rural digitalization reform. This issue directly leads to the replication of a simple set of mechanisms at different levels of government, where the competencies of different levels of government are clear. In the "block–block" structure, the authority and responsibility of government departments and state-owned enterprises are confusing; for example, a large number of business overlaps exist. Taking the scenario of digital infrastructure construction as an example, infrastructure construction may involve overlaps in the authority and responsibility of the three major mobile communication service providers. Agricultural industry restructuring may involve dealing with numerous construction units outside the Ministry of Agriculture and Rural Development and the Ministry of Industry and Information Technology. Basic public services, on the other hand, involve at least the Ministry of Education and the Health and Wellness Commission. Rural governance, which encompasses public administration, public safety, and public services, involves almost all government departments. The existing institutional design has not succeeded in clarifying the powers and responsibilities of various departments, and the confusion that this issue has caused is obvious. The linkage and coordination mechanism among various departments is not smooth enough, and each subject is in a state of its own promotion plan, making it difficult to share basic data resources, let alone imitate construction methods.

Excessive fiscal dependence constitutes another dilemma of in situ urbanization 2.0. Fiscal dependence manifests in two ways. First, there is a lack of finances. Rural digitalization reform, as the focus of rural revitalization, is a strategic and logical part of political and economic legitimacy, but financial problems are common in practice. After the tax-sharing reform was implemented, the tax revenue of local governments was insufficient to allow large-scale rural investments. The relevant financial resources are scattered across many departments and have not yet been unified [51]. Many construction projects that require joint efforts and long-term funding, such as the digitalization of basic public services, have difficulty obtaining long-term, stable financial investment. This issue has limited the progress of rural digitalization reform to certain extent. The second is the lack of social capital. The participation of market players in government-led rural digitalization reform is insufficient. Apart from rural enterprises, the external force of rural digitalization reform is mainly the government. However, local governments can provide only limited policy and financial support. The lack of inclusion of more diverse development agents may lead to a lack of sustainability in the development of in situ urbanization 2.0. Historical experience shows that government investment cannot bring sustainable development to in situ urbanization, which is mainly seen in the lack of motivation among the public and the lack of industrial dynamism. To sustainably develop in situ urbanization 2.0, stimulating long-term, stable financial support to leverage the market's own dynamism will be a key component of the government's future efforts [25].

4.1.2. The Target Implementers: Incentive Deficiency and Incentive Distortion

In regulating the target actors in the in situ urbanization 2.0 process, grassroots paralysis must be overcome by reducing the cost of communication of various types of information and shortening the chain of governance. However, in practice, there are notable performance distortions and deficits at the grassroots level.

On the one hand, incentive distortion causes rural digitalization to fail to break up the information monopoly of grassroots cadres. In some critical issues, such as poverty alleviation, distorted performance incentives encourage grassroots cadres to provide false data to meet targets. This issue has led to the failure of rural digitalization to connect with the deep rural social power structure and social life production process, and rural digitalization is thus rendered as only a new municipal project. Digital technology has no realistic value for decision-making in local social governance.

On the other hand, incentive deficiency leaves local government officials with little incentive to complete rural digitalization to drive in situ urbanization 2.0. Currently, most of the reforms involving rural digitalization rely on village-rank administrators. China's "county–township–village" structure of local public service organizations suffers from a lack of financial resources as administrative rank decreases. Zhou's research (2012) found that financial allocations at the county-rank level are almost entirely used to support the salary expenditures of county-rank authorities and cannot fully cover the finances of the township-rank officials. At the village-rank level, even the base salaries of the main technical departments are not covered by current financial allocations. If village technical departments are able to perform technical services, they can be self-supporting. Otherwise, they cannot obtain sufficient financial means, even if they are working. Thus, the work of the technical departments at the local level is often paralyzed. In short, government employees at the village-rank level lack both financial and promotion incentives, which limits their motivation to efficiently promote village digitalization.

In addition, the talent support for rural digitalization reform is insufficient [52]. First, although all governments have introduced talent-attraction policies, these are implemented mostly in urban areas, and the digital talent within villages is small in number and stays only briefly. Second, at present, most of the beneficiaries of rural digitalization reform construction projects in China are local residents in the countryside who are less digitally literate and less innovative than digital professionals, and have difficulties mastering the necessary digital skills. Coupled with the problem of rural labor turnover, there is still a shortage of labor for digital rural construction.

4.1.3. The Content Dilemma: Insufficient Economic Volume and Hollowed-Out Population

The two vectors of in situ urbanization are industrial urbanization and demographic urbanization [23]. Although top government documents indicate the way forward for rural digitalization reform, the current challenges of the rural context still make it difficult to implement rural digitalization reform. Specifically, in situ urbanization 2.0 has encountered obstacles related to both industrial urbanization and demographic urbanization, which are the main impediments to successful rural digitalization reform.

First, regarding industrial urbanization, rural digitalization reform is unable to address the transition of industry in its entirety. The most prominent problem is that rural digitalization reform currently has minimal impact on primary industries. According to the data in the "White Paper on China's Digital Economy Development", the digital economy penetration rate of agriculture is only 8.9%, the lowest among all industries. Although rural digitalization reform still has an enormous effect on increasing the income of the rural agricultural population (an increase of 8.9% after the first reform [53]), the small scale of rural digitalization reform in agriculture is nevertheless undeniable. This means that a vast market space has yet to be tapped and the digitalization of the industry is far from limited at the moment. Another even more significant issue is the scale of the agricultural industry, which is hardly able to support in situ urbanization 2.0. Among all industries, the agricultural industry accounts for the smallest share of China's economy. Although the widespread application of a new generation of digital information and communication technologies can empower the economic vitality of township regions, such empowerment cannot escape the reality that the agricultural industry itself does not carry enough weight in the market-oriented national economy. This means that digital reform relies solely on the agricultural industry and industrial urbanization is difficult to accomplish. A recent idea is to open up secondary and tertiary markets in the digital reform of the agricultural industry, but a clear plan has not yet emerged.

Second, in population urbanization, the contemporary problem of the hollowing out of the rural population creates an enormous obstacle to launching in situ urbanization 2.0. Currently, China faces the challenge of a shrinking rural population. Some Chinese scholars argue that the urban–rural dichotomy has led to a siphoning effect of cities on rural populations. Because of the way the system is set up, the factors of production in rural areas cannot obtain the same market value as those in cities, and compared to urban residents, farmers face limited access to public services [54]. Under this predicament, farmers move to cities in large numbers based on the great attraction of urban development opportunities and space, which directly breaks the social structure of rural areas and causes the hollowing-out and atomization of rural areas [21]. These problems constitute the current dilemma of in situ urbanization 2.0. The core focus of in situ urbanization 2.0 is changing the employment structure and lifestyle of the local population and attracting more people to return to rural areas. Doing so requires a sufficient population during the initial construction of rural digitalization; otherwise, the slow progress of the most basic construction will lead to a significant decrease in the efficiency of rural digitalization. Ultimately, the initial stages of in situ urbanization 2.0 are difficult.

4.2. External Conflict Risk of In Situ Urbanization 2.0

4.2.1. The Conflict between Governance Power and Individual Rights

In in situ urbanization 2.0, digital technologies have thoroughly impacted the logic of traditional governance. New governance theory radically challenges the traditional norms of individual rights [55]. Traditionally, the right to privacy, as a traditional fundamental right of the individual, was protected by the Chinese constitution. Unless specifically reserved by law, it is illegal to violate a citizen's constitutionally guaranteed fundamental rights. However, the "panoramic society" created by new methods of rural security management, such as the "Skynet Project" and the "Snow Bright Project", which involve 24/7 monitoring with no blind spots, has a direct impact on Chinese citizens' right to privacy. (These are closely related to the expansion of the functions of the Ministry of Public Security [56]) Even more concerning is the fact that the current national video surveillance system construction is based on norms determined mostly by low-level administrative department regulations. According to Chinese law, administrative departmental regulations do not supersede the constitution; thus, these video surveillance systems are currently suspected to be illegal for use on a large scale.

In practice, the application of new technologies still brings all kinds of secondary problems. The scale of control has a negative correlation with social dynamics. Strict control would inevitably lead to a loss of vitality in economic development, technological innovation, institutional iteration, and resource utilization, while deregulation would engender negative impacts from disorderly development. Therefore, how can the scale of monitoring be weighed? In addition, the excessive use of aspects of the "Snow Bright Project", such as the drone video surveillance of private activities in villagers' homes, is a serious violation of the basic rights of people that has grown out of digital reform. How can such breaches be regulated? Various secondary issues constitute the most serious risks of in situ urbanization 2.0.

4.2.2. The Conflict between Digital Society and Acquaintance Society

By examining practices such as precision poverty alleviation, scholars have argued that digital technology is an important way for the state to intervene and penetrate rural areas, but the operation of digital technology often hovers above grassroots governance and rural social life. As a standardized and normative industrial technological discourse, digital technology lacks the space for flexibility in some cases. This means that technological governance that pursues policy precision may neglect village community ethics and fail to serve as a mediator between the overall discourse of state governance and local ethical discourse, instead leading to a lack of social ethics and legitimacy resources for the state governance process.

A typical example is local conflict governance. For example, new types of mediation, such as online standardized mediation and online litigation by local conflict mediation centers and "Internet and people's mediation", which has the potential to escape the domination of social structures, can self-generate authority and gain the trust of the parties involved precisely because of their characteristics, such as neutrality and procedural fairness. However, standardized technical governance cannot meet the needs of the audience of grassroots governance for flexible considerations such as human feelings and customs, which is precisely what the traditional Chinese model of rural governance relies on. The rural governance models currently considered to be effective, such as the Ma Xiwu dynamic trial and the Fengqiao experience, cannot be separated from the framework of moral governance, which is determined by the fundamental characteristics of China's rural acquaintance society. Currently, rural China is still unable to completely break away from the acquaintance society framework, which creates a conflict between standardized digital governance and a resilient human society. This issue limits the further establishment of digital governance in rural areas.

5. The Future of In Situ urbanization 2.0: From Technical Reform to Institutional Adjustment

5.1. The Limits of Digital Technology in In Situ Urbanization 2.0

As early as the 1.0 era of digital reform, technology reform and system adjustment were key components of China's digital reform of government affairs. Policy makers realized early on that technological reform should be promoted together with institutional reform. However, institutional reforms involve more difficulties and are slower at producing results than technical reforms are. To quickly obtain results that are close to matching expectations, it is rational to prioritize the investment of many resources in the broad area of technological reform rather than institutional reform. Therefore, technical reform is currently the main component of in situ urbanization 2.0, and institutional, organizational, and environmental factors are supporting components, while the institutional reform under this phenomenon comes into contact with only the instrumental side of the administrative system and does not fundamentally change the layout and mechanism of administrative power operation [14].

As the Department of Economic and Social Affairs of the UN initiative suggests, technology cannot solve the problems involved in in situ urbanization processes, such as poverty. Technical advances need to be made following a holistic approach in in situ urbanization [35].Technological change is no longer sustainable for the process of in situ urbanization. There are two reasons why. First, the marginal effects of digital technology in the urbanization process have been widely demonstrated [57–59]. Based on the marginal effect of resource inputs, the current input–output ratio of technological reforms is approaching a critical point, resulting in an involution of technological reforms. This can result in ineffective in situ urbanization. Second, and most importantly, the institutional challenges of in situ urbanization 2.0 cannot be solved by technological reforms, due to the defining characteristics of in situ urbanization. In situ urbanization is a collective concept that mixes technology, policy, and other elements [35], and digital reform, a single term for describing multiple technological changes, is destined to include only some of the connotations of urbanization. Thus, while digital technology initiates the process of in situ urbanization 2.0, it is the immediate institutional adjustments that can sustainably contribute to the process of in situ urbanization 2.0.

5.2. Specific Instruments of Policy Adjustment

In responding to the above dilemmas in in situ urbanization 2.0, institutional adjustments need to be seriously considered. First, the institutional flexibility of the rural management system should be enhanced to enable an efficient enhancement of township government (Qiang Zheng Kuo Quan). In in situ urbanization 1.0, the main way in which such enhancement is achieved is through the promotion of strong towns within the administrative hierarchy. With the rise in the administrative hierarchy, powerful towns gain powers of governance that they would not otherwise have [60], such as the administrative enforcement of building violations, administrative approval of certain economic developments, and more autonomy in administrative matters. The logic inherent in this style is the CCP's traditional financial-private power matching governance, a doctrine that requires a district's administrative rank to be tied to its economic capacity [61,62]. This means that a town can be promoted to an administrative level only if it is strong enough. It is almost impossible for a commune to acquire these powers if it is weak. This empowerment mechanism does not meet the needs of the in situ urbanization 2.0 process. In in situ urbanization 2.0, the digitalization of the countryside, covering all rural areas, has rapidly brought to a large number of villages new industries that were previously available only in strong villages and towns, but it has not brought the associated governance powers to the countryside. The sluggish empowerment system has not been able to empower these villages; thus, a change in the empowerment model at the top level is one option. In the top-level design, a list of adjustments should be established and a wide range of eligible villages and towns should be empowered. In addition, a "development trigger" should be established within traditional administrative-level reform. Villages and towns that meet basic requirements related to, for example, economic size and population density, should automatically be further empowered in accordance with the "development trigger" to meet the actual needs of social governance.

Diversified financial models, such as public–private partnerships, should be more strongly encouraged to efficiently promote in situ urbanization 2.0. Specifically, these models deserve consideration. First, in the process of rural digitalization reform, the construction of infrastructure and public services, which are not profitable areas per se, requires government agencies, not investors, to bear the costs. As an appropriate solution, provincial treasuries should set up special construction funds to guarantee the adequacy of funds. Second, financial and policy support from state-owned financial institutions, such as special lending policies, should be more strongly encouraged. Third, in construction projects and public services that the government does not have to undertake, it is advisable to actively develop policies for public–private partnerships to increase the inflow channels of social capital. In addition, appropriate tax rebate policies should be considered for potential villages and towns in the process of in situ urbanization 2.0.

In agriculture, the large-scale promotion of e-commerce is a path worth considering to precisely empower agriculture in in situ urbanization 2.0. First, qualitative research points to the sweeping changes that large-scale e-commerce has brought to rural areas. These changes include increasing local incomes, restructuring production patterns, and increasing jobs, and these changes have significantly promoted in situ urbanization. Second, official data and many scholars indicate that there is great room for e-commerce development in rural areas. On the one hand, in terms of quantity, official data reveal that e-commerce in rural areas is extremely unevenly developed. Counties with less than a 50% household broadband access rate and counties with less than a 5% informatization level of agricultural production are the subject of 21.7% and 26.9% of all domestic research, respectively [63]. On the other hand, in terms of quality, e-commerce currently faces outstanding problems, such as end-transportation capacity, professional training, and imperfect service systems. These problems have directly led to the inefficient operation of rural e-commerce [15]. Therefore, in the context of rural digitalization reform, a new, targeted and large-scale rural e-commerce policy system should be established. Such a policy system should actively expand e-commerce coverage on the one hand and guide e-commerce farmers towards entrepreneurship, specialization, and branding on the other hand.

Policies to promote the balanced supply of urban–rural public services should be set up and scaled up on a large scale in the process of in situ urbanization 2.0. The new policies should focus on two aspects. First, the public service system in villages and towns should be configured based on actual needs, taking into account the standards of urban-type public service facilities. Specifically, in the administrative system, in addition to government agencies (such as the police, business bureaus, and tax services), neighborhood committees adapted to the needs of community management should replace the original village committee system. In terms of educational facilities, in addition to improving elementary schools, a certain number of kindergartens, nurseries, and other educational institutions should be located in densely populated townships to improve the educational level of these areas. In cultural construction plans, theatres and lighted stadiums should be appropriately allocated based on the level of economic development and population. In terms of healthcare, permanent health centers (clinics, offices), family planning stations, etc., should be founded in these areas. Moreover, public services specifically needed for the development of rural agriculture should be a focus. For example, after the digital restructuring of the agricultural industry, such as the transformation of family-oriented production, the demand for public services such as training in modern agricultural techniques should be met.

6. Conclusions

Digital technologies have led to major practical and academic concerns in terms of sustainable urban planning in China. However, few scholars have focused on the impact of digital technologies on in situ urbanization from a policy-technology perspective, which is what this article is concerned with. The article argues that digital technologies have changed the development process of in situ urbanization from 1.0 to 2.0 based on four officially defined criteria: infrastructure development, agricultural industrialization, public service levels, and rural local governance, under the influence of rural digitalization policies. These changes have altered the traditional logic of in situ urbanization and revolutionized its efficiency by accelerating it. The article argues that the decapitalization and great efficiency gains generated by innovations based on digital policies constitute the key features that distinguish in situ urbanization 2.0 from 1.0. Accordingly, this paper proposes the concept of in situ urbanization 2.0 to describe this change. Historical legitimacy, performance legitimacy, and socially sustainable reproduction are three political, economic, and social reasons why rural digitalization reform has triggered in situ urbanization 2.0. Finally, this paper identifies the double limitation of the overreliance on technological reforms in the process of in situ urbanization 2.0, where there is an internal non-self-consistent dilemma and external conflict risk. Due to the limitations of digital technology, these dilemmas cannot be eradicated by technological updates. Therefore, this paper argues that an institutional change in the mode of operation of power can overcome the dilemmas faced by in situ urbanization 2.0 and it proposes some recommendations to address these issues.

This article does not consider regional characteristics, which could weaken the strength of the argument. It focuses on a holistic picture. Reform in rural areas of China, a very large country, will be greatly complex, and the focus of reform varies greatly from region to region. The intensity of reforms can also vary across regions due to differences in fiscal construction capacity. None of these phenomena are carefully considered in this paper. Furthermore, the concept of in situ urbanization 2.0 proposed in this paper has not been tested by empirical research. Thus, the concept needs further empirical research before theoretical refinement and revision can be pursued. Thus, future studies should focus on regional characteristics and conduct empirical research to test the current results.

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Appendix A

Table A1. Emphasis of digital government construction in China's provinces in 2022 [63].

Province	Emphasis of Digital Government Construction
Beijing	Create "Trouble-free Ubiquitous '6 + 4'" integrated, comprehensive supervision system
Tianjin	Create a number of application demonstration scenarios, and strengthen the "Double Random, One Public" supervision
Hebei	Accelerate the standardization of administrative licensing matters and achieve full coverage of electronic licenses
Shanxi	Further promote the reform of "Separation of Operating Permits and Business Licenses", and implement inclusive and prudent supervision over new formats and fields.
Inner Mongolia	Optimize "Government Online-offline", start "Government Online-offline Unified Management", deepen the "Mengsuban. Siban" service
Liaoning	Explore and carry out the reform of a beneficial enterprise policy "Enjoying without Application" and enhance the application level of "Liaoshitong".
Jilin	Create an efficient and convenient government environment, and continue to deepen the "Separation of Licenses" and "One Code License Passing " reform
Heilongjiang	Promote the "Separation of Licenses" and "Integration of Multi-licenses" reform, and continue to improve the ease of access of market entities
Shanghai	Promote the iterative upgrade of "Government Online-Offline Shanghai", lay out region-wide application scenarios, and accelerate the digitization of governance
Jiangsu	Deepen the "One Thing" reform, promote "Inter-provincial Government Services' 'Wangtongban", and promote the effective combination of market and the government service
Zhejiang	Improve the integrated intelligent public data platform and iteratively upgrade the digital reform
Anhui	Establish "Internet + Government Services" and promote "One Screen Services" reform
Fujian	Continuously optimize the online government service platform and build a good government information "One Net"
Jiangxi	Upgrade the new mode of separating front and back-end functions of "Ganfutong
Shandong	Improve the province's integrated big data platform and build a "Paper-Proof-Free Province"
Henan	Organize provincial government services hall to promote provincial approval matters and no approval outside the hall
Hubei	Continue to promote "Efficient Service of One Thing" to achieve maximum online and local service
Hunan	Accelerate the construction of digital government and create an upgraded version of "One Thing One Time"
Guangdong	Comprehensively promote the "Digital Government 2.0" construction
Guangxi	Promote the application of "Zhiguitong" platform, deepen the "Separation of Licenses" reform
Hainan	Reinforce the concept of whole government and promote digital transformation of government
Sichuan	Promote the digitalization and convenience of public services, and create a "City Brain" and a "Government Hub"

Table A1. *Cont.*

Province	Emphasis of Digital Government Construction
Guizhou	Take "One cloud, One network, One platform" as a carrier to accelerate the construction of digital government
Yunnan	Continuously upgrade the integrated government services platform and "One Phone Service"
Chongqing	Promote the reform of government service matters and enhance the "Yukuaiban" efficiency
Tibet	Promote "One Network for Government Services" and "Internet +" model
Shaanxi	Achieve more government services through Government Online-offline, cross-province service, second approval seconds service
Gansu	Focus on the goal of "Leading in the Midwest, First-class in the Country" goal, accelerate the construction of a digital government welcomed by enterprises and the people.
Qinghai	Promote more government services online, online and local handling cross-province service
Ningxia	Simplify business-related permits, implement "One Permit To Operate" "Simple Cancellation
Xinjiang	Vigorously promote the construction of "Digital Government", accelerate the construction of business environment of marketization, legalization and internationalization

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Behaviour-Driven Energy-Saving in Hotels: The Roles of Extraversion and Past Behaviours on Guests' Energy-Conservation Intention

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Abstract: The growing environmental concerns and the significant energy consumption in hotel buildings make the ability to proactively manage energy and lower carbon intensity essential in the global hospitality industry. Activating guests' energy-conservation behaviours is a potential strategy for sustainable hotel operation and maintenance. Yet, the psychological mechanism of hotel building energy-conservation intention and the roles of personality traits have not been sufficiently investigated. This study aims to examine the role of guests' extraversion levels in their hotel building energy-conservation behavioural intention using a modified theory of planned behaviour (TPB) model. The study extends the TPB model with personal norms and past behaviour as two additional factors and employs past behaviour as a moderator to bridge extraversion and other psychological factors. A field experiment was conducted consisting of 530 hotel guests in Shanghai, China. The results demonstrate the relationships between attitude, behavioural control, personal norms, past behaviour and energy-conservation intention. Specifically, extraversion negatively influences perceived behavioural control (PBC) ($\beta = -0.176$, $p < 0.001$) and positively impacts on personal norms ($\beta = 0.290$, $p < 0.001$), both of which significantly contribute to guest energy-saving intention. In addition, past behaviours positively moderate the effects of extraversion on subjective norms and personal norms. This research enriches the hospitality and tourism management literature by shedding novel light on how guests' personality characteristics influence their pro-environment intentions during their stays in hotel buildings. The findings would drive the hotel building energy management forward through actionable and effective energy-conservation interventions and enhanced guest satisfaction.

Keywords: energy conservation; extraversion; green hotel; past behaviour; personality traits; pro-environmental management

1. Introduction

The energy crisis sweeping the globe in 2022 underscores the importance of energy security and highlights the critical role of energy management in almost all industries. The hospitality and tourism industry has been an important energy consumer and carbon emitter [1–3] Given that rising energy consumption has burdened hospitality practitioners with additional operational costs, academia and industry have developed several sustainable strategies focusing on hotel operation and management. For example, many works encouraged energy retrofitting and equipped hotels with more energy-efficient building services [4,5]. Though these engineering-based solutions can contribute to the sustainability of hotel operations, their higher initial and maintenance costs could be a significant burden on hotel managers and operators.

In addition to the hotel energy retrofits, it has been confirmed that behaviour-driven energy-conservation strategies are also effective in sustainable hotel operation and maintenance [6]. Behavioural factors have been well discussed in both building energy modelling [7] and management [8]. In the hospitality and tourism field, several studies pointed out that people consume significantly more resources at hotels than at home [9,10]. More specifically, the excessive consumption behaviours of hotel guests contribute to over 75% of the hotels' environmental impact [10], where each guest directly consumes 272 MJ energy, 350 L water, and emits 13.8 kg CO_2 per night [11]. Given the threat of the energy consumption issues, many empirical studies have shifted their focus on energy-conservation behaviours in the household [12,13] and workplace [14,15] contexts. In addition, sufficient evidence suggested that behavioural intervention can reduce building energy demand by 10% to 25% [16,17] Therefore, behaviour-driven strategies present potential as a low-cost energy management approach in hotel operations.

In recent years, academia has paid more attention to pro-environmental behaviours (PEBs) in the hospitality industry. In particular, there is an increasing number of studies on waste reduction and the water-conservation behaviours of hotel guests [10,18–22]. Among these studies, the theory of planned behaviour (TPB) framework has been widely employed to explain the psychological mechanism of PEBs in hotels [3,21,22]. Additionally, some studies have shown the importance of personality traits as antecedents of individual behaviour differences in hotel PEBs [23,24]. For example, Kozako et al. (2013) found that personality, especially extraversion and agreeableness, has a strong influence on hotel employees' individual work behaviour rather than their organisational behaviour [25]. In addition, extraversion plays an important role as the driver of the stable individual differences in hotel PEBs [23,26]. Although much research found that personality has the potential to influence individuals' PEB, there is still a lack of sufficient research to explore how each specific personality trait plays an important role in guests' hotel energy-saving willingness.

A thorough understanding of guests' energy-conservation behavioural process could be essential for intervention development and implementation. However, only a few studies have examined the energy-conservation behaviours of hotel guests [3]. Existing studies do not fully explain the factors that trigger customers to conserve energy during their hotel stays and the psychological mechanism of the hotel energy-conservation behaviour is still unclear. To address the aforementioned research gaps, the purpose of this study is to explore the relationship between extraversion and hotel guests' hotel energy-saving intentions, and whether the adoption of behavioural habits contributes to moderating the effects on psychological factors by employing an extended TPB model. Given the sustainable trend in the hospitality industry, this study will provide concrete and reliable measures for both managerial and theoretical implications for sustainable hotel operation and maintenance.

The remainder of the paper is constructed as follows. Section 2 provides a literature review, presents the theoretical framework and develops hypotheses based on this review. Section 3 presents the materials and methods used in this study. Section 4 shows the hypotheses results and mentions the model outcome. Section 5 discusses the findings and proposes potential further research directions. The last section presents the conclusion.

2. Literature Review

2.1. Theory of Planned Behaviour

The theory of planned behaviour (TPB) is an extension of the theory of reasoned action (TRA) with an enhanced predictive power [27]. The TPB model also pays more attention to the hedonistic side of human behaviours. Specifically, this model assumes that an individual's behaviour (or decision making) is driven by her/his intention to carry out the specific behaviours (or decisions). The term of intention refers to an individual's readiness to perform a specific behaviour or to make a specific decision. The TPB model develops three psychological factors to determine the behavioural intention: (1) attitude, which refers to one's subjective evaluation of the nature and the outcome of a specific behaviour; (2) subjective norms, which refers to one's perceived expectations from other people and society in general; and (3) perceived behavioural control (PBC), referring to the perceived ability to perform a specific behaviour or the self-evaluation of the convenience of the specific behaviour, which is rooted under Bandura's social cognitive theory [27,28]. The TPB model has been employed in predicting a wide range of pro-environmental intentions and behaviours such as recycling [29], green product consumption [30] and household and office energy conservation [12,13,31].

Recently, many existing studies have attempted to incorporate the TPB model into hotel PEBs research. Several studies examined the role of three TPB factors in green hotel visiting intention. For example, Verma and Chandra (2018) [24] and Chen and Tung (2014) [32] report that all three factors in the TPB model are positively correlated with guests' green hotel visiting intention in the India and China context, respectively. In addition to green visiting behaviour, some researchers also adopted the TPB model to explain guests' PEBs during their hotel stays. For example, Budovska et al. (2020) [21] observed significant relationships between three TPB factors and hotel towel use intention. In addition, Fatoki (2020) [22] also noted similar findings in his research on hotel water conservation behaviours. Based on the aforementioned discussions, this research posits the following hypotheses:

Hypotheses 1 (H1). *Attitude positively influences the hotel energy-conservation intention of guests.*

Hypotheses 2 (H2). *Subjective norms positively influence the hotel energy-conservation intention of guests.*

Hypotheses 3 (H3). *PBC positively influences the hotel energy-conservation intention of guests.*

2.2. Personal Norms

The TPB can be modified and extended in different situations. Personal norms is a widely used determinant to extend the TPB (also called the morally extended TPB). The term "personal norms" refers to the perceived responsibility or moral obligation of an individual for a certain action or a decision [33]. Several studies have identified that there is a direct correlation between personal norms and PEBs in hotels. For example, Han et al. (2020) [18] found that personal norms have a significant and positive relationship with both hotel water-conservation intention and waste-reduction intention. Another study noted that personal norms have a direct impact on towel reuse behaviours [34]. Although the morally extended TPB gained prevalence in PEBs research, some researchers also reported different views and results [32,35]. For instance, Chen and Tung (2014) [32] reported a less significant statistical relationship between personal norms and green hotel visiting intention (i.e., $p < 0.10$). Hence, the following hypothesis is developed:

Hypotheses 4 (H4). *Personal norms positively influence the hotel energy-conservation intention of guests.*

2.3. Extraversion

Personality traits reflect the individual's stable perception and behaviour patterns. In 1949, Fiske summarised the previous personality research and proposed the Big Five personality model [36]. In decades of development, the Big Five personality traits have become the most widely used personality model [37]. Previous research has confirmed the cross-cultural reliability of the Big Five personality model [38]. In particular, an increasing number of studies employ the Big Five personality traits to explain individual stable differences in pro-environmental behaviours and decision making [14,23,39–41].

Extraversion is a particular personality trait that shows the individual's group participation and sociality [42,43]. Extraverts are more willing to participate in group activities and pursue mainstream ideas [41]. Thus, extraversion might have a stronger impact on pro-environmental behaviour in public places. For example, studies found that extraversion can significantly promote energy-conservation behaviour in offices [14] rather than at home [13]. Moreover, the extraversion personality trait also presented positive roles in the donation to the WWF charity [44] and in waste management [45]. Additionally, in the tourism and hospitality industry, Kvasova (2015) [23] found that extraversion shows a direct impact on sustainable tourism in Cyprus. Tang and Lam (2017) [26] also reported that extraversion is positively associated with the individual's willingness to pay for green hotels. In recent years, several empirical studies have also evidenced that personality factors can have an indirect effect on PEBs through the TPB factors [29,31,46,47]. This study hypothesises that extraversion also plays a positive role in hotel energy-conservation intention and develops the following hypotheses:

Hypotheses 5 (H5). *Extraversion positively influences the hotel energy-conservation intention of guests.*

Hypotheses 6 (H6). *Extraversion significantly influences attitude (6a), subjective norms (6b), PBC (6c) and personal norms (6d) towards hotel energy-conservation intention.*

2.4. Past Behaviour

Relevant existing studies have also discussed the role of past behaviour in predicting future actions and decision making [31,48–51]. However, this contract has been a controversial predictor in the PEBs research. On the one hand, Ajzen (1991) [27] argued that past behaviour only indirectly contributes to the intention. Norman et al. (2000) [49] noticed that past behaviour only plays a mediating role. Han et al. (2018) [52] also reported that household behaviour is a moderator in predicting hotel towel reuse behaviour. On the other hand, more studies have observed contrasting results in recent years [3,31,53,54]. More empirical evidence has been reported in the tourism and hospitality management field; for example, Budovska et al. (2020) [21] highlighted the significant effect of past behaviours on the towel reusing intention of hotel guests. Similarly, Yadegaridehkordi et al. (2021) [54] also found a strong influence of past behaviours on green hotel visiting. It is believed that past behaviour is related to the development of habits and can be a direct predictor of some pro-environmental intentions. Based on the abovementioned discussion, this study develops the following hypotheses:

Hypotheses 7 (H7). *Past behaviour positively influences the hotel energy-conservation intention of guests.*

Hypotheses 8 (H8). *Past behaviour moderates the relationships between extraversion and attitude (8a), subjective norms (8b), PBC (8c) and personal norms (8d) towards hotel energy-conservation.*

In general, Figure 1 illustrates the developed theoretical framework that summarises all of the aforementioned proposed hypotheses.

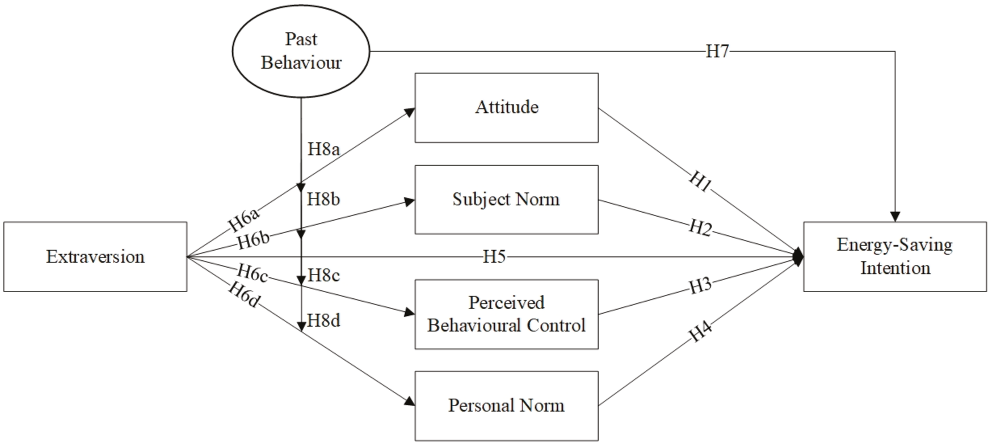

Figure 1. Theoretical framework.

3. Methodology

3.1. Questionnaire Design

The study employed a questionnaire survey method and collected data from hotel guests, which is a widely used method in pro-environmental behaviour studies. The constructs of the questionnaire were developed from the literature review. The questionnaire contained three sections: personality traits, psychological characteristics, and sociodemographic information. Referring to the literature review, the items in the questionnaire included the psychological characteristics of extraversion, attitude, subjective norms, perceived behavioural control, personal norms and energy-conservation intention. In addition, the personal characteristics (e.g., gender, age, education, income) of the respondents are indicated as the potential factors in expounding energy conservation [55], and the information was thus gleaned from the questionnaire survey.

The Likert scale is an effective method to capture the respondents' viewpoints [29]. The study employed a five-point Likert scale measurement for psychological variables (ranging from 1: totally disagree to 5: totally agree). Based on the suggestions and feedback from respondents in the pilot study, the study employed a seven-point Likert scale for personality characteristics (1: totally disagree; 2: disagree; 3: slightly disagree; 4: neutral; 5: slightly agree; 6: agree; 7: strongly agree). There are several PEB studies that use a seven-point Likert scale to measure the personality traits of the respondents, such as Kvasova (2015) [23] and Milfont and Sibley (2012) [40]. The questionnaire started with an introduction session on the research purposes, and privacy protection commitments. The survey presented the explanation of "There is no right or wrong answer and just consider what your thoughts are" to the respondents on each page.

3.2. Data Sampling

Before the formal survey, the researchers organised three rounds of the pilot study to validate the design rationality, readability and items of the questionnaire. The attendant of the first-round pilot study provided some suggestions on the sequence of a few items and the clarity of the statements. The researchers accordingly improved the quality of the questionnaire based on the discussion. Some hotel customers were invited to participate in the second- and third-round pilot studies. Their feedback contributed to further slight improvements to the questionnaire.

After the pilot study, the formal questionnaire survey was conducted in Shanghai, one of the representative cities in China. The study received 827 responses from hotel guests and 530 final responses were utilised for analysis after checking the quality of the collected questionnaire results and eliminating invalid feedback. Table 1 shows the demographic information of the efficient responses from 530 respondents.

Table 1. Demographic information of respondents.

Demographic		Frequency	Percentage
Gender	Female	224	42.26%
	Male	306	57.74%
Age	Under 25	123	23.21%
	26 to 30	123	23.21%
	31 to 40	197	37.17%
	41 to 50	74	13.96%
	51 to 60	10	1.89%
	above 60	3	0.57%
Education Level	Secondary Degree or Below	4	0.75%
	High School or Equivalent	22	4.15%
	Diploma Degree or Continuing	71	13.40%
	Bachelor's Degree or Equivalent	376	70.94%
	Master's Degree or Equivalent	51	9.62%
	Doctoral Degree or Equivalent	6	1.13%
Yearly Income (CNY)	100,000 and Below	133	25.09%
	100,000 to 150,000	167	31.51%
	150,000 to 200,000	91	17.17%
	200,000 to 250,000	53	10.00%
	250,000 and Above	40	7.55%
	Not Applicable	46	8.68%

Note: CNY is Chinese Yuan (1 US Dollar is approximately equivalent to 6.37 Chinese Yuan).

The demographic result reveals that female respondents account for 42.26% and the proportion of males is 57.74%, thus, the gender ratio basically consists of the local situation. It is worth noting that 31 to 40 years is the largest age group, which occupied 70.94%. The age groups of both under 25 and 26 to 30 are the second largest groups, accounting for 23.21%. The other groups represent a smaller percentage. In addition, most of the respondents obtained a bachelor's degree or had equivalent experience (70.94%). The percentage rate of respondents who received a diploma degree (13.40%) is similar to the group with a master's degree or equivalent (9.62%). Moreover, among the 530 respondents, the majority of people (31.51%) earned 100,000 to 150,000 CNY (equivalent to 15,699 to 23,575 USD) in a year, followed by those who made 100,000 CNY (equivalent to 15,699 USD) and below (25.09%), and 150,000 to 200,000 CNY (equivalent to 23,575 to 31,397 USD) (10.00%). The sociodemographic information characteristics of the respondents in this study are similar to the local characteristics, which proves that the sample is representative to a certain extent.

4. Data Analysis

Structural equation modelling (SEM) is a method of establishing, estimating and examining the causality of a model [56]. The method combines the statistical methods of factor analysis and path analysis, which explore the relationship between observed variables and latent variables [56]. Specifically, SEM includes two aspects: the measurement model and the structural model. The study aims to investigate the relationship between variables and explore the interaction effect of extraversion and psychological variables. SmartPLS 3.0 was employed for the SEM analysis in this study. SmartPLS 3.0 is a widely-used Java-based software for variance-based SEM with the partial least squares path method. Several studies use SmartPLS 3.0 in PEB research, such as Liu et al. (2021) [31], Wang, Chang et al. (2021) [13] and Wang et al. (2020) [14].

4.1. Model Fit and Variance Inflation Factor

Before assessing the path coefficient, the researchers tested the model fit and variance inflation factor (VIF) in advance. The Standardized Root Mean Square Residual (SRMR) is the absolute goodness-of-fit index, which assesses the model explanation ability [57]. An SRMR value below 0.10 or 0.08 is considered a sufficient model fit [58]. VIF quantifies the severity of multicollinearity in ordinary least squares regression analysis, which is an important criterion to measure the multicollinearity issue between independent variables [56]. The VIF value is suggested to be less than 5 [56]. Table 2 presents the VIF values of the variables.

Table 2. Variance inflation factor value.

Item	VIF	Item	VIF	Item	VIF
E-1	1.717	ATT-1	1.332	INT-1	1.543
E-2	1.495	ATT-2	1.349	INT-2	1.593
E-3	1.728	ATT-3	1.372	INT-3	1.321
E-4	1.430	PBC-1	1.236	PB-1	1.122
		PBC-2	1.086	PB-2	1.097
		PBC-3	1.309	PB-3	1.132
		SN-1	1.420	PB-4	1.090
		SN-2	1.610		
		SN-3	1.220		
		PN-1	1.159		
		PN-2	1.370		
		PN-3	1.290		

Note: VIF is variance inflation factor value; E is extraversion; ATT is attitude; PBC is perceived behavioural control; SN is subjective norms; PN is personal norms; INT is energy-conservation intention; PB is past behaviour.

The analysis reports that the SRMR of the proposed model is 0.079, which meets the goodness-of-fit requirement. The VIF values of the variables range between 1.086 and 1.717, confirming that there is no significant multicollinearity issue between the variables.

4.2. Measurement Model

Table 3 represents the results of the convergent validity tests. The analysis results reveal that the Cronbach's alpha ranges between 0.627 and 0.780, the composite reliability ranges between 0.801 and 0.859, and the AVE ranges between 0.535 and 0.671. All constructs satisfy the criteria of convergent validity.

Table 3. Convergent validity testing.

Construct	Item Number	Factor Loading	Cronbach's Alpha	Composite Reliability	AVE
Extraversion	4	0.649–0.862	0.780	0.848	0.587
Attitude	3	0.776–0.806	0.694	0.830	0.620
Subjective Norms	3	0.761–0.865	0.763	0.859	0.671
Perceived Behavioural Control	3	0.738–0.835	0.739	0.840	0.637
Personal Norms	3	0.678–0.821	0.627	0.801	0.575
Energy-Conservation Intention	3	0.745–0.848	0.733	0.849	0.652
Past Behaviour	4	0.681–0.778	0.639	0.821	0.535

Discriminant validity requires that the observed values should be able to distinguish constructs. The Heterotrait–Monotrait (HTMT) is a ratio to evaluate discriminant validity, whose values should be below 0.9 [59]. Table 4 shows the result of the HTMT of the analysis fulfilling the statistical requirements.

Table 4. Heterotrait–Monotrait ratio.

	Extraversion	Attitude	Subjective Norm	PBC	Personal Norm	Intention	Past Behaviour
Extraversion							
Attitude	0.191						
Subjective Norms	0.486	0.649					
PBC	0.196	0.519	0.230				
Personal Norms	0.444	0.609	0.826	0.118			
Intention	0.162	0.752	0.472	0.646	0.701		
Past Behaviour	0.291	0.599	0.527	0.645	0.533	0.663	

Note: PBC is perceived behavioural control; Intention is energy-conservation intention.

4.3. Structural Modelling

Structural modelling is used to examine the significance of the hypotheses by using a bootstrapping technique. The study ran a 5000-bootstrap resampling to test the proposed model to find out the significance of the path coefficients, and Table 5 reveals the analysis result.

Table 5. Path coefficient results.

Hypotheses	Relationship	Path Coefficient	Standard Deviation	T Statistics	*p* Values
H1	Attitude → Energy-Conservation Intention	0.267	0.046	5.825	***
H2	Subjective Norms → Energy-Conservation Intention	0.028	0.053	0.528	0.598
H3	PBC → Energy-Conservation Intention	0.290	0.042	6.891	***
H4	Personal Norms → Energy-Conservation Intention	0.310	0.043	7.258	***
H5	Extraversion → Energy-Conservation Intention	−0.022	0.036	0.621	0.535
H6a	Extraversion → Attitude	0.075	0.041	1.842	0.066
H6b	Extraversion → Subjective Norms	0.322	0.038	8.559	***
H6c	Extraversion → PBC	−0.176	0.042	4.205	***
H6d	Extraversion → Personal Norms	0.290	0.038	7.715	***
H7	Past Behaviour → Energy-Conservation Intention	0.109	0.039	2.814	0.005 **

Note: PBC is perceived behavioural control; *** is $p < 0.001$; ** is $p < 0.01$.

Regarding the psychological factors that affect hotel energy-conservation intention, the results show that personal norms ($\beta = 0.310$, $p < 0.001$) are the most important predictor of hotel energy-saving intention. The finding indicates that perceived behavioural control ($\beta = 0.290$, $p < 0.001$) has the second-greatest effect on guests' energy-conservation intention among these variables. Moreover, attitude ($\beta = 0.267$, $p < 0.001$) and past behaviour ($\beta = 0.109$, $p = 0.005$) significantly contribute to the energy-saving intention of hotel customers. Therefore, hypotheses 1, 3, 4 and 7 are supported. However, hypotheses 2 and 5, which proposed the positive influences from extraversion and subjective norms on hotel energy-conservation intention, are not identified. Figure 2 displays the SEM result of the proposed model.

The results show that extraversion plays the most principal key role in hotel guests' subjective norms ($\beta = 0.322$, $p < 0.001$). Extraversion is also significantly positively associated with their personal norms ($\beta = 0.290$, $p < 0.001$). Hence, the result supports hypotheses 6b and 6d. By contrast, the result implies a negative effect of extraversion on perceived behavioural control ($\beta = -0.176$, $p < 0.001$). In addition, the path from extraversion to energy-conservation intention and attitude are nonsignificant, thus failing to provide support for hypotheses 5 and 6a.

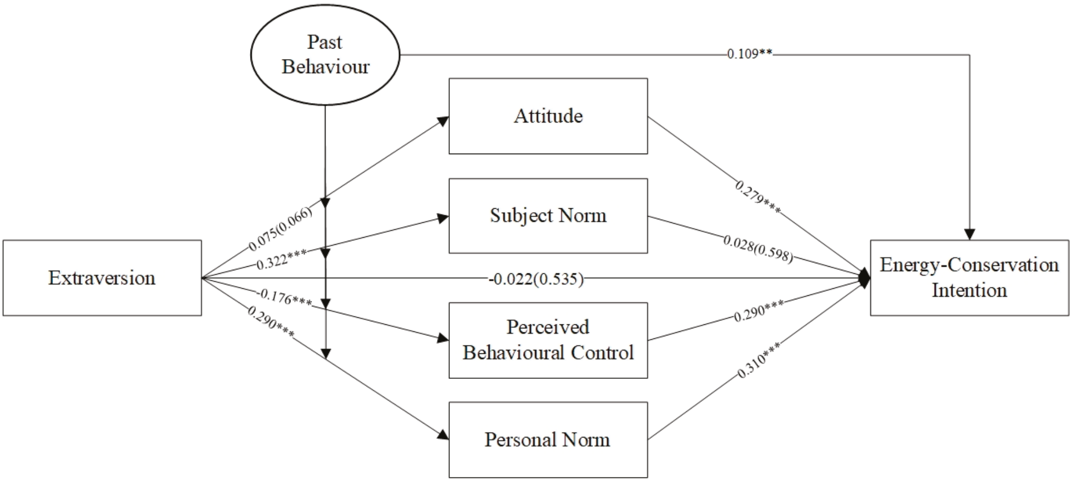

Figure 2. Testing result of structural equation model. *** is $p < 0.001$; ** is $p < 0.01$.

4.4. Moderating Effect of Past Behaviour

According to hypotheses 8a, 8b, 8c and 8d, past behaviour moderates the effect of extraversion on attitude, perceived behavioural control, subjective norms and personal norms. In order to investigate the moderating effect of past behaviour, the study further tested the simple slopes analysis in SEM. The SEM-estimated result of the moderation effect is listed in Table 6, and the slope analysis result is presented in Figure 3.

Table 6. Result of the moderation effect of past behaviour.

Hypotheses	Relationship	Path Coefficient	Standard Deviation	T Statistics	*p* Values
H8a	Extraversion × Past Behaviour→Attitude	0.090	0.050	1.794	0.073
H8b	Extraversion × Past Behaviour→Subjective Norms	0.090	0.010	2.173	0.030 *
H8c	Extraversion × Past Behaviour→PBC	0.119	0.039	3.065	0.002 **
H8d	Extraversion × Past Behaviour→Personal Norms	0.087	0.044	1.981	0.048 *

Note: PBC is perceived behavioural control; ** is $p < 0.01$; * is $p < 0.05$.

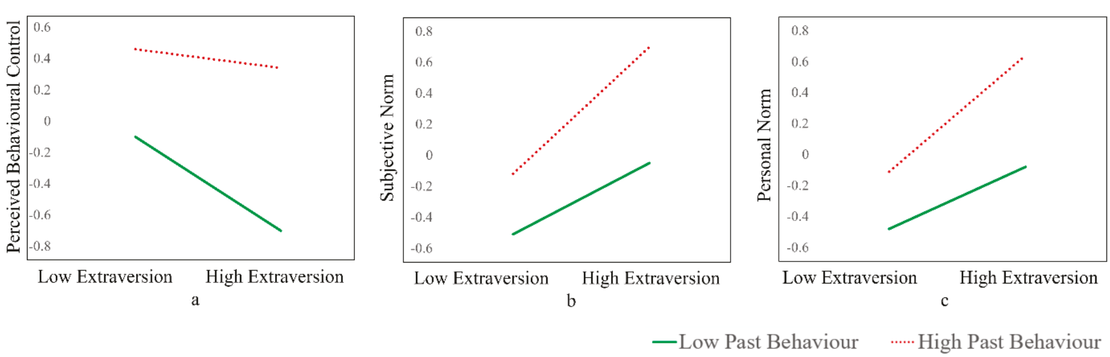

Figure 3. Moderating effect of past behaviour. (**a**) Perceived Behavioural Control. (**b**) Subjective Norm. (**c**) Personal Norm.

The results illustrate that the interaction of extraversion × past behaviour is positively correlated to three psychological factors. In the impact path of extraversion on perceived behavioural control, the coefficient value is the highest (β = 0.290, $p < 0.001$), revealing that past behaviour is correlated to extraversion on perceived behavioural control positively. The path of extraversion on hotel guests' subjective norms and personal norms are slightly similar. The interaction of extraversion × past behaviour has the second strongest effect on subjective norms (β = 0.090, $p = 0.030$). The path coefficient of extraversion × past behaviour on personal norms is 0.087, with a p-value of 0.048. The above results supported hypotheses 8b, 8c and 8d. On the contrary, the result shows there is no significant effect on the path of extraversion on customers' attitude, meaning that past behaviour plays no moderating effect on the path.

Figure 3 displays the plots of the significant interaction between past behaviour and extraversion on perceived behavioural control, subjective norms and personal norms. For instance, Figure 3a illustrates that a high degree of past behaviour improves the impact of extraversion on perceived behavioural control obviously. Similarly, the high level of past behaviour improves the influence of extraversion on both subjective norms and personal norms.

4.5. Results Summary

According to the abovementioned measurement modelling, structural equation modelling and moderating analysis, the test results show that H1, H3, H4, H6 (b, c, d), H7 and H8 (b, c, d) are supported, while H2, H5, H6a and H8a are rejected. The results indicate that most of the psychological characteristics (i.e., attitude, subjective norms and PBC) and past behaviour have a significant positive influence on hotel energy-conservation intention. At the same time, hotel guests' extravert personalities positively affect subjective norms, PBC and personal norms. In addition, guests' past behaviour plays an important role in moderating extraversion's effect on energy-saving intention. Table 7 summarises the test results.

Table 7. Reflection of the test results.

Hypotheses	Relationship	Hypotheses Result
H1	Attitude → Energy-Conservation Intention	Support
H2	Subjective Norms → Energy-Conservation Intention	Reject
H3	PBC → Energy- Conservation Intention	Support
H4	Personal Norms → Energy-Conservation Intention	Support
H5	Extraversion → Energy-Conservation Intention	Reject
H6a	Extraversion → Attitude	Reject
H6b	Extraversion → Subjective Norms	Support
H6c	Extraversion → PBC	Support
H6d	Extraversion → Personal Norms	Support
H7	Past Behaviour → Energy-Conservation Intention	Support
H8a	Extraversion × Past Behaviour→Attitude	Reject
H8b	Extraversion × Past Behaviour→Subjective Norms	Support
H8c	Extraversion × Past Behaviour→PBC	Support
H8d	Extraversion × Past Behaviour→Personal Norms	Support

Note: PBC is perceived behavioural control.

5. Discussion

Based on the proposed theoretical framework, we examine the statistical relationship between the psychological factors in the extended TPB and hotel energy-conservation intention. Specifically, the study observes that the direct correlation between subjective norms is insignificant, but highlights the criticality of personal norms in in-hotel energy conservation (i.e., β = 0.310, $p < 0.001$). This result is in line with previous work on in-hotel PEBs [18,34,60]. Existing hotel practitioners often employ social normative messages as an intervention to encourage the PEBs of hotel guests [52]. However, the finding suggests that internal normative factors (i.e., sense of moral obligation) play more important roles than external pressure in hotel energy conservation. Therefore, personal norm-based interventions would be more effective in promoting hotel energy-conservation behaviours.

For example, persuasive moral norm messages, such as "saving energy is our responsibility" and "energy conservation is important to save the environment", might be a potential intervention in practice.

The research also suggests that hotel guests' intention to save energy increases with stronger attitude toward hotel energy conservation. Therefore, it is important to enhance the guests' subjective evaluation as well as perceived outcomes of the hotel's energy-saving behaviours. For the guests, the perceived outcomes of their energy-saving behaviours are usually in terms of resource or environmental benefits. Therefore, hotel practitioners may consider informing guests of the more figurative or even quantified environmental impacts of hotel energy-saving behaviours. For example, hotel practitioners may inform guests that "saving 10% of energy during the stay is equivalent to protecting a plant" rather than "saving energy is good" in the welcome letters. In addition, hotel practitioners can share the economic benefits of energy-saving behaviours with their guests. For example, the hotel can use the reduced energy budget for public welfare and acknowledge the contribution of their guests. In addition, some studies mention that guests' perception of energy-saving behaviour outcomes can be changed by means of cash incentives [32] or energy-saving options [61].

In addition, this study sheds new light on the psychological process of in-hotel energy-conservation behaviours from the view of extraversion. Some researchers have considered personality traits in hotel PEB studies [24,26] However, there is an apparent lack of research focusing on the role of personality factors in hotel energy-conservation. We find that extraversion exerts a direct and positive influence on subjective norms and moral norms, while it also has a significant, but negative, effect on PBC. Thus, extraverted traits prompt hotel guests to tend to consider the expectations of others and moral factors, while they are more likely to be held back by the convenience of energy-saving behaviours. This finding is different from a previous study on household energy-saving behaviours [13], which reported an insignificant link between extraversion and normative factors. A potential explanation is that the household provides a more private context, and extraversion presents a stronger influence on PEBs in public contexts rather than in private environments [14]. The findings can contribute to more customised energy interventions in hotel operations.

The study also discusses the role of past behaviour in hotel energy-conservation behaviour. We observe a direct and significant correlation between past behaviour and energy-saving intention, which is consistent with the findings of Budovska et al. (2020) [21] and Han and Hyun (2018) [34] on other in-hotel PEBs of guests. In addition, our analysis results reveal the moderating mechanism of extraversion and the psychological drivers of hotel energy-saving intention and demonstrate that past behaviours moderate the linkages between extraversion and subjective norms, personal norms and PBC. The findings suggest that at a similar level of extraversion, guests who perform more energy-saving behaviours at home or in the workplace gain stronger levels of subjective norms, personal norms and PBC. The critical effects of past behaviours emphasise the habitual influence and imply that it is important to boost residents' daily energy-saving actions to promote their hotel energy conservation. In practice, hotel practitioners can employ message interventions to strengthen the link between energy-saving behaviours in the hotel and the household.

In terms of the limitations, first, the survey in this study only focuses on hotel guests in China and, therefore, more future investigations are necessary to generalise the findings to other racial populations, countries and areas. Second, although the widely used five-factor personality scale or the HEXACO scale can explain the personality differences among guests well, they are difficult to apply in the practice of hotel operations. Additionally, in practice, hotel operators and practitioners need to consider the comprehensive impact of different personality traits on hotel PEB, not just extraversion. Therefore, further work would benefit the hospitality industry by revealing the integrated effect of personality traits on hotel PEBs and further simplifying the personality scales (e.g., setting up personality profiles) to develop feasible differential interventions. Third, this study only focuses on the energy-conservation behaviours of hotel guests. Other PEBs for hotel guests, such as water conservation, food conservation and waste recycling, are also critical to the sustainability of the hospitality industry. Future studies could consider these PEBs more comprehensively and establish more effective interventions.

6. Conclusions

This study employs an extended TPB model to reveal the role of extraversion in hotel guests' energy-saving behaviours. The result shows that among all of the hypotheses, 10 are supported while 4 are rejected. According to the analysis results, the study firstly found that attitude, PBC, personal norms and past behaviour have direct positive effects on hotel energy-conservation intention. Second, although extraversion cannot directly affect energy-conservation intention, it can significantly influence two normative factors and PBC. Third, past behaviour moderates extraversion's statistical relationship to normal factors and PBC. Overall, this study found that most of the psychological factors had a positive effect on the guests' energy-saving intention in hotel scenarios, and individuals' extraversion trait had a positive effect on most of the psychological factors. In addition, past behavioural habits positively moderate the relationship between extraversion and some of the psychological factors. Therefore, based on the results of this study, guests' moral sense and trust in their abilities are important factors that affect their willingness to save energy in hotels. Thus, this study advocates that hotels can consider adopting appropriate prompts, such as reminding guests that everyone is responsible for maintaining the living environment to make guests acknowledge the importance of their responsibility. Similarly, in the actual operation process, hotels should consider taking advantage of the characteristics of the extraversion of the guests and adopt specific measures. For instance, it is suggested that hotels express that the participation of the guests will help achieve the goal of sustainable development, thus actively reminding the guests to use the characteristics of friendliness, gregariousness, self-confidence and cheerfulness to participate in the hotel's energy-saving actions. In addition, since past behaviours have a moderating effect on extraversion and psychological factors, communities or other environmental protections, organisations should also actively encourage people to develop energy-saving habits, and integrate energy-saving behaviours into people's daily activities. Thus, people are able to similarly and habitually adopt energy-saving behaviours while staying at the hotel as a customer.

In conclusion, the findings of this study reveal the critical impact of personality traits on in-hotel PEBs. We empirically explain the generation of hotel energy-saving behavioural intentions and the unique roles of psychological factors in this process from the perspective of extraversion. The study provides a psychological explanation for the long-term stable heterogeneity of hotel guests' PEB. Hospitality managers might consider differential interventions to hotel guests with different personality characteristics and provide additional incentives for those who present strong energy-saving potential. However, the behavioural interventions for hotel guests should strictly adhere to ethical requirements. In addition, this study enriches the PEB research literature in hotel and tourism management, providing a theoretical basis for hotel practitioners to develop more effective energy-saving behavioural interventions. The findings of this study contribute to more efficient hotel energy management and operation.

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The Influence of Administrative Division Adjustment on Enterprise Earnings Management: A Quasi-Natural Experiment on City–County Consolidation

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Abstract: City–county consolidation is a common measure used by many cities to promote urbanization. This study develops the theoretical transmission mechanism, "city-county consolidation intensifies competition in the enterprise market improves the earnings management level of enterprises," to analyze the influence of city–county consolidation on enterprises' earnings management. An empirical analysis using the difference-in-differences (DID) method was conducted on data of industrial enterprises from 1999 to 2006. The results show that city–county consolidation promotes motivation for the use of enterprises' earnings management. Second, city–county consolidation significantly intensifies enterprises' downward earnings management behavior. Third, following city–county consolidation, non-state-owned enterprises are more strongly motivated to implement earnings management than state-owned enterprises. Fourth, city–county consolidation only significantly impacts the earnings management of enterprises affiliated with counties; it does not significantly impact the earnings management of those affiliated with central, provincial, or municipal governments. Therefore, this study provides empirical evidence from the perspective of market competition, which has important reference significance for urbanization development to improve national governance capacity by optimizing administrative divisions.

Keywords: city–county consolidation; market competition; earnings management; urbanization development

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1. Introduction

City–county consolidation is an administrative division adjustment method adopted by a city government to develop the regional economy, straighten out hierarchical relations, and exert government functions. To develop the regional economy, straighten out hierarchical relations, and fully exert government functions, the city government finds a way to adjust administrative divisions. In China, cities have direct jurisdiction over municipal districts, and only have partial jurisdiction over counties. Specifically, county governments have relatively independent decision-making powers in administrative management, fiscal revenue, and expenditure, while the authorities of municipal districts are subordinate, and subject, to the jurisdiction and control of the city. City–county consolidation is an important measure to optimize administrative division, promote the optimal development of the urban spatial layout [1], and drive the integration of regional markets [2]. It is also a common measure taken by many cities to promote urbanization [3]. Since China's city–county consolidation and opening up, according to national statistics, the number of counties decreased steeply, from 2011 in 1978 to 1312 by the end of 2020, whereas the number of municipal districts increased annually, reaching 973 in 2020 (Chinese version: https://data.stats.gov.cn/easyquery.htm?cn=C01 (accessed on 10 February 2022); English version: http://www.stats.gov.cn/english/Statisticaldata/AnnualData/ (accessed on 10 February 2022)). City–county consolidation directly resulted in an increase in municipal districts. Specifically, by directly integrating counties into central cities, city–county consolidation broke the administrative barriers between cities and counties, comprehensively promoting the integration of regional markets. Land, population, and other resources are concentrated in cities, intensifying market competition [4]. Therefore, city–county consolidation plays an important role in promoting regional economic growth, and improving the efficiency of resource allocation, industrial upgrading, and urbanization development [1,5].

However, with a continued expansion of the market scale, and an intensification of market competition, a market-screening mechanism will be triggered. Specifically, with increased competitive pressure on enterprises, some face the risk of being eliminated, thus, triggering their motivation to implement earnings management. Meanwhile, following the implementation of city–county consolidation, the merged counties' fiscal earnings become semi-level fiscal, while their fiscal autonomy is significantly reduced, which leads to a reduction in fiscal subsidies, tax preferences, and other preferential policies [6,7]. As the government's ability to distribute funds to enterprises and to help them save on operating costs decreases, the cost of enterprises may increase, thus, intensifying market competition among those within a city–county consolidation. Increased market competitive pressure may intensify earnings management behavior [8–10]. In addition, existing studies show that fierce product market competition creates a stricter external governance environment for enterprises, inhibiting their earnings management [11]. The research finds that the existing research about the relationship between city–county consolidation and earnings management is not clear. Therefore, there is a need for research on whether city–county consolidation promotes or inhibits enterprises' earnings management. Meanwhile, the research also needs to further explore the mechanism of earnings management that affects enterprises.

The present study uses the difference-in-differences (DID) method on data from the industrial enterprise database from 1999 to 2006 to verify the impact of city–county consolidation on enterprises' earnings management behavior. The innovation of the study lies in three aspects: first, it evaluates the impact of city–county consolidation on enterprises' earnings management behavior, which provides empirical evidence from the perspective of market competition. Second, this study provides reverse evidence on the relationship between administrative division adjustment and enterprises earnings management in China, by using the quasi-natural experiment of city–county consolidation, which solves the endogenous problem effectively. Third, this study enriches the research on city–county consolidation, and provides further micro-evidence for understanding the economic consequences of city–county consolidation.

In summary, this study focuses on answering the following three questions: First, what impact does county and city consolidation have on enterprise earnings management? Second, how does county and city consolidation affect earnings management? Thirdly, is there any difference in the impact of county and city consolidation on earnings management behavior of enterprises with different ownership or affiliation?

2. Literature Review

2.1. Reviews of City–County Consolidation

City–county consolidation is one of the most extensive forms of consolidation for local governments. The main purpose of city–county consolidation is to promote urban economic development, and improve public service efficiency, employment, and land use to solve problems in urbanization [12].

Most studies on city–county consolidation focus on three aspects: urban economic development, government revenue and expenditure, and enterprise development.

Based on the experience of the United States, from the urban economic development perspective, most studies are skeptical of the economic results of city–county consolidation, since the economic development of city–county consolidation in the United States has not reached the expected level [1,2,13,14]. However, there are some successful cases of city–county consolidation. Hall et al. [12] use the synthetic control method, and find that Lafayette experiences an increase in per capita income, population, and employment after consolidation, which positively impacts economic growth. In addition to studies in the United States, Egger et al. [15], a German scholar who uses satellite data to study Germany's recent municipal mergers, applies the DID method to measure German cities' economic activities; the scholar finds increased economic activities for areas under consolidation. Moreover, based on China's experience with city–county consolidation, a city's economic growth can be accelerated; however, this is not true for its long-term growth, which shows an inverted "U" growth trajectory [4].

From the perspective of government revenue and expenditure, city–county consolidation expands government size and jurisdiction, affecting government revenue and expenditure to a certain extent [16–20]. However, the influence is mainly on public services [16] and government tax [18,20].

From the perspective of enterprise development, Lu and Chen [6,7] find that city–county consolidation negatively impacts the export performance of enterprises within the consolidated jurisdiction, and aggravates their degree of financial constraints.

2.2. Market Competition and Enterprise Earnings Management

Enterprise earnings management entails attempts by enterprises to maximize earnings by adjusting or controlling accounting income information in accordance with accounting standards. Researchers study the impact of market competition on enterprise earnings management. Grossman and Hart [8] believe that market competition increases an enterprise's earnings pressure by affecting its performance and increasing the risk of bankruptcy, which is not conducive to its profitability. Peteraf [21] argues that enterprises experience increasing difficulty in obtaining excess profits with more intense market competition, and that managers are under pressure to manipulate profit. Tinaikar and Xue [9] show that market intensity causes fluctuations in enterprises' future earnings. The fiercer the market competition, the more enterprises increase their earnings management behavior. Datta et al. [10] find that market competition significantly promotes accrued earnings management.

However, there are opposing views. For instance, corporate governance studies generally believe that market competition provides an external governance mechanism to alleviate conflicts of interest between managers and owners [11]. Moreover, Holmström [22] studies information asymmetry, and finds that market competition could reduce it, bind the interests of both managers and shareholders, and cause timely economic losses in a company's operation. Through a model, Schmidt [23] finds that the greater the number of enterprises in a specific industry, the stronger the comparability of performance among the enterprises. Although market fluctuation impacts every enterprise, relatively comparable performance can offset its impact to a certain extent, and intuitively show managers' business ability and effort level, thus, reducing the level of earnings management. From studying American enterprises, Marciukaityte and Park [24] find that the stronger the market competition a listed company faces, the lower the absolute value of discretionary accruals, indicating that market competition is negatively related to earnings management. Similarly, Krishnan and Cohen [25] find that the degree of market competition limits an enterprise's management behavior of misstating accounting information, to a certain extent.

Some other studies argue that the impact of market competition on earnings management depends on the characteristics of enterprises, such as strategy and performance. Markaria and Santalo [26] find that market competition not only promotes earnings management, but also find that this phenomenon occurs only in slightly underperforming firms, and that market competition does not seem to increase the propensity for earnings management in firms that perform at, or above, the level of competitors. Wu et al. [27] use the data of Chinese listed firms, and find that, from the perspective of corporate strategy, market competition further improves the earnings management of cost leaders, while the earnings management level of enterprises following the differentiators is not affected by market competition.

2.3. Summary of the Literature

Through a review of the literature on city–county consolidation and market competition with enterprise earnings management, this study finds two gaps in previous research. Research on city–county consolidation remains insufficient in the micro-field of corporate governance. Furthermore, research on city–county consolidation is mainly focused on the exploration and analysis of the economic development of cities, government revenue, and expenditure, which belong to the macro fields, while micro research has not received much attention. Therefore, this study investigates the impact of city–county consolidation on enterprises' earnings management, provides further evidence on the economic consequences of city–county consolidation, and enriches the existing research literature in the field. Additionally, previous research conclusions on the impact of market competition on earnings management are inconsistent. This may be due to insufficient consideration of endogeneity in previous studies, which requires further exploration.

Therefore, this study chooses the exogenous policy of city–county consolidation to measure the degree of market competition, which can effectively resolve the endogeneity problem in previous studies, and is of great significance in the study of enterprises' earnings management.

3. Theoretical Mechanism Analysis

This study proposes a theoretical transmission mechanism that can be divided into two levels: one is that city–county consolidation leads to greater market competition among enterprises, while the other is that greater market competition, in turn, has a large impact on enterprise earnings management. Therefore, it can be summarized as, "city-county consolidation intensified market competition among enterprises improved level of enterprises' earnings management."

3.1. City–County Consolidation Intensified Market Competition among Enterprises

This theoretical transmission mechanism can be analyzed from two perspectives. From the perspective of market integration, academia reached the unanimous conclusion that city–county consolidation promotes regional market integration and intensifies market competition [2,4]. Specifically, under the Chinese system of decentralization, the nature of political promotion in economic competition results in a need for local governments to consider administrative regions as borders, by implementing local protectionism and dividing local markets. City–county consolidation breaks down rigid administrative barriers between cities and counties, which helps integrate regional markets. Furthermore, the spatial gathering of talent and technology can promote the expansion of market scale, resulting in a simultaneous increase in the intensity, and an expansion of the scope, of market competition. When the market screening mechanism is effective, the market competition among enterprises is further intensified [28,29].

From the perspective of financial management model transformation, city–county consolidation is not only a spatial reorganization of the transformation from a county economy to a city economy, but it is also an institutional reconstruction of the transformation from a relatively independent county management mode to a semi-governmental city management mode [3]. Generally, city–county consolidation is accompanied by a centralization of planning, financial, approval, and management rights to a city government, so that the city government can smoothly implement the top-down management of counties that have been removed and merged. However, the inertia of the system and social network may lead to some peculiar phenomena, such as the continuation of conflicts between the original city and county systems, and the phenomenon of "different treatment in the same city" [4]. A decline in the autonomy of dismantled counties reduces the policy tendency for fiscal subsidies, tax expenditures, and fund subsidies that can be obtained by enterprises in the jurisdictions. It also reduces the ability of the government to distribute funds to businesses, or help them save on operating costs. This may lead to an increase in enterprise costs, leading enterprises in the area under the county jurisdiction to cease operations, or merge in the face of greater pressure from market competition.

3.2. Intensified Market Competition among Enterprises Improved Level of Enterprises' Earnings Management

Earnings management takes agency theory as the main theoretical framework [30]. Based on agency theory, the theoretical transmission mechanism can be analyzed from the following two perspectives. On the one hand, the separation of ownership and control leads to conflicts and information asymmetry between owners (principals) and management (agents). Agents tend to act in their own interests on behalf of principals [31]. Fierce market competition brings more operating pressure to enterprise managers, who are more inclined to protect their own interests and career development by implementing financial earnings management [32].

On the other hand, the agency conflict occurs between the government (principal) and the enterprise (agent). In the fierce market competition, the level of excess profit that enterprises can obtain is relatively low. This strengthens enterprises to improve earnings management and reduce tax costs by hiding, to maintain strong risk response ability in the competitive market, and avoid operating difficulties caused by capital shortage.

Specifically, intense market competition affects enterprises' earnings management behavior, and reduces the transparency of corporate earnings. The main purpose of earnings management is to limit the flow of enterprise information to potential competitors, in order to avoid competition.

4. Methods

4.1. Date

This study obtained data provided by the National Bureau of Statistics from the industrial enterprise database from 1999 to 2006. There are two main reasons for studying the data from 1999 to 2006: one relates to the historical development trend for city–county consolidation. Following 2000, city–county consolidation in China reached a peak, especially from 2000 to 2003; more than ten counties implemented city–county consolidation annually. Examining the economic effects of city–county consolidation during this special period provides an effective reference for current city–county consolidation, and promotes the development of central cities. The other reason is data availability and comparability. Although the industrial enterprise database was updated in 2015, the accounting system was reformed in 2007; thus, the data from 2006 onward may have a systematic impact on enterprises' accounting systems, which may result in different statistical data calibrations. The database contains important data on enterprises' basic information, input–output, financial status, and profit information.

The database was pre-processed before use. First, following Brandt et al. [33], this study combined eight year data into one panel. Second, the following three observation values were deleted: (1) missing indicators, such as sales volume, number of employees, and total assets; (2) if the sales volume was less than CNY 5 million, and the number of employees was less than eight; and (3) observation values that were inconsistent with accounting principles. Enterprises that operated within the jurisdiction of the four municipalities directly under the central government (Beijing, Shanghai, Tianjin, and Chongqing) were deleted. Finally, 202,276 enterprises were identified, with 653,636 observations. To reduce the effect of possible spurious outliers, all extreme values in the statistical data at 1% and 99% winsorization were adopted.

4.2. Model Design and Description

This study draws heavily from the measurement of earnings management by Dechow et al. [34] and Kothari et al. [35] for explained variables, and uses the absolute value of discretionary accruals. The negative value is used to measure enterprises' level of earnings management; enterprises with lower values tend to adopt earnings management activities. The Jones model only considers the change of revenue and fixed assets to measure the total accrual profit, while the method of Dechow et al. [34] and Kothari et al. [35] modifies the Jones model, adding accounts receivable and return on asset, respectively, to further improve the Jones model, and is widely used. Kothari et al. [35] propose a modified Jones model for the calculation of discretionary accruals; the model requires three-digit industry codes, and deletes industries with observation values of less than ten to perform regression; the residual values are then used to measure the accruals. The specific model is as follows:

$$TA_{i,t} = \delta_0 + \delta_1(1/Assets_{i,t-1}) + \delta_2\Delta Sale_{i,t} + \delta_3 PPE_{i,t} + \delta_4 Roa_{i,t} + \xi_{i,t} \quad (1)$$

$Assets_{i,t-1}$ represents enterprise i's total assets in period $t-1$. $\Delta Sale_{i,t}$ represents the difference between enterprise i's sales in periods t and $t-1$ divided by the total assets in period $t-1$. $PPE_{i,t}$ represents enterprise i 's capital assets in period t divided by the total assets in period $t-1$. $Roa_{i,t}$ represents enterprise i's net profit in period t divided by the total assets in period $t-1$. $TA_{i,t}$ represents the total accruals. Since there are no net cash flow data in the industrial enterprise database, this study follows the method of Kothari et al. [35] and Li and Jia [36], and measures net cash flow by subtracting the change in current liabilities ($\Delta Cl_{i,t}$) from the change in inventory and accounts receivable ($\Delta Inv_{i,t} + \Delta Rec_{i,t}$), and then subtracting the current year's depreciation ($Dep_{i,t}$). The model is expressed as follows:

$$TA_{i,t} = (\Delta Inv_{i,t} + \Delta Rec_{i,t} - \Delta Cl_{i,t} - Dep_{i,t})/Assets_{i,t-1} \quad (2)$$

The core independent variable in the model is city–county consolidation, which can be obtained through a manual sorting by reference to the changes in county-level administrative divisions in past years, which are published by the administrative division network (See http://www.xzqh.org/html/ (accessed on 10 February 2022)). If county j implements city–county consolidation in period t, it assumes a value of 1; otherwise, it assumes a value of 0. Considering the time lag involved in the city–county consolidation's actual completion, counties whose documents are approved by the Ministry of Civil Affairs after June are counted as starting the reform in the next year.

This study adopts a multi-stage DID model due to the different time points for implementing city–county consolidations in different regions. This model is widely applied to assess the impact of policy changes. It reflects the robustness of the experiment design, and also alleviates concerns that concurrent trends may confound the treatment effect of interest [37]. The model is expressed as follows:

$$EM_{i,j,t} = \beta_0 + \beta_1 CCC_{i,j,t} + \sum_n \beta_n \times Control_{i,j,t} + \gamma_i + \mu_t + \varepsilon_{i,j,t} \quad (3)$$

EM represents earnings management, while *CCC* represents city–county consolidation. Control refers to other control variables, including the asset–liability ratio, return on assets, enterprise scale, sales growth rate, enterprise age, and industry average level of earnings management, as shown in Table 1. γ_i is the enterprise fixed effect, μ_t the year fixed effect, while β_1 reflects the impact of reforms on earnings management.

This study also uses the Herfindahl–Hirschman index (HHI) method to measure the market competition, and analyzes the impact of city–county consolidation on market competition. In addition, the parallel trend test is used to verify whether the premise hypothesis of the DID method is valid. Robustness tests were performed by clustering to county level, controlling for the cross-fixed terms of provinces and years, and replacing other measures of earnings management.

Table 1. Description of main variables and descriptive statistics.

Variable	Description of Variables	Mean	S. D	Observation
EM	Take the negative value of discretionary accruals' absolute value	−0.179	0.190	653,636
	Total liability/total assets	0.554	0.244	653,636
ROA	Net profit/total assets	0.061	0.118	653,636
Growth	(Current period sales—last period sales)/last period sales	0.372	3.221	653,636
Scale	The logarithm of assets	10.208	1.331	653,636
Age	Current year—year of establishment + 1 (in log)	2.176	0.807	653,636
IEM	Except the enterprise itself, the current year average earnings management level of other companies in the industry (3-digit code)	−0.179	0.027	653,636

5. Results

5.1. The Impact of City–County Consolidation on Enterprise Earnings Management

Table 2 reports the regression results. EM (1) show the regression results for the impact of city–county consolidation on earnings management. The results for EM (1) show that the regression coefficient for city–county consolidation is negative, at −0.053, indicating that city–county consolidation plays a promotional role in the earnings management of enterprises within the jurisdiction of a removed county. The value of 0.053 indicates that city–county consolidation improves the earnings management of enterprises within the jurisdiction of a removed county by 0.053 units. Moreover, the regression results are significant at the 1% level, indicating the validity of the above conclusions. In addition, the R^2 value in EM (1) is greater than 0.4, indicating a reasonably high goodness of fit of the model. Regarding the regression results for the control variables, ROA, age, and IEM, all have positive effects on enterprises' earnings management, and are significant at the 1% level, with regression coefficients of 0.008, 0.025, and 0.371, respectively. In addition, LEV, scale, and growth have negative effects on earnings management, and are significantly negative at the 1% level, with regression coefficients of −0.035, −0.062, and −0.002, respectively. This conclusion is consistent with those of Hanlon et al. [38] and Ali and Zhang [39].

Table 2. The regression results.

Dependent Variable	(1) EM	(2) Upward	(3) Downward	(4) Market Competition
CCC	−0.053 ***	0.031	−0.071 **	−0.006 **
	(0.017)	(0.025)	(0.029)	(0.003)
ROA	0.008 ***	0.010	−0.004	−0.006 *
	(0.005)	(0.006)	(0.008)	(0.003)
LEV	−0.035 ***	−0.221 ***	−0.351 ***	0.001
	(0.003)	(0.003)	(0.005)	(0.001)
Age	0.025 ***	−0.018 ***	0.028 ***	−0.001 **
	(0.001)	(0.001)	(0.001)	(0.001)
IEM	0.371 ***	−0.439 ***	0.300 ***	0.188 ***
	(0.022)	(0.027)	(0.042)	(0.038)
Scale	−0.062 ***	0.021 ***	−0.087 ***	−0.002 **
	(0.001)	(0.001)	(0.002)	(0.001)
Growth	−0.002 ***	0.002	−0.003 **	0.000
	(0.001)	(0.001)	(0.001)	(0.000)
Constant	0.484 ***	−0.018	0.894 ***	0.152 ***
	(0.011)	(0.014)	(0.020)	(0.000)
Enterprise fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	653,636	366,751	286,885	609,140
R^2	0.470	0.610	0.655	0.849

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Standard errors are reported in parentheses and are clustered by enterprise. All regressions control for enterprise and year fixed effects.

Furthermore, grouping regression was performed for upward and downward earnings management. Upward earnings management refers to enterprises' behavior in regard to whitewashing financial information, while downward earnings management refers to their behavior in hiding corporate profits by manipulating financial information. Upward (2) and downward (3) show the regression results for city–county consolidation on downward and upward earnings management, respectively. The observed values are 366,751 and 286,885, with R^2 values of 0.610 and 0.655, respectively. Thus, the model exhibits a reasonably high goodness of fit. Upward (2) shows that the impact of city–county consolidation reform on downward earnings management is positive, at 0.031, indicating that city–county consolidation into districts inhibits enterprises' upward earnings management; however, the regression result is not significant. Downward (3) shows that the regression coefficient for the reform of withdrawing counties into districts is significant at the 5% level, while the regression coefficient of −0.071 indicates that city–county consolidation reform promotes downward earnings management. In other words, enterprises in the jurisdiction of a removed county tend to practice downward earnings management to cope with the intensified market competition caused by city–county consolidation. Although consolidation has an inhibitory effect on upward earnings management behavior, the effect is not obvious.

5.2. Transmission Mechanism Test for Market Competition

It was necessary to further test whether the reform of city–county consolidation intensifies market competition, to determine whether city–county consolidation has the above-mentioned mechanism of influence on enterprises' earnings management. The Herfindahl–Hirschman index (HHI) was used to measure market competition [40]; specifically, the smaller the Herfindahl–Hirschman index, the stronger the market competition. The calculation of the Herfindahl–Hirschman index excludes industry data from samples with less than five enterprises. In addition, this study only examines market competition in cities after the consolidation reform; thus, the Herfindahl–Hirschman index was calculated only in cities.

The results are presented in Table 2. The results for market competition (4) show that the regression coefficient for city–county consolidation is −0.006, which is significant at the 5% level, indicating that city–county consolidation significantly improves the degree of market competition. The results show that city–county consolidation has a stronger promotional effect on market competition when control variables are included. The R^2 value is 0.849, indicating a reasonable goodness of fit for the model.

Therefore, this study argues that city–county consolidation intensifies enterprises' earnings management behavior. The main influencing mechanism is that the weakening of market barriers, and the continuous agglomeration of enterprises, brings about more intense market competition, driving enterprises to adopt earnings management behavior in the face of higher competitive pressure.

5.3. Robustness Checks

5.3.1. Parallel Trend Test

This study tests the parallel trend hypothesis by analyzing the changes in earnings management in the treatment and control groups, before and after city–county consolidation. Following Fan and Zhao [20], the 2002 observations, when the most reforms occurred during the period 1999–2006, were selected as the treatment group.

As shown in Figure 1, the fluctuation in earnings management in the control group is relatively stable, while the fluctuation in the treatment group decreases after 2002. This indicates that there are significant differences in the earnings management trends between enterprises that undergo city–county consolidation and those that do not. In other words, city–county consolidation affects enterprises' earnings management behavior; therefore, the DID method used in this study is effective.

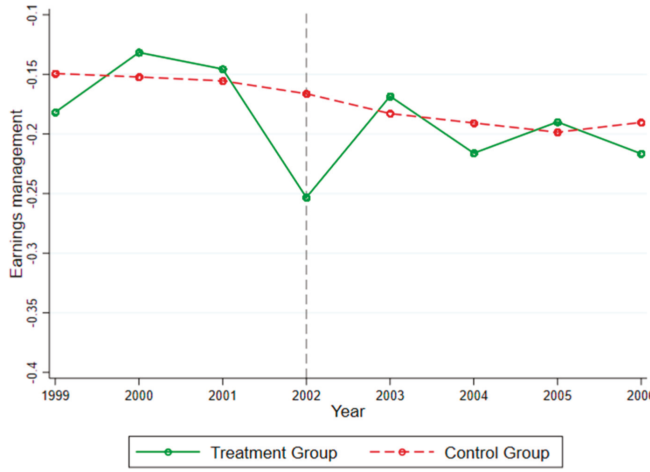

Figure 1. Parallel trend test.

5.3.2. Clustering by County

EM (1) in Table 2 shows the regression result after clustering to the enterprise level, and analyzes the autocorrelation problems of the control enterprises in different years. Businesses within the same county jurisdiction are likely to be affected by the same policy; that is, they have autocorrelation problems. Based on this, further analysis was performed after clustering at the county level. Of the results in Table 3, EM (1) shows that after clustering to the county level, the regression coefficient for city–county consolidation on earnings management is –0.053, and is significant at the 1% level. The result shows that the conclusion that city–county consolidation in Table 2, EM (1) significantly promotes enterprises' earnings management behavior, remains valid.

Table 3. The results of robustness checks.

Dependent Variable	**(1)**	**(2)**	**(3)**
	EM	**EM**	**EM**
CCC	−0.053 *** (0.014)	−0.047 *** (0.017)	−0.051 *** (0.017)
ROA	0.008 (0.006)	0.012 *** (0.005)	−0.009 * (0.005)
LEV	−0.035 *** (0.004)	−0.036 *** (0.003)	−0.034 *** (0.003)
Age	0.025 *** (0.001)	0.023 *** (0.001)	0.025 *** (0.001)
IEM	0.371 *** (0.024)	0.324 *** (0.022)	0.351 *** (0.021)
Scale	−0.062 *** (0.001)	−0.062 *** (0.001)	−0.063 *** (0.001)
Growth	−0.002 * (0.001)	−0.002 * (0.001)	−0.002 * (0.001)
Constant	0.484 *** (0.019)	0.482 *** (0.011)	0.494 *** (0.011)
Clustered by enterprise	Yes	Yes	Yes
Clustered by county	Yes	No	No
Cross-fixed effects of provinces and years	No	Yes	No
Enterprise fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Replace other measures	No	No	Yes
Observations	653,636	653,636	653,636
R^2	0.470	0.471	0.471

Note: *** and * denote significance at the 1%, 5%, and 10% levels, respectively. The standard errors are reported in parentheses.

5.3.3. Endogeneity Problems

Counties that implement city–county consolidation are not random. Consolidation is related to the characteristics of the counties, the degree of economic development, and population, as well as the games between provinces and cities against the background of fiscal decentralization in China. Specifically, consolidation seeks to reduce municipal government intervention in county-level fiscal affairs, that is, to promote the development of counties' economies by guaranteeing the independence of their county-level financial affairs. Therefore, the provincial government will not approve of city–county consolidation in some economically strong counties. Based on this, this study controls for the differences in games between provincial and municipal governments in different provinces, by controlling for the cross-fixed terms of provinces and years, which can avoid the endogeneity problems that may be caused by omitted variables.

The regression result is presented in Table 3, EM (2). The regression coefficient for city–county consolidation is −0.047, and is significant at the 1% level. These results confirm that the conclusion in Table 2, EM (1), that city–county consolidation significantly promotes enterprises' earnings management behavior, remains robust.

5.3.4. Replace Other Measures of Earnings Management

This study follows Dechow et al. (1995), and uses the modified Jones model for regression estimation of earnings management. This model improves the Jones model by adding accounts receivable. The estimation model is as follows:

$$TA_{i,t} = \varphi_0 + \varphi_1(\Delta Sale_{i,t} - \Delta Rec_{i,t}) + \varphi_2 PPE_{i,t} + \epsilon_{i,t} \quad (4)$$

The calculation methods for $TA_{i,t}$, $\Delta Sale_{i,t}$, $\Delta Rec_{i,t}$, and $PPE_{i,t}$ are the same as above. The regression result is shown in Table 3 for EM (3). The regression coefficient for city–county consolidation reform is –0.051, and is significant at the 1% level. This further shows that the impact of city–county consolidation in Table 2's EM (1) on enterprises' earnings management remains robust. In addition, the R^2 value in the robustness result is 0.471, indicating a reasonable goodness of fit for the model setting.

5.4. Research on Heterogeneity

This study finds that the impact of reform on earnings management may be influenced by enterprise ownership; therefore, state-owned enterprises are identified by determining whether the ratio of the capital to the paid-in capital of an enterprise is more than 50%. The regression results, which show the impact of city–county consolidation on state-owned enterprises' earnings management, are shown in Table 4's state-owned enterprises (1). The regression coefficient is −0.52, and not significant. The regression coefficient for Table 4's non-state-owned enterprises (2) is −0.054, which is significant at the 1% level, indicating that city–county consolidation plays a significant role in promoting non-state-owned enterprises' earnings management. In addition, the R^2 is 0.475, which is a reasonable goodness of fit for the model.

From the above regression results, the impacts of city–county consolidation on state-owned and non-state-owned enterprises' earnings management are different. One possible reason is that state-owned enterprises' managers do not take great political risks in manipulating profits, while non-state-owned enterprises are not exposed to such political risks. Conversely, state-owned enterprises generally have a strong monopoly on resources, and their products remain competitive in the market after city–county consolidation. Therefore, compared to non-state-owned enterprises with greater competitive pressure, state-owned enterprises are less motivated to manipulate profit. However, non-state-owned enterprises' products are influenced by the expansion of market scale, and the strengthening of the market competition effect brought about by city–county consolidation, to adopt earnings management to cope with market competition.

Table 4. Regression results of heterogeneity test.

Dependent Variable	(1)	(2)	(3)	(4)
	State-Owned Enterprises	Non-State-Owned Enterprises	Belonging to the Central, Provincial, and City Governments	Belonging to the Central, Provincial, and City Governments
CCC	−0.052 (0.049)	−0.054 *** (0.020)	−0.031 (0.024)	−0.065 ** (0.025)
ROA	−0.017 (0.021)	0.010 ** (0.005)	−0.071 *** (0.015)	0.018 *** (0.005)
LEV	0.005 (0.010)	−0.038 *** (0.003)	−0.038 *** (0.007)	−0.034 *** (0.003)
Age	0.009 *** (0.002)	0.022 *** (0.001)	0.017 *** (0.002)	0.023 *** (0.001)
IEM	0.251 *** (0.050)	0.351 *** (0.024)	0.264 *** (0.040)	0.357 *** (0.025)
Scale	−0.032 *** (0.004)	−0.068 *** (0.001)	−0.027 *** (0.003)	−0.068 *** (0.001)
Growth	−0.000 *** (0.000)	−0.005 *** (0.001)	−0.001 ** (0.000)	−0.007 ** (0.002)
Constant	0.248 *** (0.047)	0.539 *** (0.012)	0.199 *** (0.033)	0.528 *** (0.012)
Enterprise fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	58,797	594,839	85,936	567,700
R^2	0.525	0.475	0.479	0.476

Note: *** and ** denote significance at the 1%, 5%, and 10% levels, respectively. The standard errors are reported in parentheses.

In addition, this study conducts group tests based on of enterprises' affiliations. The results are shown in "Belonging to the central, provincial, and city governments" (3) and "From the central, provincial, and city governments" (4) in Table 4. Of the results, (3) shows the impact of city–county consolidation on the earnings management of enterprises that are affiliated with central, provincial, and municipal governments, with a regression coefficient of −0.031, which is not significant. The regression coefficient in (4) is −0.065, which is significant at the 5% level, indicating that city–county consolidation has a significant promotional effect on the earnings management of enterprises that are affiliated with county-level government. In addition, the R^2 is 0.476, with a reasonable goodness of fit for the model.

A possible reason is that, after city–county consolidation, the governments of the withdrawing counties have decreased autonomy in their financial affairs, and their policy support in terms of financial subsidies, tax expenditures, and fund subsidies to enterprises within their jurisdictions is weakened. Moreover, with market expansion and a rise in competitive pressure, enterprises face greater pressure to increase costs, which aggravates their earnings management behavior.

5.5. Discussion

There are three obvious findings between this study and the existing literature:

First, this study is similar to Fan and Zhao (2020) [20]. They both study the impact of city–county consolidation on enterprise business behavior, but the transmission mechanism and analysis perspective of this study are different from those of Fan and Zhao. They analyze it from the perspective of tax collection and management, and believe that the enterprise tax avoidance caused by city–county consolidation is affected by the weakened tax collection and management of county governments. However, this study argues that city–county consolidation strengthens market competition, which leads to the increased operating pressure on enterprises, and then promotes the downward earnings management of enterprises to hide profits and avoid taxes.

Second, Xue and Tinaikar (2009) [9] and Markarian and Santalo (2014) [26] also study the relationship between market competition and earnings management. They find that intense market competition promotes earnings management, which is the same as the conclusion of this study. However, they all use the OLS method to verify their research, which may not solve the problem of endogeneity well. Compared with them, this study introduces the strict exogenous natural experiment of city–county consolidation, and uses the DID method to solve the endogenous problems existing in previous studies on market competition and earnings management.

Third, it can be seen from the previous literature that, whether in China or other countries, the studies on city–county consolidation pay more attention to the macro level. Egger et al. (2018) [15] and Hall et al. (2020) [11] study the influence of city–county consolidation on economic development, and Taylor et al. (2016) [19] study the influence of city–county consolidation on government revenue and expenditure. However, this study pays more attention to the micro level, and studies the influence of city–county consolidation on enterprise development.

6. Conclusions and Implications

6.1. Conclusions

China is currently in the second half of rapid urbanization. While the urbanization speed is slowing down, there remains considerable room for improvement in urbanization. It is particularly important to prudently and selectively promote city–county consolidation in order to improve central cities' driving capacities. However, existing studies mainly focus on the impact of city–county consolidation on economic growth, finance, taxation, and so on, while research on the impact of micro-enterprises remains weak and has gaps.

This study introduces the theoretical mechanism of "city-county consolidation intensified market competition among enterprises improved level of enterprises' earnings management." Based on data on industrial enterprises from 1999 to 2006, this study provides empirical evidence on how city–county consolidation affects enterprise earnings management using the DID method. In addition, through empirical research, the study verifies the theoretical mechanism. There are four main findings from this study.

First, the regression results that city–county consolidation impacts enterprises' earnings management is significant, indicating that city–county consolidation promotes the motivation for enterprises' earnings management. The main reason is that city–county consolidation breaks the rigid administrative barriers between cities and neighboring counties, promotes the integration of regional markets, intensifies product market competition, and aggravates enterprises' earnings management behavior under the pressure of competition, which also reflects the significant drawback of the policy.

Second, from the perspective of earnings management, the regression results show that city–county consolidation has a significant promotional impact on downward earnings management, while it has an opposite, but insignificant, effect on upward earnings management. This finding indicates that enterprises are more inclined to adopt downward earnings management to hide their profits when faced with competitive pressure.

Third, from the perspective of enterprise ownership, the regression results show that the impact of city–county consolidation on state-owned enterprises' earnings management is not significant, while the impact on non-state-owned enterprises' earnings management is significant.

Fourth, from the perspective of enterprise membership, compared with the insignificant results for enterprises belonging to central provinces and cities, the results for those belonging to counties are more significant. Specifically, county enterprises face greater competitive pressure after city–county consolidation, which leads them to practice earnings management.

In summary, this study finds that city–county consolidation intensifies product market competition and, thus, promotes enterprises' earnings management behavior. Furthermore, the study enriches the literature on the impact of administrative division adjustment on enterprise earnings management by using city–county consolidation as a natural experiment. Moreover, it provides empirical evidence from the perspective of market competition, and has important reference significance for optimizing the setting of administrative divisions to enhance national governance capacity.

6.2. Implications

This study enriches the research on the development of enterprises by withdrawing counties and establishing districts. Specifically, the research also has important practical significance in prompting the government to create a fair, competitive institutional environment, and strengthen enterprise governance capacity, namely:

First, the study, for the first time, evaluates the impact of city–county consolidation on earnings management behavior of enterprises from the perspective of market competition as a transmission mechanism, and verifies the effectiveness of the transmission mechanism of market competition, which is of great significance in enriching the existing literature. Meanwhile, the study also introduces the exogenous policy of city–county consolidation, which well-solved the endogenous problems of previous research on earnings management affected by market competition, which is an important supplement to the existing literature.

Second, the study finds that city–county consolidation leads enterprises to implement downward earnings management behavior, which is unfavorable to optimizing the regional accounting information environment. Therefore, the study puts forward relevant policy suggestions from two aspects of institutional environmental governance and enterprise internal governance, to provide useful references for further improving urban governance capacity. From the perspective of institutional environment construction, the government should pay attention to the establishment of market supervision mechanisms, with clear reward and punishment, and take specific management measures based on the market competition situation, so that the expected loss of the enterprise subject carrying out earnings management and other violations is greater than the gains obtained from the violation. From the perspective of corporate governance, compared with state-owned enterprises, private enterprises need to further improve their corporate governance ability, standardize accounting information, avoid "crossing the red line" to seek profits, and rationally choose between short-term interests and long-term survival, in order to establish unique competitive advantages. In addition, enterprises under the jurisdiction of the original county should optimize and adjust their corporate strategies to adapt to the new market competition.

Although this study has effectively verified city–county consolidation on earnings management, there are still some limitations.

First, this study uses the database of Chinese industrial enterprises, which mean only analysis of enterprises in the industrial field are adopted, but does not include service enterprises in the research scope, which has certain limitations. In the future, the database of listed companies can be used for further research to comprehensively consider the earnings management behavior of listed companies in different industries after city–county consolidation.

Second, this study focuses on China, but whether it is also applicable to the practice of city–county consolidation in other parts of the world needs further research. In the future, data from other countries can be used for verification, and it can be extended to enterprise innovation, investment, and other fields. These are important decisions for enterprise development, and in-depth research is very necessary.

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