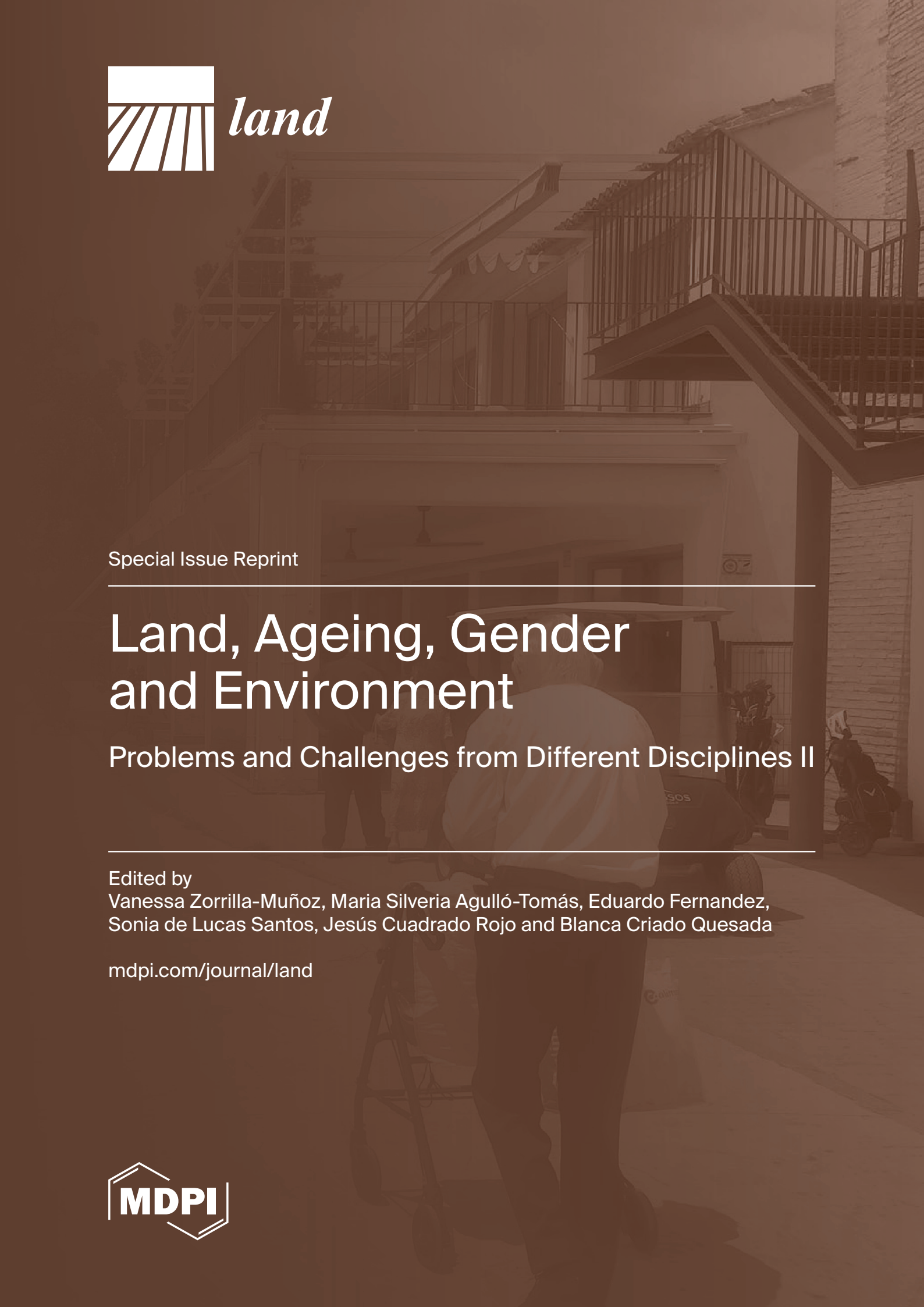


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Special Issue Reprint

Land, Ageing, Gender and Environment

Problems and Challenges from Different Disciplines II

Edited by
Vanessa Zorrilla-Muñoz, Maria Silveria Agulló-Tomás, Eduardo Fernandez, Sonia de Lucas Santos, Jesús Cuadrado Rojo and Blanca Criado Quesada

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Land, Ageing, Gender and Environment: Problems and Challenges from Different Disciplines II

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Guest Editors

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About the Editors

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Preface

The following Reprint, entitled "Land, Ageing, Gender and Environment: Problems and Challenges from Different Disciplines", extends the intellectual trajectory initiated in the first edition. It deepens and broadens the analytical perspectives on how demographic ageing, gender relations, spatial inequalities, environmental change, and land governance intersect across diverse territorial contexts. The twelve collated papers reflect a collective commitment to interdisciplinary, evidence-based, and socially grounded research capable of highlighting some of the most pressing challenges of the twenty-first century.

The urgency of this research agenda is underscored by ongoing global environmental transformations and demographic change. The Reprint addresses how these pressures disproportionately impact older adults and women, who face structural inequalities in adaptive capacity. Conceptually, gender and intersectionality remain decisive dimensions in shaping these dynamics, combined with the persistence of ageism.

A total of 48 authors contributed to the development of these papers, 31 of whom are women and 17 are men. As observed in the first edition, female researchers once again show a particularly notable presence in studies related to gender, ageing, and territorial inequalities.

The papers cover a wide range of topics, including social equity in park accessibility, community outdoor environments, spatial distribution of elder care facilities, optimization of service layouts, representations of ageing and assistive devices, women-inclusive city studies, rural sustainability, land circulation and health of older farmers, Indigenous knowledge and agriculture, and tax planning for tobacco-related products. The authors employ quantitative, qualitative, and mixed methods, highlighting the hybrid nature of this Reprint.

Together, the thematic, disciplinary, and methodological diversity of the Reprint demonstrates that contemporary challenges at the intersection of ageing, gender, and territory require integrated and collaborative approaches. Ageing emerges not merely as a demographic trend but as a spatial, environmental, and socio-political condition shaped by land-use patterns, access to public resources, and gendered life trajectories.

This Reprint is aimed at researchers, students and professionals interested in land studies, gerontology, gender studies, urban and rural planning, and environmental governance. It is our hope that it will contribute to more equitable, inclusive, and sustainable policies.

We express our sincere gratitude to all authors, reviewers, co-editors, and collaborators whose commitment has made this Reprint possible. We also extend our appreciation to the journal *Land* for its continuous support throughout the process.

Vanessa Zorrilla-Muñoz, Maria Silveria Agulló-Tomás, Eduardo Fernandez, Sonia de Lucas Santos, Jesús Cuadrado Rojo, and Blanca Criado Quesada

Guest Editors

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Editorial

Ageing, Gender, and Territorial Inequalities: Environmental and Socio-Spatial Challenges in Contemporary Societies

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1. Introduction and New Emphases of the Second Special Issue

This second volume of this Special Issue of Land, entitled 'Ageing, Gender and Environment: Problems and Challenges from Different Disciplines', continues the intellectual trajectory launched with the first compendium of 16 articles, which covered the years 2021–2022 and helped consolidate an emerging field at the intersection of land, ageing, gender, and environmental challenges. Building on this initial effort, the present volume gathers contributions published between 2023 and 2025, further expanding the thematic, methodological, and territorial scope of the Special Issue and responding to the call, already formulated in the first preface, to maintain a sustained, interdisciplinary research agenda on vulnerability, inequality and sustainability in a context of multiple crises.

Compared with the first edition, where the contributions were broadly grouped into social sciences and health/technology and often focused on climate change, sustainability, urban ageing, care arrangements, and environmental monitoring, the articles in this second volume introduce several new emphases and refinements that are already apparent from the titles of the contributions. First, there is a notable consolidation of spatial–analytic and planning tools specifically oriented to older people, with contributions such as 'Beyond Proximity: Assessing Social Equity in Park Accessibility for Older Adults Using an Improved Gaussian 2SFCA Method', 'GIS-Based Analysis of Elderly Care Facility Distribution and Supply-Demand Coordination in the Yangtze River Delta', and 'Optimizing the Layout of Service Facilities for Older People Based on POI Data and Machine Learning: Guangzhou City as an Example'. These works show how fine-grained GIS, accessibility metrics, and machine learning are now being mobilised to design more equitable territorial configurations for ageing populations, moving beyond general references to urban ageing present in the first volume toward explicit modelling of spatial justice, service allocation and supply–demand coordination.

Secondly, the new volume sharpens the analysis of how built environments and land-use dynamics interact with health and well-being in later life. 'Nonlinear Associations Between Built Environment and Overweight: Gender and Marital Status Differences in Urban China'; 'Can Land Circulation Improve the Health of Middle-Aged and Older Farmers in China?'; and 'Associations Between Physical Features and Behavioral Patterns in Macau Outdoor Community Public Spaces and Older Adults' Performance of Instrumental Activities of Daily Living' focus on specific health outcomes (overweight, functional performance, self-reported health), and link them to micro and meso-level characteristics of urban and rural spaces. While the first volume already included quantitative work on

climate change, ecological footprint and regional economies, these new contributions go further in testing differentiated effects regarding gender, marital status, and rural–urban position, and in uncovering mechanisms through which land policies (e.g., land circulation) and public-space design shape ageing trajectories.

Thirdly, gender is addressed in an even more diversified and multi-scalar way, extending beyond the predominance of women's participation and care roles highlighted in the earlier issue. 'Indigenous Knowledge, Gender and Agriculture: A Scoping Review of Gendered Roles for Food Sustainability in Tonga, Samoa, Solomon Islands and Fiji' broadens the geographical focus to the Pacific and foregrounds indigenous epistemologies and gendered agricultural practices, connecting gender and land to food systems and sustainability in ways that were only indirectly present in the previous collection. 'Unveiling the Trajectories and Trends in Women-Inclusive City Related Studies: Insights from a Bibliometric Exploration' contributes a meta research perspective on how women-inclusive urban studies have evolved, adding a reflexive layer on knowledge production itself. 'Towards Equitable Representations of Ageing: Evaluation of Gender, Territories, Aids and Artificial Intelligence' directly takes up one of the forward-looking suggestions of the first preface—the need to build bridges between ecofeminist, intergenerational approaches and artificial intelligence and technology—and materialises it in an empirical evaluation of how AI and assistive technologies intersect with gendered and territorial representations of ageing.

Fourthly, this volume adds new thematic axes around education, taxation, and territorial development that enrich the original triad of land–ageing–gender. 'Importance of STEM and STEAM Education for Improvement of the Land in the RURAL Environment: Examples in Latin America' connects land and rural development with educational strategies, indicating how training in STEM/STEAM can empower communities and potentially address territorial inequalities in line with the broader concerns of sustainability and intergenerational justice outlined in the first Special Issue. 'Tax Planning on New Tobacco Risk-Reduced Products in Europe: Assessment and Implications for Public Policies' explores public finance and health-related regulation, showing how fiscal and regulatory decisions around new products are also land- and population-relevant, given their implications for public health, territorial revenues, and behavioural inequalities. 'Evaluation of Territorial Capacity for Development: Population and Employment' further strengthens the macro territorial and demographic dimension by examining how population structures and employment patterns condition territorial development, thus providing a backdrop against which ageing, gender, and environmental vulnerabilities are produced and mitigated.

Finally, the temporal extension of the Special Issue to 2023–2025 allows this second volume to mirror more closely the evolving global context described in the first volume, marked by accelerating climate change, post-pandemic inequalities, inflationary pressures and the deepening of intersectional vulnerabilities, particularly for women and older people. While the first volume made a strong case for understanding climate change and COVID-19 as "twin crises of the Anthropocene" and called for intersectional, intergenerational, and ecofeminist perspectives that integrate technological innovation, this new collection demonstrates how those agendas are being operationalized through concrete studies on park equity, elderly care infrastructure, land circulation, AI, indigenous knowledge, and women-inclusive urban research. Together, the two volumes thus trace an ongoing and expanding research programme that remains anchored in land, ageing, gender, and environment, while incorporating new regions (China, Latin America, Pacific Islands, Europe), new methods (advanced accessibility modelling, machine learning, bibliometrics, scoping reviews) and new policy arenas (food sustainability, tax policy, territorial

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capacity, and service planning), with the shared ambition of informing more just and sustainable territorial futures.

2. Theoretical and Empirical Framework

Beyond the specific contributions collected in this second volume, a broader and rapidly expanding body of scholarship provides the theoretical and empirical backdrop against which these articles can be situated. Over recent decades, numerous studies have shown how demographic, social, and environmental transformations converge into a single structural transition that cuts across highly diverse territories. Population ageing, the presence or absence of essential services, processes of rural depopulation, and gender inequalities are increasingly understood not as separate phenomena, but as interdependent dimensions of a socio-environmental crisis that both manifests in space and is mediated through it.

In urban contexts, research on ecosystem services has highlighted how the distribution of green areas and infrastructures often follows lines of social stratification, with direct implications for environmental equity [1]. Studies on older adults' accessibility to green spaces indicate that the mere presence of parks is insufficient: what matters are effective distances, transport networks, and the location of green areas in relation to residential neighbourhoods [2]. Work on the characteristics of the built environment further documents non-linear effects of density, functional mixing, and urban configurations of walking times and mobility behaviours in later life [3]. Analyses of spatial "trade-offs" between urban green, residential density, and physical inactivity combine environmental and social dimensions, showing how the protective effects of green spaces may be attenuated or even reversed in highly dense contexts [4]. From this perspective, studies that integrate natural and built factors in explaining older adults' self-perceived health consolidate the idea of a close interweaving between urban form, environmental quality, and well-being [5]. In parallel, proposals for spatial indicator frameworks to assess how far living environments are genuinely age-friendly translate these insights into operational tools for territorial diagnosis [6], while the notion of the "city of care" invites us to consider material infrastructures, governance arrangements, and everyday relationships as components of an integrated urban care infrastructure [7].

On a different but closely related level, population ageing is reshaping the relationship between working-age and dependent-age groups, with far-reaching implications for welfare systems and territorial equilibria [8]. Recent analyses of global demographic projections show that in many regions the peak of both the total population and the working-age population will be reached earlier than aggregate readings suggest, with rising old-age dependency ratios and an accelerated transition towards "old" societies [9]. Studies conducted in China highlight how ageing is accompanied by highly differentiated spatial patterns in the distribution of health resources and new forms of productivity, with varying degrees of coordination between older people's needs and the provision of services [10]. In an Australian context, projections for rural areas indicate a growing demand for residential and home-based care in remote communities, where distance from services is already a critical factor [11]. In Europe, the link between depopulation and ageing has been documented both at the scale of Italian municipalities, where depopulation and population ageing tend to reinforce each other [12], and in rural areas of the European Union, where processes of demographic decline intersect with limited access to services, infrastructures, and opportunities [13].

These dynamics affect not only quantitative balances, they also impinge on the pact between families and the state and on intergenerational relations, redefining roles and

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responsibilities in care within heterogeneous welfare regimes [14]. At the same time, more macro-level work urges caution with respect to catastrophic narratives of a "demographic apocalypse" [15], showing that the impact of ageing on health systems depends primarily on changes in morbidity rates and patterns of service use, rather than on age structure alone [16].

Within this broader picture, the experience of "ageing in place" acquires central importance and directly resonates with several contributions in this volume. The concept of ageing in place has underscored how home, neighbourhood, and community constitute spaces of identity, security, and belonging, whose meaning goes far beyond the physical dimension of the dwelling [17]. Research on neighbourhood characteristics and the built environment shows how long-term exposure to deprived, poorly serviced, or environmentally degraded contexts can accelerate processes of frailty, whereas environments rich in opportunities for social interaction, services, and accessible infrastructures can sustain independence in later life [18]. In this framework, technologies assume an ambivalent role: systematic reviews of digital solutions for ageing in place indicate that monitoring devices, communication platforms, and support systems can facilitate older adults' ability to remain at home in good health [19], yet older people's own perceptions often portray technology as "not designed for them", potentially generating feelings of exclusion and reinforcing digital divides within the older population [20]. In addition, there is a broad dimension, as content analyses of social media have shown that ageing and old age are frequently represented in problematic ways, portraying older people as vulnerable, homogeneous, and dependent, which contributes to the reproduction of ageist discourses in the digital public sphere [21].

A third cross-cutting dimension concerns gender and processes of inclusion and exclusion, which are also central to the Special Issue. Cities and territories are profoundly shaped by gender relations, and applying this lens to urban space makes it possible to grasp how social structure and spatial structure are co-constitutive. Research on gendered cities has shown the ways in which patriarchal norms have historically organised urban space, delimiting women's roles, mobility, and visibility in the city [22]. Analyses of urban structure in the light of gender differences have further demonstrated that access to housing, transport, paid work and spaces of care remains unequal, despite normative and cultural advances [23]. On the economic side, studies on small businesses have documented persistent gaps in success between men and women, modulated by urban or rural context, which point to mechanisms of structural discrimination and to *gender queues* in local markets [24]. More recent work has reconstructed the long process through which women have claimed their right to the city, intertwining symbolic struggles, legislative change, and demands for full citizenship in public space [25]. Research on walking practices and perceptions of pedestrian mobility in Europe further reveals systematic differences in satisfaction and perceived safety between women and men, confirming that urban spaces remain traversed by gender asymmetries in the possibility of moving in a sustainable and safe way [26].

3. Thematic Insights, Territorial Contexts, and Methodological Approaches

Against this theoretical and empirical backdrop, the articles collected in this second volume engage, each in its own way, with three interrelated thematic axes: (*a*) territory and environment, including questions of spatial justice, accessibility, and environmental equity; (*b*) population ageing, with a focus on health, care, and intergenerational arrangements; and (*c*) gender and inclusion, as they are inscribed in everyday spaces, policies, and technologies.

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Taken together, they offer a multifaceted view of ageing societies in profoundly unequal territories, while also pointing to concrete tools and pathways for more just and sustainable futures.

To facilitate reading and provide a more immediate overall view of the contributions included in this volume, a summary is presented below the Table 1. It organizes the individual papers according to the study area, the method employed, the thematic area addressed (*a*, *b*, *c*) and the main outputs that emerge from each contribution.

Table 1. List of contributions, key methods used, and relevance to the thematic area.

Author (Year)	Case Study Area	Method(s) Used	Thematic Area	Main Output
Huang et al. (2025) [*i*]	Nanjing (Gulou District), China	Improved Gaussian 2SFCA, entropy-weighted park quality evaluation, multi-source spatial data, Pearson correlation	*a*, *b*	Quality-integrated 2SFCA model; identification of low–low equity zones; targeted planning strategies
Zhong et al. (2025) [*ii*]	Shanghai, China	5-stage survey, XGBoost machine learning, SHAP interpretation, subgroup analysis	*a*, *c*	Evidence of nonlinear and subgroup-differentiated effects; gender- and marital-status-sensitive planning insights
Lai et al. (2025) [*iii*]	Macau	Environmental audits, non-participant behavioural observation, IADL survey, Spearman correlations, multiple regression (VIF-tested)	*a*, *b*	Visible greenery and seating positively associated with IADL; design guidance for supportive public spaces
Hu et al. (2025) [*iv*]	Yangtze River Delta, China	GIS spatial analysis, Moran's I, Kernel Density Estimation, Standard Deviation Ellipse, coupling coordination model, entropy weighting	*a*, *b*	Integrated "distribution–evolution–coordination" model; evidence of urban–rural inequalities; policy directions for balanced care provision
Zorrilla-Muñoz et al. (2024) [*v*]	International/virtual	Visual content analysis, manual coding, Cohen's Kappa reliability, AI-generated image analysis	*b*, *c*	Mapping of gender/age stereotypes in digital images; proposal of AI + quantum computing bias-reduction framework
Feng et al. (2024) [*vi*]	Guangzhou, China	POI big data analysis, 500 × 500 m grid modelling, ID3 decision tree (ML)	*a*, *b*	High-accuracy predictive siting model; identification of priority grids; smart spatial planning strategies
Gavari-Starkie et al. (2024) [*vii*]	Rural Latin America and Spain	Comparative qualitative analysis, policy/document review, case-based evidence	*a*, *b*, *c*	STEM/STEAM as a lever for rural resilience, gender equity, and youth retention; policy guidance
Pinto Hernández and Delgado Rodríguez (2023) [*viii*]	Europe (Spain and Sweden)	EHIS microdata analysis, probit models, negative binomial regression, counterfactual scenario analysis	*a*	Empirical support for differentiated taxation of reduced-risk products; public health policy implications
Calvo-Palomares et al. (2023) [*ix*]	Rural Valencia (Spain)	Statistical demographic analysis, surveys with local development agents, READI© matrix	*a*, *b*, *c*	Replicable territorial capacity model; detection of underused local potential and governance weaknesses

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Table 1. *Cont.*

Author (Year)	Case Study Area	Method(s) Used	Thematic Area	Main Output
Li et al. (2023) [*x*]	Rural China	IV ordered probit, instrumental variables for endogeneity correction, mechanism regressions	*a*, *b*	Land circulation-out improves older farmers' health via income diversification and reduced physical burden
Thomas et al. (2025) [*xi*]	Pacific Islands	Scoping review (PRISMA-ScR), thematic analysis (Braun and Clarke)	*a*, *c*	Evidence of complementary gendered knowledge systems; call for inclusive and decolonized food policies
Hermaputi and Hua (2024) [*xii*]	Global	Bibliometric analysis (Bibliometrix), co-citation analysis, MCA, thematic mapping	*c*	Operational framework for women-inclusive cities; mapping of research trends, clusters, and gaps

(a) Territory and Environment

The first thematic area concerns the ways in which territory and the environment—both natural and built—shape access to resources, the distribution of risks, and individuals' ability to lead autonomous and dignified lives. The contributions that deal with this aspect show how, at different spatial scales, it is possible to measure territorial equity in a more fine-grained way and to identify strategies for rebalancing the provision of services and environmental resources.

Several studies directly interrogate the accessibility and quality of urban spaces. Contribution (*i*) develop an improved Gaussian 2SFCA method to assess older adults' accessibility to parks in Gulou District (Nanjing), integrating multi-source data on park quality, mobility patterns, and residential characteristics. The result is a map of service "blind zones" that are not captured by traditional indicators and that point to the need for targeted interventions on micro-parks, pedestrian infrastructures, and transport connections. Contribution (*iii*) analyse outdoor community public spaces in Macao, linking physical configuration (visible greenery, availability of seating, layout) to observed behaviours and performance in instrumental activities of daily living, and showing how specific design choices can either support or constrain older people's autonomy.

Other contributions approach the geography of services for older adults as an eminently territorial issue. Contribution (*iv*) reconstruct the spatial distribution and twenty-year evolution of care facilities in the Yangtze River Delta, highlighting a transition towards smaller-scale community services but also a marked polarisation between well-served central areas and underprovided rural or peripheral territories. Contribution (*vi*) apply machine-learning algorithms to point of interest (POI) data in Guangzhou to identify spatial cells most suitable for hosting new facilities for older people, distinguishing between differentiated strategies for saturated historic centres, emerging commercial districts, suburbs and peripheral areas.

The theme of territory as both a resource and a constraint emerges particularly strongly in rural areas. Contribution (*ix*) assess the territorial capacity for development of two rural comarcas in the Valencian Community, combining demographic and employment indicators with the READI© methodology, and show how spatial resources, local actors, and cooperative dynamics translate into divergent trajectories of resilience or further marginalisation, with direct implications for depopulation and ageing. Contribution (*vii*) propose to conceptualise rural territory as a privileged educational space: STEM/STEAM education, rooted in local natural and cultural resources and in the intergenerational transmission of

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knowledge, is interpreted as a tool to counter youth outmigration, reduce gender inequalities, and valorise older adults as pedagogical resources.

In the Chinese context, contribution (*x*) explore the relationship between land circulation and the health of middle-aged and older farmers, showing how the transfer of land-use rights can improve health outcomes by reducing physically demanding labour and enabling access to less strenuous income sources, albeit in a framework where land continues to function as an informal guarantee of security in old age. Lastly, contribution (*xi*) widen the lens to Tonga, Samoa, the Solomon Islands, and Fiji, bringing to the fore how indigenous knowledge and gendered roles in food production and natural resource management are central to sustainability and climate adaptation, and how decolonised territorial policies must integrate these forms of knowledge in order to strengthen local resilience.

The insight provided by contribution (*viii*) on tax regimes for reduced-risk tobacco products also has a territorial dimension: national fiscal systems, health markets, and the socio-demographic profiles of consumers combine to define differentiated geographies of health risks and costs, with concrete implications for health in ageing regions.

(b) Population Ageing

The second area focuses on population ageing as a process that permeates welfare systems, labour markets, production structures, intergenerational relations, and territorial development trajectories. The collected contributions show how ageing takes on different configurations depending on whether one looks at large metropolitan areas, regions undergoing rapid economic transformation or rural contexts marked by demographic decline.

At the urban scale, several studies place ageing in place and the possibility for older people to remain in their living environments in conditions of autonomy at centre stage. Contribution (*i*) demonstrate the scale of the share of communities in Gulou District that have poor pedestrian accessibility to parks, suggesting that, in the absence of adequate infrastructural adaptations, ageing risks translating into greater exposure to physical inactivity and social isolation. Contribution (*iii*) show that specific configurations of community public spaces (e.g., greater visibility of green elements, availability of seating, and layouts that encourage encounters) are associated with better performance in instrumental activities of daily living, pointing to the possibility of designing spaces that sustain functional independence in later life.

At the regional scale, contribution (*iv*) analyse the system of care facilities in the Yangtze River Delta, documenting an overall growth in provision but also an increasing territorial misalignment between the needs of the older population and the distribution of services, with the risk of exacerbating divides between central and peripheral areas. Contribution (*vi*) address this issue from a prospective approach, using predictive models to identify priority areas for service expansion in relation to the current and future distribution of the older population in Guangzhou.

In rural settings, ageing assumes specific features linked to depopulation, institutional fragility and dependence on traditional productive sectors. Contribution (*ix*) describe rural comarcas characterised by very high old-age and dependency ratios but also by signs of employment strengthening and increased female participation in the labour market. Therefore, ageing becomes both a challenge and an opportunity to rethink models of local development. Contribution (*vii*) place rural ageing within a pedagogical framework, in which older adults are recognised as active subjects in the transmission of knowledge and in the construction of educational pathways aimed at rooting younger generations in the territory.

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Contribution (*x*) approach ageing from a micro perspective, placing farmers' decisions concerning the circulation of agricultural land at the centre of analysis for those aged over 45, as the transfer of land-use rights is associated with improved self-rated health due to the reduction in physical strain and the possibility of diversifying income sources towards less burdensome activities. Contribution (*v*), finally, remind us that ageing is also a symbolic construction. By analysing visual representations of old age in digital image banks and AI-generated images, they show that older people are often depicted as fragile, passive, and confined to indoor environments. This suggests the need to critically interrogate such narratives to promote an image of ageing consistent with the ideas of participation, citizenship, and capability.

Taken together, these contributions show that ageing is not a simple demographic fact but a spatially situated process whose outcomes depend on the alignment between demographic structures, service provision, working conditions, local social capital, and cultural representations.

(c) Gender and Inclusion

The third area places the role of gender and inclusion at the centre of the processes that connect territory, ageing, and environment. The papers discussed here confirm that gender is not an additive dimension but a structuring principle of the organisation of space, territorial policies, and the very experiences of ageing.

In urban contexts, contribution (*ii*) analyse non-linear relationships between the built environment and overweight risk in Shanghai, with particular attention to differences regrading gender and marital status. The results show that the protective effects of greenery and other features of the urban context are not uniform; in fact, men and women, both single and married individuals, experience the same environmental conditions differently, confirming that care roles, social norms, and gender expectations modulate the impact of territory on health. From a symbolic and media perspective, contribution (*v*) highlight how images of ageing circulating in image banks and artificial intelligence systems tend to reproduce stereotypes that associate old age—and particularly older women—with frailty, sadness, and dependence, alongside a marked underrepresentation of natural environments and technologies that support autonomy.

In rural and island contexts, gender intersects with local knowledge and the organisation of work. Through a scoping review on Tonga, Samoa, the Solomon Islands, and Fiji, contribution (*xi*) show how men, women and non-binary people contribute in differentiated but complementary ways to food production, resource management, and the transmission of indigenous knowledge, and how their exclusion from decision-making processes entails a concrete loss in terms of adaptive capacity and sustainability. Contribution (*vii*) interpret STEM/STEAM education in terms of gender justice, showing how educational projects rooted in the territory can counter the masculinisation of rural villages, promote the continued presence of girls and women, and valorise older adults within educational circuits.

Economic dimensions and territorial development are also permeated by gender. In the work of contribution (*ix*), the increased participation of women in the labour market in Valencian rural comarcas is read as resulting, at least in part, from the expansion of social services and local cooperative projects, albeit within a context still marked by demographic imbalances and pronounced population ageing. Contribution (*xii*), lastly, locate the topic within the broader field of women-inclusive cities. Their bibliometric analysis reconstructs trajectories and theoretical nodes in research on cities inclusive of women, from urban safety to mobility, from political participation to feminist urbanism,

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offering an essential conceptual framework for rethinking urban and territorial policies that structurally integrate women's needs across the life course, including in later life.

In summary, the contributions in this area show that gender and inclusion are constitutive elements of the ways in which space is designed, lived and represented, and of the ways in which ageing is enabled, supported, or hindered. Only by systematically integrating this lens with perspectives on territory/environment and ageing is it possible to outline development pathways that are genuinely sustainable and socially just for ageing societies in deeply unequal territorial contexts.

Looking at the geography of the cases considered, a marked variety of contexts emerges. A substantial share of the contributions focuses on large urban areas in East Asia, in particular cities and metropolitan regions characterised by high density, rapid demographic transition, and intense pressure on land use. Other studies are situated in rural contexts in Europe and Latin America, marked by depopulation, population ageing and institutional fragility, or in island systems in the Pacific, where vulnerability to climate change intersects with subsistence economies and indigenous agricultural knowledge. Alongside these traditional territorial realities, we also find a supranational European scale, a global analytical space on women-inclusive cities, and even a digital territory constructed through image databases and artificial intelligence systems. Overall, the cases range from neighbourhoods and community public spaces to regional networks of services for older adults, as well as entire rural regions and sets of countries, offering a rich spectrum of scales and contexts.

4. Conclusions and Future Directions

At the methodological level, overall, the contributions display considerable heterogeneity and a clear interdisciplinary orientation. Some studies adopt a strongly quantitative and spatial approach, combining indicators of environmental quality, accessibility measures, and advanced GIS techniques, such as new-generation 2SFCA models, entropy indices, spatial autocorrelation analysis, and models of demand/supply coordination. Other works employ interpretable machine learning tools to capture non-linear relationships between urban environment, health and risk behaviours, or econometric models with instrumental variables to address endogeneity problems and uncover causal mechanisms linking working conditions, income, and health status in older populations. There are also studies based on highly articulated matrices of territorial indicators, which combine demographic, employment, governance, and social capital data.

Alongside these approaches, we find more qualitative and conceptual research, including comparative analyses of educational policies and practices in rural areas, scoping reviews on indigenous agricultural knowledge and gender roles in food systems, visual analyses and systematic codings of images of old age, as well as bibliometric investigations that map the evolution of entire fields of study.

Taken together, the contributions integrate tools from spatial sciences, statistics, economics, social sciences, pedagogy and gender studies, often combining applied, participatory and analytical methods to support evidence-based territorial planning.

Essentially, empirical evidence advances knowledge along three main directions. Firstly, it improves the capacity to measure and represent territorial equity in access to resources that are crucial for ageing, such as green spaces, social and health services, and care infrastructures. Spatial and predictive models make it possible to identify systematically disadvantaged areas, quantify imbalances between urban and rural settings, and propose more targeted planning strategies.

Secondly, the contributions deepen the relationship between ageing, work, local development, and well-being. Clear links emerge between restructuring in agricultural work,

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economic security, and health conditions, as well as the often underutilised potential of rural territories characterised by pronounced population ageing but rich in environmental, cultural, and social resources. Attention is directed not only to deficits but also to capacities for resilience and to the opportunities generated by new forms of cooperation, proximity services, and re-oriented local economies.

Thirdly, the corpus of studies underscores how gender and inclusion cut across all the dimensions considered. The research shows that the effects of urban and rural environments on health, mobility and opportunities are not neutral, but vary by gender, age, marital status, cultural background and socio-economic position. Educational practices, food policies, images of old age and theoretical references on women-inclusive cities all contribute to delineating a field in which gender inequalities intersect with territorial and generational inequalities, making the need for more intersectional approaches evident.

Despite these advances, the studies also give rise to several reflections that open up important avenues for future research. At least four can be highlighted as follows:

Many contributions offer high-resolution portraits of specific contexts, yet there are still few studies capable of systematically connecting micro dynamics (domestic space, neighbourhood, local community) and macro dynamics (regions, urban systems, supranational networks) and of following their evolution over time. There is a need for longitudinal designs that observe, over longer time spans, how accessibility, environmental quality, care networks, and older people's living conditions change in relation to territorial transformations.

Although the cases cover a plurality of world regions, structured comparisons between areas with different welfare regimes, settlement models, and socio-environmental conditions remain limited. Studies that systematically compare strategies, instruments, and outcomes across urban and rural contexts, North and South, and centres and peripheries could clarify which models are genuinely transferable and under what conditions the tools need to be profoundly adapted.

In several contributions, older people, women, rural communities, and indigenous populations are at the centre of the analysis but are more rarely fully involved in the co-creation of indicators, maps, images, and design solutions. Developing more robust hands-on and co-design approaches—where those concerned are included as co-researchers and not only as informants—appears crucial for reducing the risk of paternalistic, ageist, or androcentric perspectives and for grounding proposals in needs that are actually perceived.

Many studies propose operational tools (i.e., spatial models, territorial capacity matrices, regulatory or fiscal schemes, educational frameworks) explicitly oriented towards institutional use. However, the pathways through which these tools are effectively adopted by administrations, services and local organisations, as well as the feedback generated by their concrete application, are still poorly documented. A promising research agenda thus concerns the study of the conditions that facilitate or hinder the translation of scientific evidence into policies and practices, and the analysis of feedback loops between implementation, evaluation, and redesign.

Taken together, the contributions to this Special Issue confirm the fruitfulness of a perspective that holds together territory and environment, population ageing, and gender and inclusion, moving beyond sectoral readings and addressing socio-spatial inequalities in an integrated manner. Further developing the lines sketched here, by strengthening longitudinal and comparative perspectives, expanding co-production practices with local actors, and consolidating bridges between research, policies and interventions, can contribute to building territories that are more sustainable, more just, and better able to respond to the needs of all generations.

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(i) Huang, Y.; Wu, W.; Shen, Z.; Zhu, J.; Chen, H. Beyond Proximity: Assessing Social Equity in Park Accessibility for Older Adults Using an Improved Gaussian 2SFCA Method. *Land* **2025**, *14*, 2102. https://doi.org/10.3390/land14112102.

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Beyond Proximity: Assessing Social Equity in Park Accessibility for Older Adults Using an Improved Gaussian 2SFCA Method

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Abstract: Urban park green spaces (UPGSs) play a critical role in enhancing residents' quality of life, particularly for older adults. However, inequities in accessibility and resource distribution remain persistent challenges in aging urban areas. To address this issue, this study takes Gulou District, Nanjing City, as an example and proposes a comprehensive framework to evaluate the overall quality of UPGSs. Furthermore, an enhanced Gaussian two-step floating catchment area (2SFCA) method is introduced that incorporates (1) a multidimensional park quality score derived from an objective evaluation system encompassing ecological conditions, service quality, age-friendly facilities, and basic infrastructure; and (2) a Gaussian distance decay function calibrated to reflect the walking and public transit mobility patterns of the older adults in the study area. The improved method calculates the accessibility values of UPGSs for older adults living in residential communities under the walking and public transportation scenarios. Finally, factors influencing the social equity of UPGSs are analyzed using Pearson correlation coefficients. The experimental results demonstrate that (1) high-accessibility service areas exhibit clustered distributions, with significant differences in accessibility levels across the transportation modes and clear spatial gradient disparities. Specifically, traditional residential neighborhoods often present accessibility blind spots under the walking scenario, accounting for 50.8%, which leads to insufficient accessibility to public green spaces. (2) Structural imbalance and inequities in public service provision have resulted in barriers to UPGS utilization for older adults in certain communities. On this basis, targeted improvement strategies based on accessibility characteristics under different transportation modes are proposed, including the establishment of multi-tiered networked UPGSs and the upgrading of slow-moving transportation infrastructure. The research findings can enhance service efficiency through evidence-based spatial resource reallocation, offering actionable insights for optimizing the spatial layout of UPGSs and advancing the equitable distribution of public services in urban core areas.

Keywords: urban park green spaces; social equity; accessibility; older adults; modified two-step floating catchment area

1. Introduction

Urban park green spaces (UPGSs) serve as critical public infrastructure that enhances residents' quality of life, particularly for older adults [1–3]. With global aging accelerating,

older adults face reduced mobility, heightened reliance on public transit, and increased environmental sensitivity, intensifying the mismatch between UPGS supply and spatial service demand [4–6]. To address this issue, the World Health Organization (WHO) underscores that urban design must prioritize the physical and mental needs of older adults through optimized spatial layouts [7], yet inequitable UPGS access remains a persistent challenge. Under these circumstances, developing precise UPGS configuration strategies tailored to older adults has become a critical challenge for advancing urban sustainable development.

To facilitate effective evaluation of UPGSs, numerous studies have been conducted, particularly proposing a comprehensive set of assessment indicators. Among these indicators, accessibility emerges as a pivotal metric for quantifying spatial resource access [8–10]. Initially conceptualized as the ease or difficulty of travel between locations, its definition has evolved to incorporate spatio-temporal (e.g., travel time costs) and socioeconomic dimensions (e.g., disparities in access across demographic groups) [11–13]. Current research predominantly employs three core analytical frameworks to assess UPGS accessibility, namely network analysis for spatial coverage evaluation, the Gaussian two-step floating catchment area (2SFCA) method for demand-pattern integration, and space syntax analysis for traffic-flow dynamics. [14–16]. For example, some studies analyzed the accessibility of UPGSs by integrating land use and population distribution data, with the aim of deriving targeted park site selection recommendations [17–19]. With advancements in big data technologies, scholars are increasingly using multi-source data (e.g., mobile signaling records, street view images, social media data) to leverage their complementary advantages in accessibility evaluation [20–23].

Although accessibility provides a benchmark for identifying the physical coverage of UPGSs, it fails to reflect comprehensive barriers faced by specific populations [24–26]. Consequently, the concept of equity is introduced to assess the distributional rationality of urban public service resources. It serves as a fundamental metric for assessing the equity of resource allocation between diverse social segments [27–29]. The equity analysis of UPGSs has evolved through three phases: regional equity (distribution equality) [30–32], spatial equity (accessibility efficiency) [33,34], and social equity (population disparity) [35], with current studies predominantly focusing on spatial dimensions [36–38]. Despite improvements to traditional models through distance decay functions, attraction models, and threshold settings, these single-dimensional optimizations are fundamentally limited in their ability to reveal the accessibility characteristics of specific populations [39]. Meanwhile, rapid population aging has driven a profound shift in societal needs. Due to socioeconomic vulnerabilities, older adults face heightened risk of social exclusion and exhibit greater demand for public infrastructures [40,41]. In this context, UPGSs enhance physical, psychological, and social well-being while reducing health risks for older adults [42]. Consequently, equitable access to UPGSs becomes essential for promoting the living quality of older adults [43]. Existing studies have applied methods such as AG2SFCA and gradient boosting decision trees to analyze park accessibility for older adults [14,44,45]. However, these studies have not accounted for the influence of park environmental quality on its attractiveness to older adults.

To address the above issues, this study comprehensively considers the demand characteristics of older adults and selects Gulou District in Nanjing as a case study. Specifically, we collect multi-source big data, including questionnaires, remote sensing imagery, mobile signaling records, and points of interest (POIs), to establish a UPGS foundational database. On this basis, an improved Gaussian 2SFCA method is proposed, in which the traditional area-based supply indicator is replaced by a comprehensive score of park quality across multiple dimensions. In this framework, a Gaussian distance decay function is incorporated to better simulate the travel behavior of older adults, considering that visitation probability declines

with increasing distance. This integration enables a more refined and equitable assessment of UPGS accessibility for the older adults in the study area, which can better reflect their actual needs and behavioral characteristics. Finally, from the perspective of social equity, we apply Pearson correlation coefficients to analyze UPGS equity disparities and their causes and propose corresponding strategies (Figure 1). This research aims to provide scientific references for the planning of UPGSs and ensuring environmental justice for vulnerable groups.

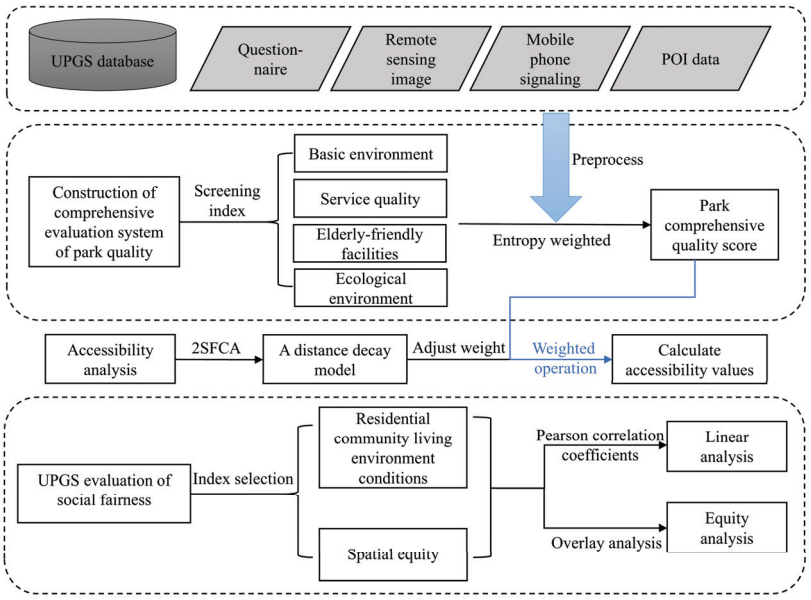


Figure 1. Overall research roadmap.

The structure of this paper is as follows: Section 1 provides the context and motivation for this study and a review of the existing literature. Section 2 establishes the research foundation by introducing the study area, datasets, and software used. Section 3 constructs the methodological framework for park quality assessment, accessibility measurement, and equity evaluation. Section 4 presents the empirical results of older adults from quality scoring, multimodal accessibility analysis, and social equity assessment. Section 5 provides an in-depth discussion by connecting key findings with regional development contexts. Section 6 synthesizes the conclusions and derives practical planning strategies.

2. Research Area and Data

2.1. Research Area

Gulou District is situated along the Yangtze River in Nanjing. With a total area of 54.18 km^2, it governs 13 sub-districts and is characterized by a gentle topography dominated by uplands and plains. The region boasts a well-developed economy, supported by a complex transportation network and abundant vegetation resources. It has multiple types of park greenery, including comprehensive parks, specialized parks, and community parks (Figure 2). Moreover, Gulou District is characterized by a deeply aged society [46]. As the most densely populated historic urban area in Nanjing, it had a permanent resident population of 942,700 at the end of 2023, which included 307,100 older adults, representing over 30% of the total. Due to historical factors, a large number of older adults in the jurisdiction are concentrated in some historically built residential communities. The existing spatial layouts and facilities in these areas are ill-suited to the living needs and activity expectations of older adults, which further accentuates the persistent issues related to the shortage and inferior quality of urban public spaces.

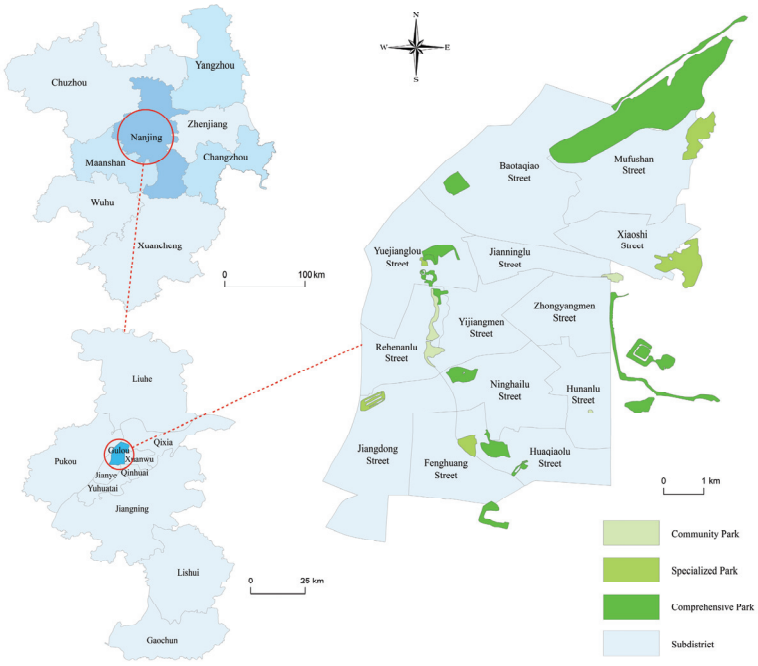


Figure 2. A sketch map of the study area (note: some parks that are adjacent to the Drum Tower area and have great influence are also included in the evaluation of this study, such as Xuanwu Lake Park, Hongshan Forest Zoo, and Mochou Lake Park).

2.2. Research Data

This study employs interdisciplinary methods such as remote sensing interpretation, big data mining, and field investigation to evaluate the service level of UPGSs for older adults. The research data comprises administrative division data, urban road data, UPGS data, residential community data, service evaluation data, park facility data, and older adults data (Table 1). The administrative division data is sourced from the Tianditu Spatio-Temporal Information Cloud Platform (https://www.tianditu.gov.cn), and the urban road data comes from Open Street Map. The UPGS data, sourced from 2024 Gaofen-2 imagery, is processed in ENVI 5.6 to extract park boundaries and calculate the annual average NDVI and NDWI. These indices serve as quantitative metrics for assessing the ecological regulation capacity and visual landscape comfort, respectively, and are used to support the evaluation of social equity. The residential community data is obtained from the points of interest (POIs) data of residential communities crawled from the Amap Open Platform, and the housing price data is provided by https://nj.lianjia.com/. This dataset encompasses 1066 residential communities, detailing their names, locations, housing prices, and affiliated sub-districts, which closely aligns with the number of 1095 communities reported by the Gulou District Real Estate Bureau in 2024. The service evaluation data is collected through questionnaires (Appendix A), with a total of 573 questionnaires evenly distributed across various parks within the jurisdiction. The questionnaire design follows the cognitive habits of older adults, with the content presented as concise as possible to facilitate quick and accurate responses. Park facility data is collected through field surveys and Gaode Map's open platform, including facility POIs (both inside and outside of the parks), night lighting, signage systems, and barrier-free facilities. The older adults data is derived from mobile phone signaling data provided by the China Unicom Smart Footprint Platform. To ensure data reliability, the older adults in the study area is quantified based on their presence within polygon-based base station units from 00:00 to 05:00 over ten days. This

dataset shows a strong correlation (r = 0.8032) with the permanent older adults from the 7th National Population Census at the sub-district level.

Table 1. Data categories and sources.

Data Type	Data Resources	Data Content
Administrative division data	Map World spatio-temporal information cloud platform	Street administrative boundaries
Urban road data	Open Street Map	Urban main roads, secondary roads, and branch roads
UPGS data	GF-2 satellite images	UPGS boundary, vegetation and water area, etc.
Residential district data	Gaode Map open platform, chain home	POIs, housing prices, etc.
Service evaluation data	Questionnaire	Subjective evaluation by older adults
Park facility data	On-site investigation, Gaode map	Public service facility POIs, accessibility of facilities, etc.
Older adults data	China Unicom Smart Footprint Platform	Number of older adults in each region

3. Research Methods

3.1. Park Quality Fairness Evaluation System

Traditional quality evaluations mostly focus on a single dimension such as spatial scale, making it difficult to meet the special needs of older adults. Therefore, supported by the age-friendly theory [47] in combination with the behavioral preference characteristics of the older adults, this study selects four primary indicators: basic environment, service quality, age-friendly facilities, and ecological environment (Table 2). Among these indicators, the basic environment indicator evaluates each park's spatial scale, layout form, and daily maintenance and encompasses three secondary indicators: area size, shape index, and sanitary conditions. The service quality indicator assesses the service efficiency and attractiveness of parks comprehensively through two secondary indicators, namely service function diversity based on external Gaode Map POI data and overall satisfaction rate derived from the questionnaires. The age-friendly facility indicator focuses on practical convenience and safety assurance during age-appropriate activities, including internal facility POIs derived from the Gaode Map data and age-friendly facility counts from field surveys. The ecological environment indicator measures the ecological regulation capacity and visual landscape comfort and consists of two secondary indicators: daily average NDVI and NDWI calculated from GF-2 satellite images.

To mitigate the inherent biases of traditional subjective weighting methods and the inaccuracies stemming from information redundancy between indicators, this study employs the entropy method for objective weighting. This approach determines the relative importance of each indicator based on the underlying data patterns. The formulas are as follows:

$$R_x = \left(x_{\mathrm{ij}}\right)_{m\times n} = \begin{Bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{Bmatrix} \quad (1)$$

$$y_{\mathrm{ij}} = \frac{x_{\mathrm{ij}} - \min x_{\mathrm{ij}}}{\max x_{\mathrm{ij}} - \min x_{\mathrm{ij}}} \quad (2)$$

$$P_{ij} = \frac{y_{ij}}{\sum_{j=1}^{m} y_{ij}} \tag{3}$$

$$e_j = -\frac{1}{\ln n}\left(\sum_{i=1}^{m} P_{ij} \times \ln P_{ij}\right) \tag{4}$$

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)} \tag{5}$$

where R_x represents the original matrix containing the data for all indicators, y_{ij} denotes positive indicators, P_{ij} is the proportion of each y_{ij}, e_j refers to the entropy value of each indicator, and w_j represents the weight assigned to each indicator.

Table 2. Park quality fairness evaluation system.

Primary Indicators	Secondary Indicators	Source	Weight
Basic environment	Area size	Statistically obtained via ArcGIS Arcmap 10.8 vectorization	0.1552
	Shape index	Calculated based on the perimeter and area of each UPGS	0.1258
	Sanitary conditions	Questionnaires, field research and public comment data, health environment data	0.0671
Service quality	Service function diversity	POI data of Gaode map outside the park	0.0283
	Overall satisfaction rate	Number of favorable comments in the questionnaires	0.1893
Age-friendly facilities	Internal supporting facilities	POI data derived from Gaode map inside each park	0.1007
	Quantity of age-friendly facilities	Field investigation, number of facilities suitable for older adults	0.1303
Ecological environment	Daily average NDVI	Calculated with GF-2 images in 2024	0.0997
	Daily average NDWI	Calculated with GF-2 images in 2024	0.1036

3.2. Accessibility Analysis Based on the Improved Gaussian Two-Step Floating Catchment Area Method (2SFCA)

Widely regarded as a premier method for assessing UPGS accessibility [48,49], the Gaussian two-step floating catchment area method effectively integrates supply–demand relationships, distance decay, and practical ease of use to attain accurate spatial accessibility metrics. However, traditional 2SFCA method only measures park supply capacity based on area and fails to fully account for the dynamic impact of distance on service accessibility. Therefore, this study starts from the demand side and optimizes the traditional 2SFCA method by introducing an attraction algorithm to build a comprehensive evaluation system for park quality. Specifically, by integrating key factors such as park facilities, landscape, maintenance, carrying capacity, and population-specific friendliness, this system generates an objective quality score for each park, establishing it as the core metric for assessing supply capacity. Furthermore, the Gaussian-based distance decay function proposed by Dai is adopted to model the travel impedance that spatial distance imposes on park access [50]. This step is crucial to mitigate the overestimation of accessibility that would otherwise arise from ignoring the friction of distance.

In the analysis, residential community centroid points (i) are designated as demand bases. To account for the travel patterns of older adults involving walking and public transportation, time thresholds of 15 and 30 min, respectively, are adopted in accordance with the Nanjing Territorial Spatial Master Plan (2021–2035). Based on the average walking speeds of older adults, the time thresholds are converted into distance thresholds (d_0) to

define the search range for each community. Within the defined search area, spatial analyses are employed to identify all UPGSs (j). For each identified park, weighted calculations are performed by incorporating the supply–demand ratio (R_j) derived from park quality equity evaluations and the Gaussian decay function-adjusted weights based on actual distances. Finally, the accessibility value (A_i) for residential community point (i) is obtained by summing all UPGS calculation results. Higher A_i values indicate greater convenience in accessing UPGS services for older adults. The formulas are as follows:

$$R_j = \frac{S_j}{\sum_{k \in [d_k j \le d_0]} G\left(d_{\mathrm{ij}}\right) D_k} \tag{6}$$

$$A_i = \sum_{j \in \{d_{\mathrm{ij}} \leqslant d_0(i)\}} R_j \times G(d_{\mathrm{ij}}) \tag{7}$$

$$G\left(d_{\mathrm{ij}}\right) = \frac{e^{-\frac{1}{2} \times \left(\frac{d_{\mathrm{ij}}}{d_0(i)}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}}, \left(d_{\mathrm{ij}} \le d_0(i)\right) \tag{8}$$

where S_j represents the supply scale of UPGS j, which is measured based on the park quality comprehensive score; d_{kj} denotes the actual distance from residential community k to UPGS j; D_k refers to the demand scale of residential community k within the search range, which is quantified by older adults counts; R_j indicates the supply–demand ratio of UPGS j within the search threshold [$d_{ij} \le d_0(i)$] for residential community i; and G(d_{ij}) defines the Gaussian decay function that accounts for the effects of spatial friction in the calculation of accessibility.

3.3. Social Equity Evaluation Method

Social equity has been narrowly conceptualized in traditional evaluations, which emphasize spatial resource distribution without connecting it to the quality of the residential environment [43]. To address this limitation, this study conducts social equity assessments from two perspectives: composite living environment conditions and spatial equity. (1) The composite living environment index, which is grounded in the concept of age-friendly communities, characterizes residential environment quality through three pillars: comfort (represented by housing prices), aesthetics (measured based on 30 min park accessibility), and harmony (using density of older adults as a negative indicator of public service pressure). The entropy method assigns weights to standardized indicators that are multiplied by normalized data to calculate the composite living environment score for each community. (2) Spatial equity evaluation comprises three indicators: park quality accessibility, walking accessibility, and public transport accessibility. Park quality accessibility is defined as the sum of UPGS quality scores calculated for each residential community within a given service range.

The Pearson correlation coefficient characterizes the linear relationship between the composite living environment and spatial equity for each residential community. An overlay analysis of the composite living environment and spatial equity indicators reveals their spatial associations, which are categorized into four spatial patterns: “high–high”, “high–low”, “low–high”, and “low–low”. Specifically, “high–high” indicates high-quality living environment and strong spatial equity, representing high social equity. “High–low” and “low–high” reflect imbalanced states, corresponding to moderate social equity. “Low–low” signifies low-quality living environment and weak spatial equity, indicating low social equity. Service blind spots are defined as “low–low” regions in the overlap analysis results, which represent priority zones requiring improvement in subsequent planning.

4. Results

4.1. Comprehensive Evaluation of the Quality of Parks in Gulou District

Figures 3 and 4 show that significant differences exist in the UPGS comprehensive scores. A few large parks, such as Xuanwu Lake Park and Hongshan Forest Zoo, have quality scores that are far above the average, while more than 60% of parks have scores below the mean. This pattern indicates an imbalance in both quantity and quality of park resources within the study area.

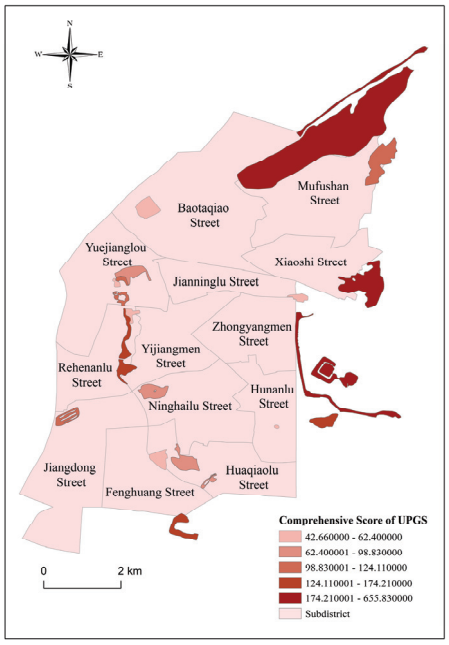


Figure 3. Spatial distribution of green space comprehensive scores.

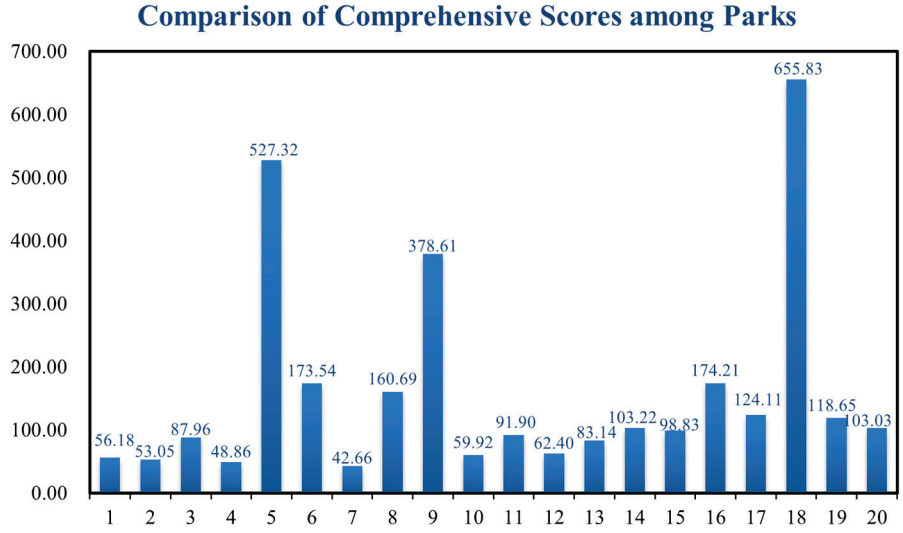


Figure 4. Comparison of UPGS comprehensive scores (note: the numbers on the horizontal axis correspond to the parks as follows: 1—Bazishan Park, 2—Daqiao Park, 3—Gulin Park, 4—Gulou Park, 5—Hongshan Forest Zoo, 6—Jimingsi Park, 7—Jinghai Temple, 8—Mochou Lake Park, 9—Nanjing Muyan Riverside Landscape Area, 10—Nanjing Stone City Heritage Park, 11—Qingliangshan Park, 12—Shence Gate Park, 13—Lion Mountain Scenic Area, 14—Tao Xingzhi Memorial Hall, 15—Wulongtan Park, 16—Xiaotao Park, 17—Xiuqiu Park, 18—Xuanwu Lake Park, 19—Yuejianglou Scenic Area, 20—Zhenghe Baochuan Heritage Park. These numbers corresponding to the park names are also applicable to Figure 5).

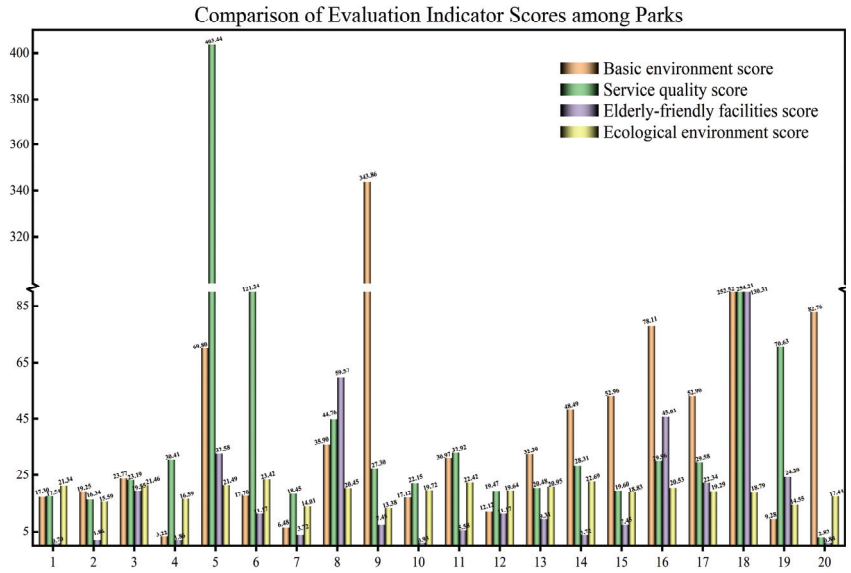


Figure 5. Evaluation scores of UPGSs.

Figure 5 indicates a skewed distribution of basic environment scores, with the scores of 75% of parks falling below the average. Only a small number of parks, including the Nanjing Muyan Riverside Scenic Area and Xuanwu Lake Park, score above the average. This result aligns closely with the questionnaire results. Specifically, only 38% of older adults are satisfied with basic environment conditions, suggesting this inadequacy is a widespread concern. Thus, enhancing these conditions remains a critical challenge for most UPGSs.

Regarding service quality, only four UPGSs, including Hongshan Forest Zoo and Xuanwu Lake Park, score above average. Conversely, the scores of 80% of parks fall below the mean, making service quality the lowest-rated indicator across all evaluation criteria. This finding aligns with the questionnaire results, in which only 32% of older adults express satisfaction with park service quality, including staff attitude and activity diversity. Furthermore, the considerable gap between the highest and average scores suggests that excellence in providing diversified services is currently confined to a small number of parks.

Regarding age-friendly facility scores, 30% of parks achieve scores above the mean. This percentage is relatively high among all evaluation indicators, which indicates that targeted progress has been made in constructing age-friendly facilities in some parks. However, the extremely low minimum score reveals serious deficiencies in certain parks. This outcome aligns with the questionnaire results, which show that 29% of respondents characterize park supporting facilities as "sufficient", while 24% characterize them as "insufficient". Overall, these findings highlight that most parks fail to adequately meet the needs of older adults regarding service diversity and facility completeness.

Ecological environment demonstrates the highest performance among all evaluation criteria, as evidenced by 60% of parks scoring above the average. This result is highly consistent with the evaluation of park ecological environment in the questionnaire. The survey shows that 35% of respondents rate the park ecological environment (e.g., green coverage, water cleanliness) as "satisfactory," 50% consider it as "general," and only 15% are "dissatisfied". The results suggest that most parks exhibit specific ecological strengths, yet the overall scores remain low, indicating substantial potential for upgrading their ecological quality and service functions.

In summary, high-quality parks achieve higher scores regarding basic environment and diversity of service functions, while medium- and low-quality parks score higher in service quality and ecological environment.

4.2. Evaluation of Accessibility of UPGS for Older Adults Under Different Transportation Modes

Given that older adults rely predominantly on walking and public transit for their daily travel, this study analyzes UPGS accessibility under these two transportation modes. Under the walking mode with a 15 min threshold, the UPGS accessibility exhibits significant spatial heterogeneity. Low-value areas (Ai $\leq$ 0.5) account for 50.8% of the total, revealing that in more than half of the communities, older adults cannot effectively access UPGS within a practical walking range.

When the walking time threshold is extended to 30 min, the accessibility range exhibits a reduction. Concurrently, there is a substantial decrease in the proportion of extremely low values, being 39.2 percentage points lower than that under the 15 min threshold. This aligns with the survey results, wherein 46% of respondents report commuting times within 30 min. Extending the threshold can enhance the spatial coverage efficiency of UPGS. Nevertheless, persistent localized gaps in certain areas require targeted optimization of green space layouts to mitigate service deficits across different threshold scenarios.

In summary, the accessibility of green spaces for older adults in Gulou District shows significant spatial clustering, with high-quality parks located in the northern and eastern regions. This synergy between quality and accessibility is empirically confirmed: 42% of older adults give ratings indicating satisfaction when parks are accessible within a 15 min walk, compared with 28% when it is beyond 30 min (Figure 6). Well-equipped parks enhance both appeal and practical access, confirming that quality directly shapes usage convenience. These findings provide an empirical basis for addressing spatial mismatch and optimizing public service resource allocation.

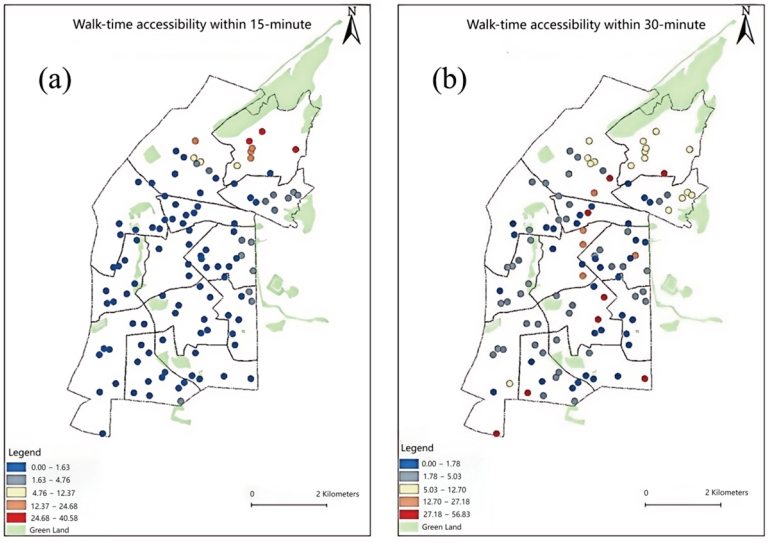


Figure 6. Spatial distribution of parks accessible for older adults within 15 and 30 min walking thresholds.

From the perspective of public transportation, park accessibility for older adults in Gulou District exhibits a clear spatial pattern of differentiation (Figure 7). High-value areas in Yijiangmen and Zhongyangmen subdistricts exhibit radiating distribution patterns toward the southwest. Low-value clusters in the southern districts reflect weak service capabilities regarding green space provision. These findings suggest targeted strategies are needed to improve park quality and optimize public transport connections in the southern districts, which could address imbalanced resource distribution between regions.

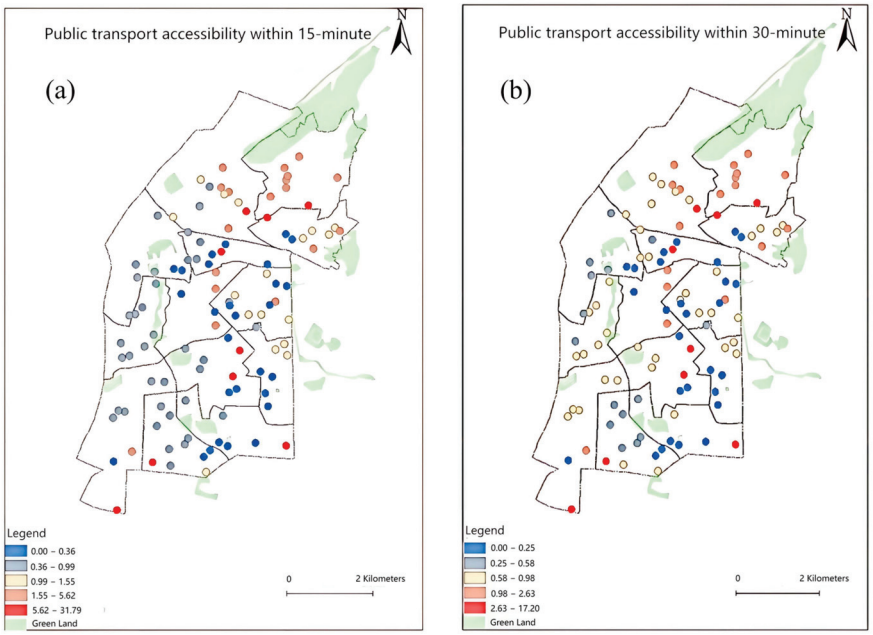


Figure 7. Spatial distribution of parks accessible to older adults within 15 and 30 min public transit thresholds.

When the public transit time threshold is set to 30 min, there are minimal horizontal differences regarding accessibility. The gap between the maximum and minimum values reaches 17.16543844. Higher transit efficiency expands the service radius of parks, allowing older adults to overcome the constraints of walking and reach quality parks, effectively diminishing the extent of low-accessibility zones. However, high-value areas remain relatively limited. This limitation can be attributed to the surge of older adults within transit coverage zones, which has heightened pressure on green space capacity and restricts the expansion of high-accessibility areas.

From the perspective of spatial distribution patterns, areas with extremely low accessibility (Ai $\leq$ 0.5) account for 26.6% of the total and show a distinct spatial clustering in central and southwestern Gulou District. These regions exhibit insufficient public transit route coverage density, low UPGS quality, or inadequate age-friendly facilities, which prevent older adults from efficiently accessing high-quality green spaces. These findings confirm that public transportation partially reduces the proportion of low-accessibility areas by 24.2 percentage points compared to walking accessibility. While this improvement is notable, it has yet to address structural imbalances in resource allocation across districts. A targeted optimization of bus route planning in central and southwestern areas should be prioritized to promote equitable UPGS distribution.

4.3. Analysis of the Social Equity of UPGS Accessibility for Older Adults in Gulou District

A comprehensive assessment of UPGS services for older adults in Gulou District reveals suboptimal equity performance, with significant geographical variations in accessibility across the district's regions and communities. From a social equity perspective, these disparities systematically stem from three core factors:

(1) Imbalanced UPGS spatial distribution: A significant disparity is found between the clustered and excessive UPGS availability in some districts and severe deficits in areas with higher older population densities, indicating substantial inequality in access to nearby green spaces.

(2) Unreasonable spatial configuration of UPGS quality: UPGSs of differing quality levels are distributed sporadically throughout the study area, regardless of the actual distribution of older adults or their particular activity demands. A significant disparity

exists between high-quality, well-equipped parks and ordinary green spaces with outdated facilities and limited functions, leading to compromised service efficacy for the older adults. Consequently, the inferior quality and insufficient integration of age-friendly facilities in these spaces restrict their usability, fostering inequitable access to premium green resources despite geographical closeness.

(3) Mismatch between UPGS supply and age-specific demands: Current planning does not adequately align with the activity preferences of older adults, creating a disconnect between supply and demand. As a result, UPGSs that are physically present often fail to effectively serve older adults living nearby. This mismatch highlights an inequity in meeting the specific environmental needs of this population.

As illustrated in Figure 8, significant service inequity emerges in Gulou District, Nanjing. There is a notable number of service blind spots ("low–low" zones) under the 15 min walking threshold. This finding is corroborated by the survey results: 25% of older adults indicate that the nearby UPGS can only partially fulfill their daily recreational needs. These data reveal widespread service deficiencies within short walking distances, compounded by a distinct clustering of service blind spots in central and northwestern Gulou District. This pattern signals fundamental flaws in resource allocation and broader social equity challenges, underscoring that the city's comprehensive growth has failed to ensure an equitable distribution of green spaces. Consequently, this study identifies a necessity for targeted planning strategies to achieve more precise resource allocation and to foster greater urban equity through enhanced UPGS optimization.

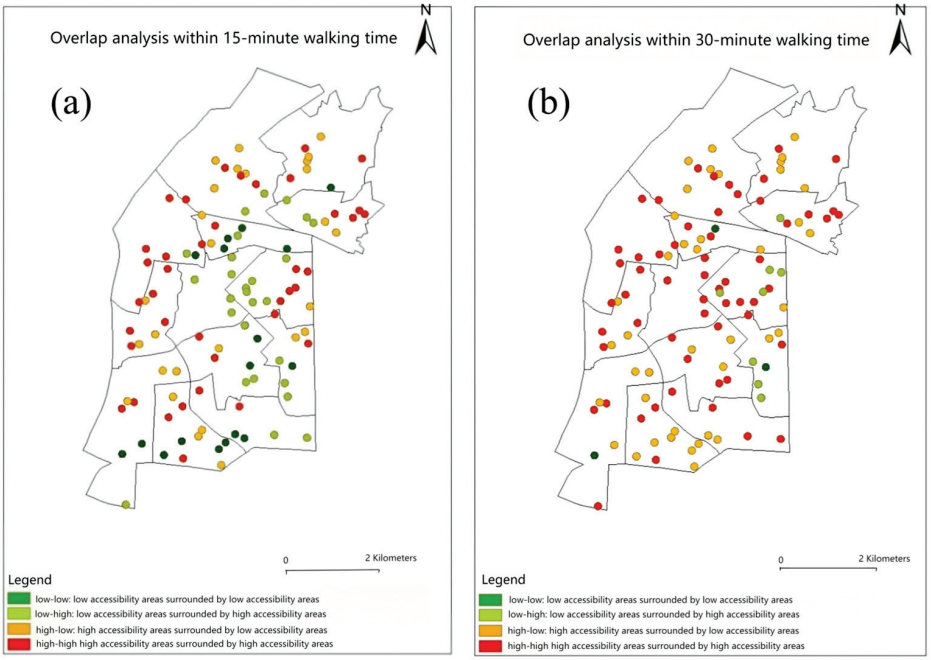


Figure 8. Overlap analysis of residential compound living index and 15 min walking time.

5. Discussion

This study integrates multi-source data, including remote sensing images, POIs, and survey data, to develop a refined analytical framework that effectively captures the spatial relationship between the distribution of UPGSs and the specific needs of older adults. Compared with traditional approaches, this study offers a more nuanced and equity-sensitive framework. It incorporates multimodal travel behaviors and replaces simplistic park supply measures with a multidimensional quality score that integrates ecological

conditions, service facilities, and age-friendly design. Furthermore, by using real-time mobile signaling data instead of aggregated population proxies, this study enables a more accurate, context-aware, and socially equitable evaluation of urban park accessibility in Gulou District, Nanjing. Overall, the proposed framework exhibits strong cross-regional applicability due to its expanded theoretical foundation, which avoids over-reliance on study-area-specific constraints. For regional adaptation, two dynamic adjustments are required. First, the park quality assessment system should be calibrated based on local facility configurations, ecological attributes, and functional usage patterns. Second, Gaussian decay function parameters need to be re-estimated using mobility data of older adults from the target region, including pedestrian movement patterns and public transit preferences.

Regarding specific findings, the high-accessibility zones in Gulou District demonstrate pronounced spatial clustering, while traditional residential areas exhibit significant deficiencies in walking accessibility. The results obtained using these quantitative metrics are consistent with the survey data (47% of older adults rate park facilities as "average," and 14% express "dissatisfaction"), which further indicates that structural mismatches in resource allocation negatively impact user experiences and reflect persistent spatial inequity. When contextualized within broader research, these findings show consistency with studies conducted in Shanghai, China, but contrast with studies conducted in European cities [23,51,52]. The primary reason for this phenomenon lies in the varying degrees of urban development among different cities. Specifically, European cities generally have a lower population density and sufficient per capita land availability, while the limited land resources in Nanjing highlight its relative gap in green space provision. In comparison, Shanghai mirrors Nanjing in its developmental trajectory and socio-cultural fabric. The similarity in results, particularly regarding the spatial equity of green resources, arises from their comparable urban density, historical planning priorities, and the similar challenges they face in serving older adults in high-demand areas. This parallel not only validates the findings of this study in Nanjing, but also suggests that the proposed evaluation framework may have broader applicability in similar urban settings.

To dissect the intra-regional disparities, a finer-grained analysis further reveals that the spatial imbalance stems from underlying regional factors. In central Gulou, historical urban patterns (ancient capital of China) have created areas with high concentrations of older adults, but insufficient park provision. The limited land resources have been predominantly devoted to government premises, educational institutions, and residential areas, making land reserved for parks comparatively scarce. This situation is worsened after the COVID-19 pandemic, as campus closures have curtailed the informal access to institutional green spaces that many older adults previously depended on. Northwestern Gulou is designated as a major logistics hub of east China following the administrative merger between former Gulou District and Xiaguan District since 2013. This transformation fosters strong industrial growth, which, in turn, drives dense urban development that intensifies traffic and noise pollution, which creates additional barriers to the development of age-friendly UPGSs. The abovementioned issues can be addressed through targeted strategies, such as establishing multi-level green networks, promoting shared institutional green spaces, and enhancing age-friendly slow-traffic infrastructures.

Based on the above findings, feasible strategies can be implemented to improve the accessibility of UPGSs for the older adults in Gulou District. For instance, the local government could address spatial supply shortages by constructing pocket parks or repurpose idle urban spaces into age-friendly green zones. Meanwhile, institutions such as universities and government agencies, which often possess abundant high-quality green spaces, could open these areas to community residents during off-peak hours. This approach would

foster shared use of green resources while maintaining normal operations, thereby helping to alleviate the supply–demand imbalances for nearby older adults. Additionally, since older adults are more vulnerable to the adverse effects of pedestrian environments on walking speed and safety, it is also recommended that Nanjing implements age-friendly modifications to its slow traffic systems to enhance walkability to UPGSs for older adults.

6. Conclusions

This study addresses inequities in UPGS accessibility and resource allocation in the context of urban aging, using Gulou District, Nanjing, as a case study, and reveals significant disparities in accessibility across transportation modes alongside structural imbalances in public service provision. We propose a comprehensive framework to evaluate the overall quality of UPGSs. The improved Gaussian two-step floating catchment area method was employed to calculate accessibility values for older adults across different transportation modes. Subsequently, Pearson correlation coefficients were used to analyze the relationships between composite living environment indicators and spatial equity metrics across residential communities. Moreover, this study explores the differences and drivers of UPGS social equity, offering a foundation for optimizing green space planning. It empowers planners to better understand spatial patterns and supply conditions through a comprehensive accessibility and equity assessment and delivers scientific evidence for accurately identifying and meeting the green space needs of older adults.

The study results reveal that high-accessibility UPGS zones in Gulou District exhibit clustered spatial distributions. Accessibility levels demonstrate pronounced disparities between the walking and public transit modes, each displaying distinct spatial gradients. Under the walking scenario, traditional residential areas consistently show accessibility deficits, with 50.8% of neighborhoods registering low accessibility within the 15 min walking threshold. Extending this threshold to 30 min reduces overall disparities, the proportion of low-accessibility communities decreases by approximately 39.2% compared to the 15 min threshold, but fails to eliminate localized service blind spots. For public transit, the high-accessibility areas radiate outward from the central zones under the 15 min threshold. When extending to a 30 min threshold, the proportion of areas with extremely low accessibility decreases to 26.6%, but deficiencies in the transit network of central and southwestern regions continue to constrain accessibility. Furthermore, an analysis of public service provision reveals structural imbalances and inequities. Over 60% of parks fall below average in comprehensive quality, with particularly low scores for the service quality and basic environmental indicators. Further analysis identifies three primary causes of this social inequity: imbalanced spatial distribution of UPGSs, suboptimal allocation of quality resources, and inadequate alignment with age-specific demands.

The research findings offer valuable references for optimizing UPGS spatial layouts in aging urban centers and advancing equitable public service allocation, ultimately contributing to the realization of inclusive development in healthy human settlements. While demonstrating strong significance, this study can still be refined from the following perspectives: (1) expanding the scope to integrate collaborative perspectives within public service systems, and exploring spatial coupling relationships between UPGSs and facilities like nursing homes and community health centers; (2) uncovering the deeper social mechanisms underlying spatial equity by integrating socioeconomic indicators such as income and education of older adults.

Author Contributions: Conceptualization, Y.H., W.W. and Z.S.; methodology, Y.H. and W.W.; validation, Y.H., W.W. and Z.S.; formal analysis, Y.H., J.Z. and H.C.; writing—original draft preparation, Y.H. and H.C.; writing—review and editing, H.C.; funding acquisition, Y.H. All authors have read and agreed to the published version of the manuscript.

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

Appendix A

Questionnaire on Park Usage Among Older Adults

Dear Senior Residents,

To improve park environments and facilities for your comfort, we conduct this anonymous survey. Your responses will remain confidential and used solely for statistical analysis. Please answer truthfully. Thank you for your cooperation.

I. Demographic Information
1. Gender:
A. Male (52%)
B. Female (48%)

2. Age group:
A. 50–60 years (23%)
B. 60–70 years (45%)
C. 70–80 years (27%)
D. ≥80 years (5%)

3. Residential community: _____

4. Most frequently visited park: _____

II. Park Usage Patterns
5. Preferred park visitation times (multiple selections allowed):
A. Early morning (5:00–9:00) (68%)
B. Morning (9:00–12:00) (28%)
C. Afternoon (12:00–17:00) (35%)
D. Evening (after 17:00) (52%)

6. Primary transportation mode to parks:
A. Walking (73%)
B. Public transit (25%)
C. Other: _____ (2%)

7. Typical travel time to parks:
A. ≤15 min (41%)
B. 15–30 min (46%)
C. >30 min (13%)

III. Park Environment and Facility Evaluation
8. Satisfaction with basic environment (e.g., space, cleanliness):
A. Satisfied (38%)
B. Neutral (45%)
C. Dissatisfied (17%)

9. Does neighborhood park greenery meet daily leisure needs?
A. Fully meets (22%)
B. Partially meets (53%)
C. Inadequately meets (25%)

10. Completeness of park facilities:
A. Complete (29%)
B. Moderate (47%)
C. Incomplete (24%)

11. Satisfaction with service quality (e.g., staff attitude, activity diversity):
A. Satisfied (32%)
B. Neutral (51%)
C. Dissatisfied (17%)

12. Satisfaction with ecological environment (e.g., green coverage, water cleanliness):
A. Satisfied (35%)
B. Neutral (50%)
C. Dissatisfied (15%)

13. Perceived overall park safety:
A. Safe (86%)
B. Neutral (13%)
C. Unsafe (1%)

14. Overall park satisfaction:
A. Satisfied (51%)
B. Neutral (41%)
C. Dissatisfied (8%)

IV. Additional Suggestions
15. Further recommendations for park environments, facilities, or services:
_____

We sincerely appreciate your participation!

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Nonlinear Associations Between Built Environment and Overweight: Gender and Marital Status Differences in Urban China

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Abstract: Overweight has become a major public health concern in China's rapidly urbanizing cities. Patterns of environmental exposure differ notably between men and women, both before and after marriage. This study examines how built environment characteristics influence the risk of overweight, with particular attention to nonlinear associations as well as variations by marital status and gender. Drawing on survey data from 2634 Shanghai residents, we applied extreme gradient boosting to model complex environment–health relationships. The results indicate that greenness, park accessibility, population density, and transit conditions are associated with overweight through nonlinear pathways, with threshold and plateau effects suggesting that benefits taper off, or risks escalate, beyond certain levels. These optimal ranges differ across gender–marriage groups: moderate density and green exposure were generally protective, but the effective ranges were narrower for women and unmarried individuals. Married men benefited more consistently, likely supported by healthier routines reinforced through spousal support, whereas married women showed weaker or even adverse effects, potentially due to greater family responsibilities. Overall, the findings reveal that overweight is shaped by socially differentiated nonlinearities in environmental exposures. Urban planning and public health policies should therefore optimize built environment attributes within effective ranges and tailor interventions to diverse demographic groups.

Keywords: overweight; built environment; nonlinear associations; gender–marriage heterogeneity; threshold effects; extreme gradient boosting

1. Introduction

Overweight has become a pressing public health concern worldwide, substantially increasing the risk of cardiovascular disease, diabetes, and other chronic conditions. According to WHO data, approximately 2.5 billion adults, 43% of the global adult population, were overweight in 2022, underscoring its growing burden on healthcare systems [1]. In China, the prevalence of overweight has risen sharply in recent decades, driven by rapid urbanization and lifestyle changes [2]. This trend highlights the urgency of identifying the determinants of overweight to guide effective prevention strategies and public health interventions.

Among these determinants, the built environment has attracted increasing attention [3,4]. A well-designed urban form characterized by adequate density, diversity, and accessibility can promote physical activity and healthy dietary habits. By contrast, car-dependent environments with limited green space or abundant fast-food outlets tend to foster sedentary behaviors and poor nutrition, thereby elevating overweight risk [5,6]. Growing evidence suggests that features such as green space, population density, and public transport accessibility influence energy balance through both physical activity and dietary pathways, positioning the built environment as a key upstream determinant of overweight [7–9].

Behavioral factors are also central to understanding overweight [10]. Insufficient physical activity, prolonged sedentary time, irregular eating patterns, and frequent consumption of energy-dense foods are well-documented risk factors [11,12]. Additional lifestyle routines, including smoking, alcohol consumption, and sleep quality, further affect weight regulation [13,14]. Moreover, subjective life satisfaction has been shown to shape health-related behaviors: individuals with higher satisfaction are more likely to maintain healthier routines, whereas those with lower satisfaction may adopt sedentary or stress-related behaviors [15,16]. These findings emphasize that overweight cannot be explained solely as a matter of individual choice, but rather emerges from the interplay between behaviors, psychological states, and environmental conditions.

Despite notable progress, relatively few studies have examined population heterogeneity in these relationships [17,18]. The Social Determinants of Health framework highlights that demographic and social attributes shape how individuals perceive and interact with their environments [19]. Gender and marital status are particularly relevant, as they influence role expectations, lifestyle routines, and access to social support. Women often face structural and cultural barriers, such as household responsibilities and concerns about safety in public spaces, that restrict opportunities for exercise and limit their ability to benefit from green spaces and recreational facilities [20,21]. By contrast, men are typically more active in outdoor and recreational environments, although their higher rates of smoking and alcohol consumption may counteract some of these health benefits [22,23]. Marital status further complicates these dynamics: while marriage can provide protective resources through spousal support [24], it may also impose additional constraints, especially on women, due to greater family and caregiving responsibilities [25]. However, empirical evidence on how overweight is differentially linked to built environments and behavioral habits across gender–marriage subgroups remains limited. Addressing this heterogeneity is crucial for identifying vulnerable populations and designing more tailored interventions.

A further issue concerns the nonlinearity of environment–behavior–health linkages. Emerging evidence suggests that the effects of population density, green space, and transit accessibility on overweight often follow nonlinear patterns, with thresholds or optimal ranges beyond which benefits diminish or risks increase [26,27]. However, little is known about whether these nonlinearities apply uniformly across demographic subgroups. Incorporating gender and marital status into this discussion is particularly important, as these attributes not only shape behavioral practices but also condition how individuals access and benefit from environmental resources.

To address these gaps, we propose three hypotheses:

Hypothesis 1 (H1): *Nonlinear associations between the built environment and overweight vary across social groups, as lifestyle routines influence how individuals can access and benefit from environmental resources.*

Hypothesis 2 (H2): *Marriage provides spousal support that enables married men to adopt healthier lifestyles [24], thereby lowering their risk of overweight compared with unmarried men.*

Hypothesis 3 (H3): *Married women, constrained by limited opportunities for physical activity and greater family responsibilities imposed by social expectations [25], are more likely to face an elevated risk of overweight.*

This study drew on survey data from 2634 residents in Shanghai and applied XGBoost to examine how built environment, lifestyle, and socio-demographic factors are associated with overweight.

2. Literature Review

2.1. Built Environment and Overweight

The built environment is a key determinant of overweight, shaping both opportunities and constraints for healthy living. Core elements such as green space, population density, and transport accessibility influence physical activity, dietary behaviors, and psychosocial conditions, thereby affecting weight outcomes. Green space has consistently been shown to reduce overweight risk by providing venues for exercise, alleviating stress, and fostering social interaction [7–9]. Importantly, not only the presence but also the accessibility and quality of green areas matter, with some studies identifying threshold effects beyond which health benefits diminish [28,29]. Population density exerts mixed effects: moderate levels promote walkability and access to services, whereas very high density can reduce satisfaction, restrict recreational space, and increase sedentary time, thereby elevating overweight risk [30]. Transport accessibility also has dual implications. Proximity to transit supports active commuting and incidental walking [31], but long commuting times may reinforce sedentary behavior and reduce opportunities for exercise or healthy eating [32]. Taken together, these findings underscore that the built environment shapes overweight through both physical access and behavioral incentives, highlighting its importance as a modifiable factor in weight prevention.

2.2. Gender and Marital Status as Moderators of Overweight

Existing research highlights the important role of marital status and gender in shaping health outcomes. Marriage is frequently linked to protective effects, whereas divorce or widowhood elevates risks of morbidity and mortality, particularly among men [33,34]. In parallel, urban and public health studies emphasize the influence of the built environment on physical activity and obesity. Features such as neighborhood walkability, recreational facilities, and safety are positively associated with healthier lifestyles, though these associations often differ by gender [35].

While the built environment provides opportunities and constraints for health, its effects on overweight are mediated by behaviors and conditioned by gender and marital status. Behavioral factors, including physical activity, sedentary lifestyle, diet, sleep, smoking, alcohol use, and life satisfaction, directly shape overweight risk [36–39]. Regular exercise reduces risk by improving energy balance, whereas inactivity, poor diet, and inadequate sleep promote weight gain [40–42]. Smoking is sometimes associated with lower body weight but harms overall health, while alcohol consistently contributes excess calories [43,44]. In addition, life satisfaction influences weight regulation through stress, emotional eating, and motivation to maintain healthy routines [15,45].

These behaviors do not develop in isolation but are strongly shaped by socio-economic contexts [46,47]. Gender and marital status, in particular, influence both health behav-

iors and the use of the built environment, thereby reshaping daily routines and health outcomes [48,49]. Women often face structural and cultural constraints, such as safety concerns in public spaces or greater household responsibilities, that limit opportunities for physical activity and reduce their ability to benefit from urban green spaces, recreational facilities, or walkable neighborhoods [20,50]. Men, by contrast, tend to report higher levels of physical activity but also greater engagement in risky behaviors such as smoking and alcohol consumption [22], which may offset the advantages of their more active use of parks, sports facilities, and other urban amenities [22]. These differences suggest that identical environmental or behavioral exposures may yield divergent outcomes by gender. Marital status adds another layer of complexity. Marriage is frequently associated with weight gain due to shared meals, reduced activity, and lifestyle adjustments, a phenomenon sometimes described as the "marriage market hypothesis" [25]. At the same time, married individuals may benefit from spousal support that fosters healthier routines, particularly among men [24]. Single, divorced, or widowed individuals often display different behavioral patterns shaped by social networks, stress, and economic stability [51]. When combined, gender and marital status create intersecting subgroups with distinct risk profiles. Married women, for example, may experience greater time constraints from household responsibilities, leaving them less able to take advantage of nearby parks, green spaces, or recreational facilities, even when such resources are physically accessible [50]. By contrast, men, especially single men, may be more vulnerable to unhealthy dietary patterns [24]. They are also more likely to use outdoor and recreational spaces actively while simultaneously frequenting fast-food outlets or bars, linking physical activity with riskier lifestyle habits [23]. These dynamics underscore that overweight is not simply the outcome of individual choices or environmental exposures but rather of social positions that mediate how people interact with and respond to them.

2.3. Nonlinear Effects and Subgroup Heterogeneity in Overweight

Despite a growing body of literature on overweight [22,46,47], conventional approaches often fail to capture the complex dynamics of its determinants. Traditional regression models typically assume linear and additive relationships between variables [31,52], thereby overlooking the threshold effects and nonlinear patterns that characterize the influence of the built environment on health. For example, the benefits of green space may plateau beyond a certain level, while the risks associated with population density may only emerge once critical thresholds are exceeded [30]. Similarly, lifestyle factors such as physical activity, sleep, alcohol consumption, and smoking have been shown to follow nonlinear trajectories, with optimal ranges rather than monotonic effects [53,54]. These lifestyle routines also vary substantially across demographic subgroups [43,55], meaning that the same built environment may produce divergent health outcomes depending on how it is used. Ignoring such nonlinearities and subgroup interactions risks obscuring vulnerable populations and generating oversimplified policy recommendations. Furthermore, comparative analyses across demographic subgroups remain limited. Recent advances in machine learning offer tools well-suited to address these complexities [27,56], providing more precise and context-sensitive insights into overweight risks.

3. Data and Methodology

3.1. Data Source

The data for this study were drawn from the project Spatial Structure, Social Structure, and Residential Satisfaction of Neighborhoods in Shanghai, jointly initiated by the Center for the Study of Social Transformation at Fudan University and the Center for Urban and Social

Research at Tongji University. Neighborhood surveys were conducted between 2015 and 2017, and resident questionnaires between 2019 and 2021. Two structured questionnaires were employed. The neighborhood survey collected information on locational features, spatial structure, social composition, and governance, while the resident questionnaire covered demographics, occupation and life course, social capital, values and attitudes, housing, and self-rated health.

A five-stage probability-proportional-to-size sampling design was used to ensure representativeness. First, 30 subdistricts/towns within the Shanghai Outer Ring were selected based on location and the latest population data. From each, 4 neighborhood committees were chosen (120 total). Within these committees, 300–400 residential communities were sampled. In each community, approximately 60 households were contacted to obtain 20 completed interviews, yielding 3648 interviews in total (a 30% success rate). Finally, one individual aged 18–70 was randomly selected from each household using a Kish table. Neighborhood-level data were obtained from community committees and property managers, while resident-level data were collected through face-to-face household interviews, supplemented by field observations of greenery, facilities, and community activities. In total, 399 neighborhoods and 3630 residents were surveyed. After excluding incomplete or erroneous cases, 2634 valid samples were retained (Figure 1). In Figure 1, red squares denote the sampled neighborhoods, with their size corresponding to the boundary extent of each community.

3.2. Variable Description

The dependent variable in this study is the presence of overweight, defined as a body mass index (BMI) of 24 kg/m^2 or higher [57]. BMI is widely used in large-scale epidemiological research because it is simple to calculate, enables cross-study comparability, and is available in most survey datasets [58]. However, it reflects weight relative to height and does not capture body fat distribution or composition [59]. Alternative measures such as waist circumference, waist-to-hip ratio, or body fat percentage provide more direct assessments of central adiposity and metabolic risk, but these indicators were not available in the present dataset. Guided by the framework of health determinants, we examine both built environment attributes and individual behavioral habits as key explanatory factors of overweight. Built environment characteristics include the normalized difference vegetation index (NDVI) within a 1000 m buffer, distance to the nearest park, green view index (GVI) within a 1000 m buffer, total park area, population density, community green space ratio, and public transit travel time. Together, these variables capture greenery exposure, spatial accessibility, and mobility conditions, and are widely used in the literature to represent built environment features. Behavioral habit variables include monthly exercise frequency, alcohol consumption frequency, smoking frequency, sleep quality, and life satisfaction. These indicators are commonly employed to reflect individual lifestyle patterns and subjective health perceptions. In addition, several sociodemographic covariates were included: gender (male/female), age squared (continuous), marital status (married/unmarried), education level (categorical), and log-transformed personal income (continuous, in CNY).

3.3. Model and Analytical Approach

We employed extreme gradient boosting (XGBoost) to model associations between built environment and lifestyle attributes and overweight status. XGBoost is an advanced implementation of gradient boosting decision trees that integrates regularization, shrinkage, feature subsampling, and second-order optimization, thereby reducing overfitting and enhancing computational efficiency [60,61]. These properties make it particularly well suited for modeling complex, nonlinear relationships between environmental and behavioral factors and health outcomes in urban contexts [26,56].



Figure 1. Sample distributions.

Compared with traditional linear regression, XGBoost can flexibly capture nonlinear and interactive effects without assuming linearity, handle multicollinearity, and accommodate missing data [62]. It also performs robustly with moderate sample sizes and class

imbalance, delivering strong out-of-sample accuracy. These strengths are especially relevant for built environment–health research, where predictors often interact across spatial, behavioral, and socioeconomic domains [63,64]. In this study, XGBoost allowed more accurate estimation of predictor importance and effect shapes than conventional regression, thereby improving interpretability and predictive power in multidimensional datasets.

Analyses were conducted in Python 3.11 using the XGBoost library. Data preprocessing involved variable cleaning, one-hot encoding of categorical predictors, and a stratified 75/25 train–test split. Class imbalance was addressed by setting the scale_pos_weight parameter according to the prevalence of overweight. The final model was configured with a binary logistic objective, 800 boosting iterations, a maximum tree depth of 3, a learning rate of 0.05, a subsample ratio of 0.8, and a column sampling ratio per tree of 0.8. On the test set, the model achieved an AUC of 0.529, accuracy of 0.530, sensitivity of 0.436, specificity of 0.599, and an F1-score of 0.440. Four subgroup models (female/male × unmarried/married) were fitted using identical parameters to assess heterogeneity in predictor importance and partial dependence curves across demographic strata.

We reported gain-based relative importance (RI) scores to quantify each predictor's contribution to loss reduction. Partial dependence plots (PDPs) were generated on quantile grids (5th–95th percentiles), with background data restricted to the same range to avoid extrapolation. Curves were smoothed using PCHIP for continuous features and LOWESS for ordinal behavioral variables, applying milder smoothing to built environment indicators and stronger smoothing to behavioral variables. Subgroup PDPs included 95% bootstrap confidence bands (B = 50) to capture uncertainty, enabling nuanced interpretation of nonlinear and threshold effects across domains [65].

4. Results

4.1. Descriptive Statistics

Table 1 summarizes the dependent variable and individual-level covariates. In our sample, 42% of respondents were classified as overweight, a proportion somewhat higher than the national average of approximately 34–35% reported in recent Chinese surveys [2]. Males represented 37% of participants, and 80% were married. On a four-point categorical scale of education level (1 = primary school or below, 4 = postgraduate or above), the sample mean was 2.35, suggesting that the typical respondent had completed education between the secondary and undergraduate levels. The mean value of log-transformed personal income was 10.20, corresponding to an annual income of approximately CNY 74,352. This figure is slightly above the 2019 average annual disposable income of Shanghai residents (CNY 69,442; Shanghai Municipal Bureau of Statistics, 2020). The higher average income likely reflects the inclusion of employed residents living in built-up districts, resulting in a sample with somewhat higher socioeconomic status than the general Shanghai population.

Table 1. Personal Characteristics.

	Mean (Tiesdell & Allmendinger)/%
Personal characteristics	
Overweight	
Yes	42%
No	58%
Sex	
Male	37%
Female	63%

Table 1. *Cont.*

	Mean (Tiesdell & Allmendinger)/%
Married	
Married	80%
Unmarried	20%
Education level	
Primary or below	3%
Secondary (Junior high/vocational high/general high/technical school)	62%
Undergraduate	33%
Postgraduate or above	3%
Age (years)	57.03 (13.89)
Log personal income	10.20 (1.70)

Table 2 presents the characteristics of lifestyle attributes and built environment variables in the study area. Regarding lifestyle, nearly half of respondents (48%) reported exercising daily, while smaller proportions exercised several times per week (18%), monthly (8%), or less frequently (8%); 18% reported no exercise at all. Most participants consumed alcohol less than once per week or not at all (81%), and 70% were non-smokers. Sleep quality was generally stable, with 86% reporting no deterioration, and life satisfaction was high, with 81% expressing satisfaction or strong satisfaction.

Table 2. Behavioral Habits and Built Environment Variables.

Variables	**Mean (Tiesdell & Allmendinger)/%**
Lifestyle attributes	
Exercise Freq	
No exercise	18%
≤1/month	8%
Several times/month	8%
Several times/week	18%
Daily	48%
Drinking Freq	
Former drinker	8%
<1/week or none	81%
1–2/week	5%
3–4/week	1%
Nearly daily	5%
Smoking Freq	
Non-smoker	70%
Non-smoker, passive smoke	8%
Former smoker	6%
Few cigarettes/week	2%
Daily (few)	10%
Daily (≥20/day)	4%
Sleep Quality	
Much worse than usual	2%
Worse than usual	12%
About the same	37%
As good as usual	49%
Life Satisfaction	
Very dissatisfied	2%
Dissatisfied	4%
Neutral	14%
Satisfied	54%

Table 2. *Cont.*

Variables	Mean (Tiesdell & Allmendinger)/%
Very satisfied	27%
Built environment	
NDVI (1000 m buffer)	0.16 (0.03)
Distance to nearest park (m)	651.01 (333.55)
Green View Index (1000 m buffer)	0.22 (0.06)
Park area within 1000 m (m^2)	78,102.14 (55,370.08)
Population density (persons/km^2)	37,744.85 (19,631.22)
Green space ratio (%)	26.89 (15.71)
Public transport accessibility (min)	4.18 (2.66)

With respect to the built environment, within a 1000 m buffer of participants' residences, the mean NDVI was 0.16, the mean GVI was 0.22, and the average park area was 78,102 m^2. The average distance to the nearest park was 651 m, while the mean green space ratio was 26.89%. Population density averaged 37,745 persons/km^2, consistent with the high-density urban form of the study area. Public transport accessibility was strong, with an average walking time of just over four minutes. Taken together, these indicators suggest that respondents lived in highly urbanized neighborhoods characterized by dense populations, moderate vegetation cover, convenient access to green spaces, and abundant public transportation options.

4.2. Feature Importance Comparison

Table 3 reports the RI of predictors for overweight in the total sample and across gender–marital subgroups. In the total sample, built environment factors contributed the largest share of predictive power (37.79%), followed by sociodemographic characteristics (35.57%) and lifestyle attributes (26.64%). At the individual level, gender (12.23%), education level (7.30%), and drinking frequency (5.75%) emerged as the strongest predictors, alongside built environment indicators such as distance to the nearest park (5.65%) and population density (5.54%).

Gender comparisons revealed that men's overweight risk was more strongly shaped by built environment factors (47.41–49.05%) than women's (47.00–48.24%), with population density, public transport accessibility, and green space ratio exerting greater influence in male models. Women's outcomes, by contrast, were more affected by sociodemographic and lifestyle factors, particularly education and income. Marital status also moderated predictor importance. Unmarried respondents, both male and female, showed greater reliance on built environment characteristics (male–unmarried: 49.05%; female–unmarried: 48.24%) than their married counterparts (male–married: 47.41%; female–married: 47.00%). Married groups gave greater weight to lifestyle factors such as drinking and exercise frequency, while unmarried groups were more sensitive to public transport accessibility, green space ratio, and education.

In the four-way subgroup breakdown, male–married participants were most influenced by built environment factors (47.41%), especially population density and NDVI, with drinking frequency as the leading lifestyle contributor. Male–unmarried participants exhibited the highest overall built environment share (49.05%), dominated by public transport accessibility and green space ratio, while drinking frequency ranked first across domains. Female–married participants were similarly shaped by built environment factors (47.00%), with the GVI as the top predictor, complemented by exercise frequency and sleep quality. Female–unmarried participants showed the strongest effect of education across all subgroups, alongside significant contributions from population density and park area within 1000 m.

Table 3. RI of predictors for overweight.

Variables Built Environment Variables	All Sample-RI, %	All Sample-Ranking	Male-Married-RI, %	Male-Married-Ranking	Male-Unmarried-RI, %	Male-Unmarried-Ranking	Female-Married-RI, %	Female-Married-Ranking	Female-Unmarried-RI, %	Female-Unmarried-Ranking
Total	37.79		47.41		49.05		47		48.24	
Park area within 1000 m (m^2)	5.37	10	6.72	8	6.86	6	7.07	4	6.87	4
Population density	5.54	6	7.18	2	6.33	11	6.84	6	8.48	2
NDVI (1000 m buffer)	5.46	8	7.06	3	6.83	7	6.55	10	6.48	10
Green space ratio	5.25	13	6.29	13	7.37	3	6.64	9	6.57	9
Distance to nearest park (m)	5.65	5	6.87	6	6.97	5	5.89	15	6.78	6
Green View Index (1000 m buffer)	5.41	9	7.01	4	6.62	9	7.57	1	6.37	11
Public transport accessibility (min)	5.11	16	6.3	11	8.08	2	6.45	11	6.69	7
Lifestyle attributes variables										
Total	26.64		33.71		32.84		31.49		29.13	
Exercise frequency	5.21	14	6.29	12	5.48	13	6.64	8	6.35	12
Drinking frequency	5.75	4	8.46	1	9.75	1	6.1	12	5.57	13
Smoking frequency	5.11	15	6.62	9	5.62	12	6.07	13	6.81	5
Sleep quality	5.3	11	5.95	14	6.74	8	6.7	7	5.02	15
Life satisfaction score	5.27	12	6.39	10	5.24	14	5.98	14	5.38	14
Sociodemographics variables										
Total	35.57		18.88		18.11		21.51		22.63	
Gender (1 = male)	12.23	1	0	16	0	16	0	16	0	16
Education level	7.3	2	5.15	15	4.42	15	7.5	2	8.72	1
Marital status (1 = married)	4.75	17	0	17	0	17	0	17	0	17
Log personal income	5.51	7	6.85	7	6.36	10	7.16	3	6.68	8
Age (squared)	5.78	3	6.88	5	7.33	4	6.84	5	7.22	3

4.3. Nonlinear Relationship Analysis

Full-sample partial dependence analysis revealed distinct and often nonlinear associations between overweight risk and built environment, lifestyle, and socioeconomic predictors (Figure 2). Both the green space ratio and GVI were positively associated with overweight, with risk increasing steadily and peaking at approximately 70–80% and 0.30, respectively. Park area within 1000 m and distance to the nearest park followed inverted U-shaped patterns: overweight probability peaked at ~100,000–175,000 m^2 for park area and ~700–900 m for park distance, with lower risks observed when park area exceeded 180,000 m^2 or distance reached 1100–1200 m. NDVI, population density, and public transit time displayed wave-like curves with clear inflection points. NDVI shifted from protective to risk-enhancing at ~0.18; population density minimized risk between 20,000 and 60,000 persons/km^2 but increased beyond 60,000 persons/km^2; and public transit time showed the lowest risk at ~12–14 min, whereas shorter times (6–8 min) were associated with higher risk. Lifestyle behaviors exhibited similarly complex associations. Smoking frequency and sleep quality both reduced risk up to moderate levels (around three to four times per week for smoking), after which the effect attenuated or reversed. Drinking frequency followed an inverted U-shape, with risk peaking at ~three times per week before declining at higher levels. Exercise frequency was consistently protective, with risk declining sharply until two to three sessions per week, after which the effect plateaued. Life satisfaction showed a positive association, with overweight risk rising sharply up to a score of three and stabilizing thereafter. Socioeconomic attributes produced comparatively stable associations. Gender was positively linked to overweight, with men at higher risk than women. Marital status exerted a protective effect, as married individuals consistently exhibited lower risk compared with their unmarried counterparts. Education level was inversely associated with overweight, suggesting that higher educational attainment reduces risk. By contrast, personal income displayed fluctuations without a clear monotonic trend, while age (squared) showed a nonlinear trajectory with oscillating risks across age groups rather than a consistent directional effect.

Subgroup heterogeneity was also evident in lifestyle behaviors (Figure 3). For drinking frequency, female subgroups displayed relatively flat risk curves, while male–married individuals experienced a decline at the level of former drinker but an increase at three to four drinks per week. Male–unmarried individuals showed little variation across drinking levels. Smoking frequency revealed more distinct thresholds. Among men, an inflection point emerged at non-smoker with passive smoke exposure, after which overweight risk declined consistently. Among women, divergence appeared at the level of former smoker: female–married individuals exhibited increasing risk, whereas female–unmarried individuals showed decreasing risk. Sleep quality also highlighted subgroup-specific thresholds. Male–married individuals maintained relatively stable risk up to about the same as usual, followed by a modest increase, whereas male–unmarried individuals displayed a steady upward trend across the entire scale. In contrast, both female subgroups faced higher risk once sleep quality reached as good as usual, with the increase steeper for female–married than for female–unmarried individuals. Exercise frequency produced contrasting effects by marital status. Married subgroups demonstrated a consistent decline in overweight risk with greater exercise frequency, while unmarried subgroups displayed an inflection at daily exercise, beyond which risk rose. Life satisfaction revealed further divergence. Male–married individuals experienced reduced risk once satisfaction reached satisfied, with male–unmarried individuals showing a similar decline only at very satisfied. By contrast, female–married individuals exhibited a continuous rise in risk with increasing

satisfaction, whereas female–unmarried individuals showed a marked decline between neutral and satisfied.

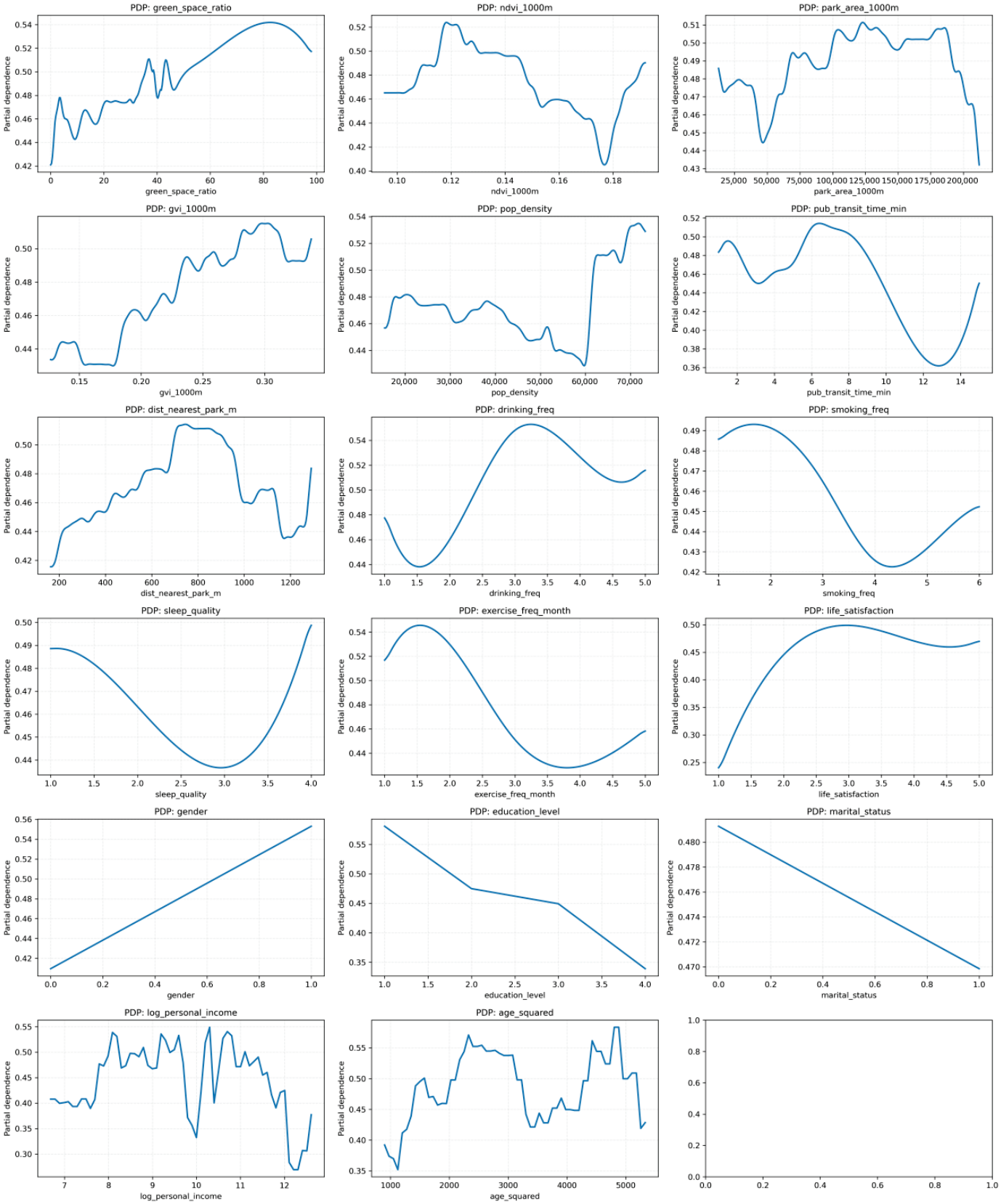


Figure 2. Nonlinear Relationship Analysis of All Samples.

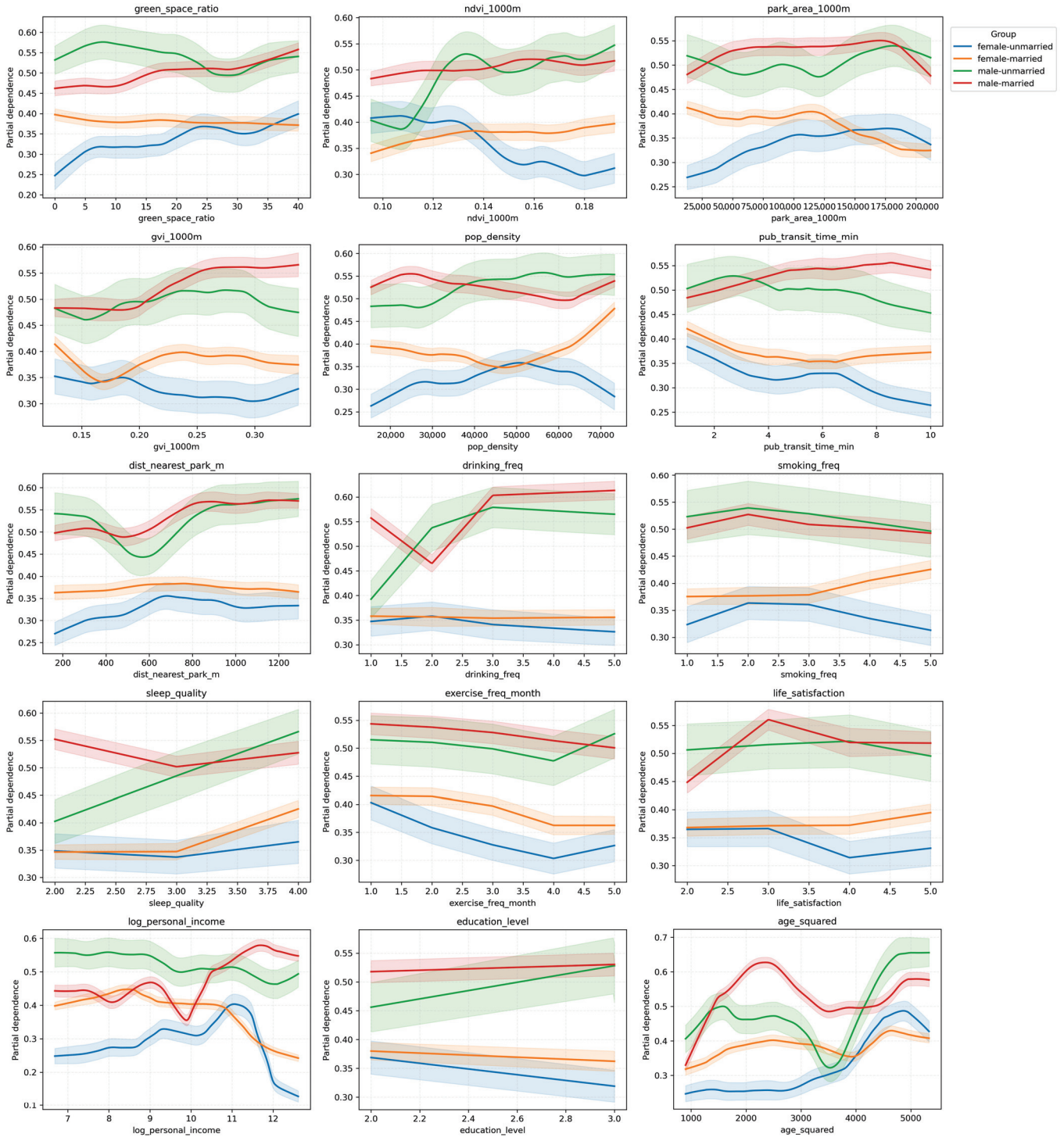


Figure 3. Nonlinear Relationship Analysis of Subgroup Sample.

4.4. Robustness Check

To assess robustness, we compared feature importance rankings from XGBoost with SHAP explanations (Figure 4). Both methods consistently identified gender, age, and personal income as the most influential predictors, underscoring their stability in explaining overweight risk. NDVI also ranked highly across approaches, confirming the importance of greenness exposure. However, the two methods differed in emphasis: SHAP attributed relatively greater importance to behavioral and green space attributes, such as exercise frequency, sleep quality, green space ratio, and GVI, reflecting their nonlinear contributions

at the individual level. In contrast, XGBoost highlighted variables such as park area and population density, which serve as frequent splitting criteria in tree construction.

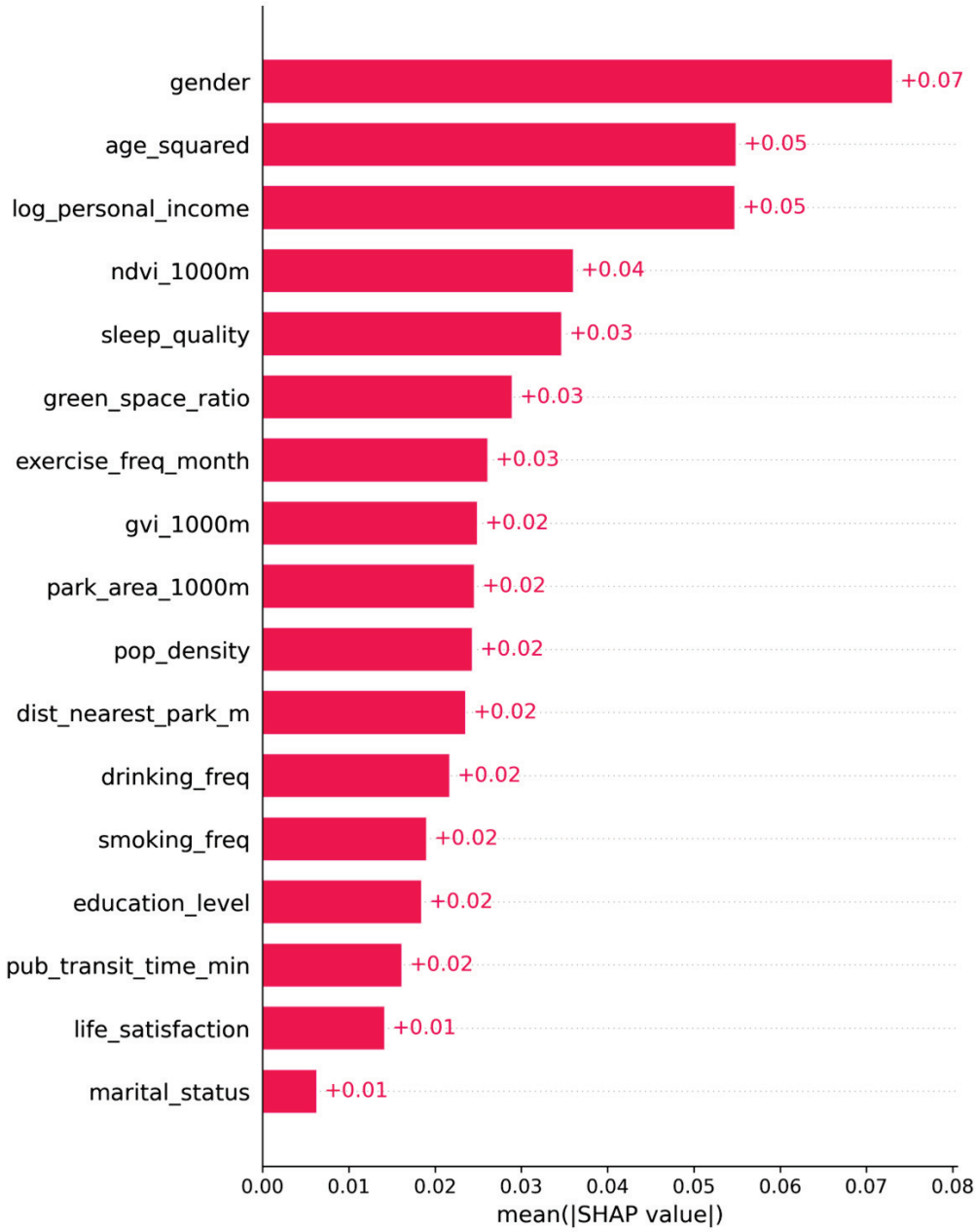


Figure 4. SHAP summary bar plot.

The SHAP value distributions further validated the direction of the main effects (Figure 5). Male gender was consistently associated with higher overweight risk, whereas higher income, more frequent exercise, and better sleep quality were protective. Smoking frequency also showed a negative association, though this should be interpreted cautiously as it reflects body weight outcomes only and does not imply broader health benefits. Several predictors displayed nonlinear or threshold-like patterns, including NDVI, green space ratio, GVI, park area, and distance to the nearest park, as well as behavioral factors such as drinking frequency, exercise frequency, and sleep quality. By contrast, life satisfaction and marital status exerted only weak and unstable effects. Taken together, the convergence of

key determinants across methods and the presence of theoretically plausible nonlinearities strengthen confidence in the robustness of the results.

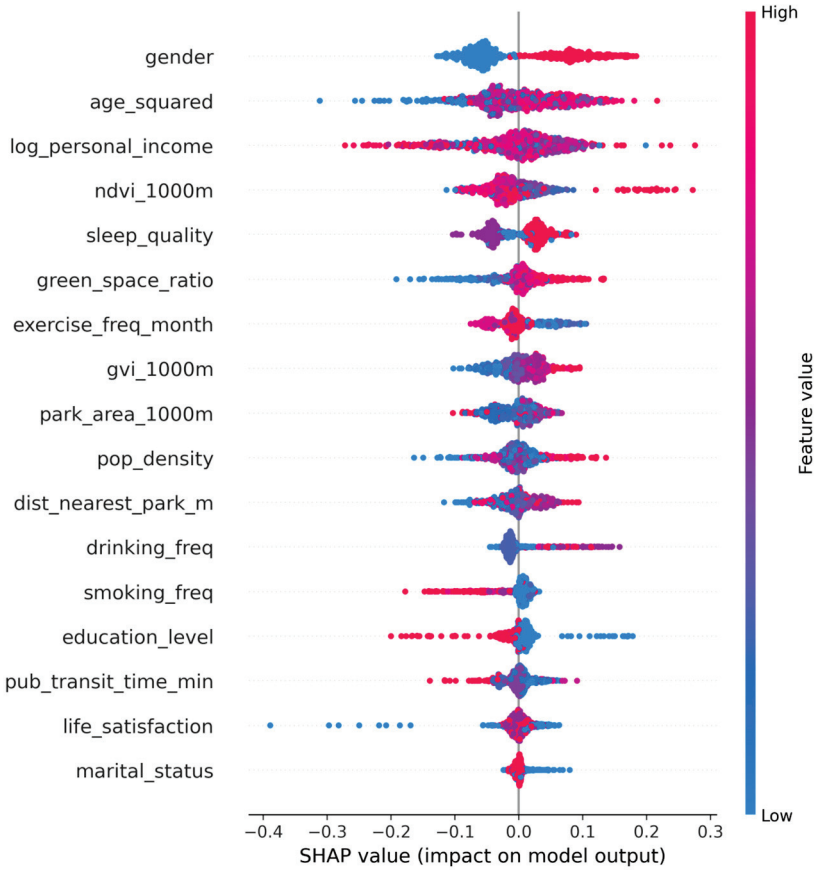


Figure 5. SHAP beeswarm plot.

5. Discussion and Limitation

First, our findings support Hypothesis 1, which posits that built environment attributes, including greenness (NDVI, GVI), park accessibility, population density, and public transport proximity, exhibit nonlinear associations with overweight risk, and that the optimal ranges vary across subgroups. NDVI was protective up to ~0.18 before reversing to risk-enhancing, consistent with diminishing returns of greenness [66]. Population density followed a U-shaped pattern, with the lowest risk at ~20,000–60,000 persons/km^2 and increased risk beyond 60,000, suggesting that density, like greenness, operates within an optimal range [30]. Subgroup analyses revealed distinct thresholds: park accessibility benefits diminished earlier for unmarried men, whose risk was more strongly linked to alcohol consumption, while GVI remained protective up to ~0.15 for unmarried men and ~0.17 for married women. These patterns demonstrate that "optimal ranges" are socially differentiated, shaped by gendered lifestyles and marital status [53–55]. Evidence from green exercise research further supports this interpretation, showing that brief exposures to natural environments produce the largest gains in self-esteem and mood, with benefits that diminish but persist under longer or more intensive engagement [67]. Overall, our findings highlight that built environment effects operate through threshold-dependent mechanisms, underscoring the need to target effective ranges rather than assuming that "more is always better."

Second, our findings support Hypothesis 2, which posits that married men are more likely to maintain healthier lifestyles and therefore face a lower risk of overweight com-

pared with unmarried men. Overall, men exhibited a higher probability of overweight than women, consistent with prior research [68,69], as shown in Figure 2 (full sample) and Figure 3 (subgroups). Within male subgroups, however, marriage played a protective role: married men maintained healthier routines and thus experienced lower overweight risk relative to their unmarried counterparts. Lifestyle factors contributed most strongly among married men (33.71%), the highest of all subgroups, with drinking frequency ranked first (RI = 8.46), followed by exercise and sleep quality. Although unmarried men were even more sensitive to alcohol (RI = 9.75), their overall lifestyle contribution (32.84%) was slightly lower. In contrast, women displayed smaller lifestyle contributions (31.49% for married, 29.13% for unmarried), indicating stronger influence from socio-demographic and environmental conditions. These patterns suggest that marriage reinforces healthier behaviors and amplifies the benefits of favorable environments, consistent with prior evidence of spousal support shaping men's diets and health practices [24,70]. Importantly, such protective effects also extended to the built environment, where married men responded more stably and beneficially to greenness and park accessibility [25].

Third, our findings support Hypothesis 3, showing that married women face a higher risk of overweight. Subgroup analyses indicated that unmarried women consistently displayed the lowest risk. For instance, their overweight risk declined with higher NDVI and longer public transport walking time, whereas risk in other groups either plateaued or increased. By contrast, married women exhibited weaker protective effects from exercise and sleep quality, and in some cases even experienced rebound risks at higher levels of NDVI. These outcomes reflect how gendered social roles condition health behaviors: unmarried women often have more discretionary time for outdoor activity and may engage in healthier routines to manage body shape [21], while married women face role overload and reduced autonomy in lifestyle choices, limiting the benefits of protective behaviors [71]. These findings emphasize the need for urban planning and public health interventions that alleviate time constraints and provide safe, accessible environments tailored to women with family responsibilities.

This study has several limitations. First, the cross-sectional design precludes causal inference between built environment attributes and overweight. Second, BMI was partly self-reported, and the dataset lacked detailed measures of diet, food environments, and occupational activity, which may introduce residual confounding. Third, the sample was drawn from urban neighborhoods in Shanghai, so the findings may not be generalizable to rural settings or cities with different social and environmental contexts. Despite these limitations, the study provides novel evidence on nonlinear and socially differentiated associations between built environments and overweight.

6. Conclusions

This study drew on survey data from 2634 residents in Shanghai and applied XGBoost to examine how built environment, lifestyle, and socio-demographic factors are associated with overweight. The analysis revealed nonlinear relationships characterized by thresholds and plateaus rather than simple linear trends. Key built environment attributes, greenness, park accessibility, population density, and transit proximity, all displayed "optimal ranges," though in distinct nonlinear forms: population density and NDVI followed U-shaped patterns with clear minimum-risk points; park accessibility showed an inverted U-shaped association with a peak protective interval; and transit proximity exhibited oscillating patterns with a specific low-risk range.

The central contribution of this study is to demonstrate that these nonlinear associations are socially differentiated. Gender and marital status condition daily lifestyles and

mediate how built environment features influence overweight risk. Subgroup-specific thresholds and turning points highlight the need for contextualized health planning. Characteristics of green space in Shanghai, such as fragmentation, small scale, and limited accessibility [72], may partly explain subgroup differences, while East Asian cultural norms and gendered household roles [73] further magnify the interaction between marriage, lifestyle, and health.

Overall, the findings underscore the importance of socially differentiated strategies in overweight prevention. In high-density cities like Shanghai, planning should maintain greenness and density within effective ranges and improve access to fragmented, small-scale green spaces. Public health measures should also address subgroup vulnerabilities, such as alcohol-related risks among men and time constraints faced by women with caregiving responsibilities. By identifying subgroup-specific thresholds and turning points, this study provides empirical evidence to inform more precise and equitable urban health planning, showing how cultural context, gender, and marital status shape the benefits of environmental exposures.

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Associations Between Physical Features and Behavioral Patterns in Macau Outdoor Community Public Spaces and Older Adults' Performance of Instrumental Activities of Daily Living

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Abstract: Objective: This exploratory study examines potential associations between the physical features and behavioral patterns of outdoor community public spaces and the Instrumental Activities of Daily Living (IADLs) performance of older adults in Macau. IADLs refer to abilities that reflect functional independence and cognitive capacity. **Methods:** Nine representative public spaces were selected in Macau. Field measurements of spatial features, non-participant behavioral observations, and standardized IADL assessments were conducted. Spearman's correlation and multiple regression analyses were employed to examine relationships among environmental factors, observed behaviors, and IADL scores. Variable selection is based on theoretical support and statistical methods, including correlation analysis and Variance Inflation Factor (VIF) diagnostics. **Results:** Findings suggest that a higher visible greenery ratio and a greater density of resting facilities are positively associated with IADL performance. Conversely, frequent engagement in sedentary activities, such as playing board or card games, appears to be linked to lower functional independence. **Conclusions:** This study highlights possible associations between public space characteristics and older adults' functional independence. The results underscore the need to further explore how spatial design and behavioral patterns may relate to aging in urban environments. Enhancing green visibility and increasing resting facilities could potentially support functional independence, whereas reducing prolonged sedentary behaviors may also be beneficial. These insights offer preliminary guidance for policymakers and urban planners aiming to develop more age-friendly environments in high-density cities.

Keywords: aging; IADLs; community; public spaces

1. Introduction

Global aging presents challenges for urban planning, social policy, and healthcare, with the population aged 65 and above expected to increase from 10% in 2022 to 16% by 2050 [1]. As the aging population grows, cities must rethink the built environment to accommodate the physical, social, and psychological needs of older adults [2]. Among the key concerns arising from this demographic shift is the need to enhance the health and quality of life of older adults, particularly through the promotion of independent living and cognitive status [3–5]. Instrumental Activities of Daily Living (IADLs) are critical indicators of independence and cognitive capacity [6], with associations to cognitive

status [5]. These activities, encompassing tasks such as shopping, transportation, cooking, and financial management, require a combination of physical, cognitive, and environmental adaptability [7]. Declines in IADL performance are often early indicators of deteriorating health or cognitive function, making IADLs a vital focus of gerontological research and public health initiatives [8,9].

While much existing research has primarily focused on the relationship between cognitive decline and the inability to perform IADLs [9,10], a significant gap remains in understanding the extent to which external environmental factors, particularly the physical features and behaviors within public spaces, may be associated with older adults' ability to perform these tasks. Although individual health factors and disease processes are widely recognized as the most direct determinants of IADLs [11], external environmental factors likely play a critical, though often underestimated, role in older adults' IADL performance. This gap is particularly relevant in the context of aging in place, where the focus has shifted from solely within the home to include the broader community [12–15].

Community public spaces are essential venues for older adults to engage in physical activity, social interaction, and recreational behaviors, all of which contribute to their overall well-being. Existing studies have highlighted the importance of the built environment in promoting the health and well-being of older adults, suggesting that the physical features and behaviors of outdoor public spaces can significantly influence older adults' physical health [16–19]. However, despite these insights, the exact extent to which physical features and behavioral patterns within public spaces affect IADL performance in older adults remains largely unexplored. To what extent do specific features and behaviors within these spaces contribute to the maintenance or improvement in IADLs in older adults? The question remains unanswered but it is essential for a fuller understanding of the role that external environments play in the cognitive health and independence of aging populations. By addressing this gap, this study aims to examine and clarify the potential associations of public space features and behaviors on older adults' IADL performance, providing a deeper understanding of how environmental factors interact with personal health in influencing daily living. Using on-site measurements, behavioral observations, and IADL assessments, this study provides insights for designing age-friendly public spaces. Ultimately, this research bridges the gap between IADL-focused healthcare studies and environmental design, contributing to the development of inclusive public spaces that enhance older adults' independence and quality of life.

2. Literature Review

The review categorizes research into four sections: (1) IADLs in Aging Research, (2) Factors Associated with IADL Performance in Older Adults, (3) Environmental Factors and Behaviors in Public Spaces, and (4) Research Gaps and Directions. This organization highlights the importance of investigating the influence of public space physical features and behavioral patterns on IADL performance in older adults, underscoring the need for further investigation into these areas.

2.1. IADLs in Aging Research

IADLs are key indicators of independence; declines often signal deteriorating health or cognition [20]. It has been shown to play a significant role in enhancing older adults' sense of autonomy and self-esteem. A study by Bleijenberg [8] found that older adults who retained the ability to perform IADLs reported higher levels of well-being and satisfaction with life. A Japanese study further highlighted that maintaining IADL abilities allows older adults to engage more actively in community activities, thereby improving

both physical independence and mental health [21]. The connection between IADLs and independence is also supported by studies examining environmental factors. For example, a cohort study conducted in Florianopolis, Brazil, found that urban environments with certain characteristics were associated with the incidence of disability in both basic and Instrumental Activities of Daily Living in older adults, promoting functional independence and better IADL performance [22]. This suggests that physical environments significantly influence older adults' ability to perform daily tasks, further underlining the importance of IADLs for independent living. Thus, understanding the interaction between external environmental factors and IADL performance is critical for supporting aging in place.

2.2. Factors Associated with IADL Performance in Older Adults

IADL performance is influenced by various factors, including demographic, health, environmental, and psychological determinants. Age and gender are primary contributors, with aging and gender differences often correlating with declining IADL performance due to factors like increased chronic illnesses and cognitive decline [23,24]. Disease burden and chronic diseases, including cardiovascular and metabolic disorders, significantly exacerbate IADL limitations, particularly when coupled with cognitive impairments such as dementia and mild cognitive decline [25,26]. The nutritional status of older adults plays an essential role in their ability to perform IADLs. Malnutrition and dehydration significantly impair energy levels, cognition, and physical strength, which are essential for executing tasks like grocery shopping or managing medications [27,28]. Physical activity and mental health are closely linked to IADL performance, with regular exercise improving both mobility and cognition, while mental health conditions such as depression can impair IADL performance [29]. Furthermore, social support plays a crucial role in maintaining IADL independence, where limited social networks are associated with increased difficulty in performing IADLs. Social engagement, conversely, supports independence and functional capacity [30–32]. In addition, factors such as socioeconomic status, education, cultural background, and familiarity with technology can further impact an individual's ability to perform IADLs [33–36].

However, environmental and built environment factors are particularly influential in shaping IADL performance. Poor street conditions, such as the absence of crosswalks and uneven surfaces, increase the risk of losing IADL abilities, especially in those already experiencing functional impairments [37]. Neighborhoods with greater safety were associated with a reduced likelihood of IADL decline, while physical features such as streetscapes, pathways, and lighting had a stronger association with IADL limitations rather than basic ADL loss [38]. Additionally, poor neighborhood cleanliness and high levels of disorder are linked to higher rates of IADL decline [39], while neighborhood cleanliness was found to specifically correlate with IADL performance [40]. Moreover, exposure to green spaces has been shown to improve physical functioning and reduce both ADL and IADL loss, thereby lowering the burden of long-term care [41]. These findings highlight the critical role of environmental factors, such as safety, street conditions, and green space access, in shaping older adults' capacity to maintain independence through IADLs.

Despite these insights, research systematically linking public space features and behaviors to IADL performance remains limited. Most existing research on environmental impacts on aging has addressed general functional disabilities or ADL loss, rather than explicitly examining the relationships between specific public space features, older adults' behavioral patterns, and IADL performance. This research gap presents an opportunity to further investigate how public space physical features are associated with the ability of older adults to perform IADLs. Understanding these connections could inform the development of public spaces that better support the independence and well-being of the aging population.

2.3. Environmental Factors and Behaviors in Public Spaces

Older adults prioritize physical comfort and environmental conditions [42]. Choi indicated that promoting age-friendly communities and supporting aging in place should prioritize enhancing the built environment as a foundation for fostering an age-friendly social environment [43]. Older adults' behaviors in public spaces differ due to specific spatial needs [44]. Understanding senior behaviors is crucial for rethinking urban strategies aimed at creating more age-friendly environments [45]. Studies on older adults' behavior in public spaces suggest that features such as seating facilities, green spaces, and safe pathways can facilitate greater mobility, social interaction, and engagement in physical activity [46]. Furthermore, public spaces that encourage social interaction have been shown to improve IADL performance by fostering community engagement and reducing social isolation [32].

Nevertheless, current research rarely explores how specific public space features directly relate to IADL performance. Moreover, although the broader relationship between environmental factors, behavioral patterns, and aging is well-documented, the specific impacts of social behaviors and interactions in public spaces on older adults' IADL performance remain underexplored.

2.4. Research Gaps and Directions

The review above identifies several critical research gaps. First, while the existing literature clearly associates various personal, health-related, and environmental determinants with older adults' overall functional abilities, few studies explicitly investigate the direct relationships between specific physical features of public spaces—such as resting facilities, visible greenery, and spatial enclosure—and older adults' IADL performance. Second, although behaviors occurring within public spaces, including social interactions and physical activities, are acknowledged as beneficial, the extent to which these specific behaviors contribute to maintaining or improving IADL performance remains underexplored. Thus, there is a need for integrated empirical studies combining precise physical measurements of public space features, detailed observational analysis of older adults' behavioral patterns, and standardized assessments of IADL performance. By exploring how distinct spatial features and behavioral patterns within public spaces might specifically relate to older adults' IADL capacities, this study aims to address these research gaps comprehensively. Such integrated analyses will inform urban design practices and policies aimed at creating supportive public environments that enhance older adults' functional independence and overall quality of life.

3. Materials and Methods

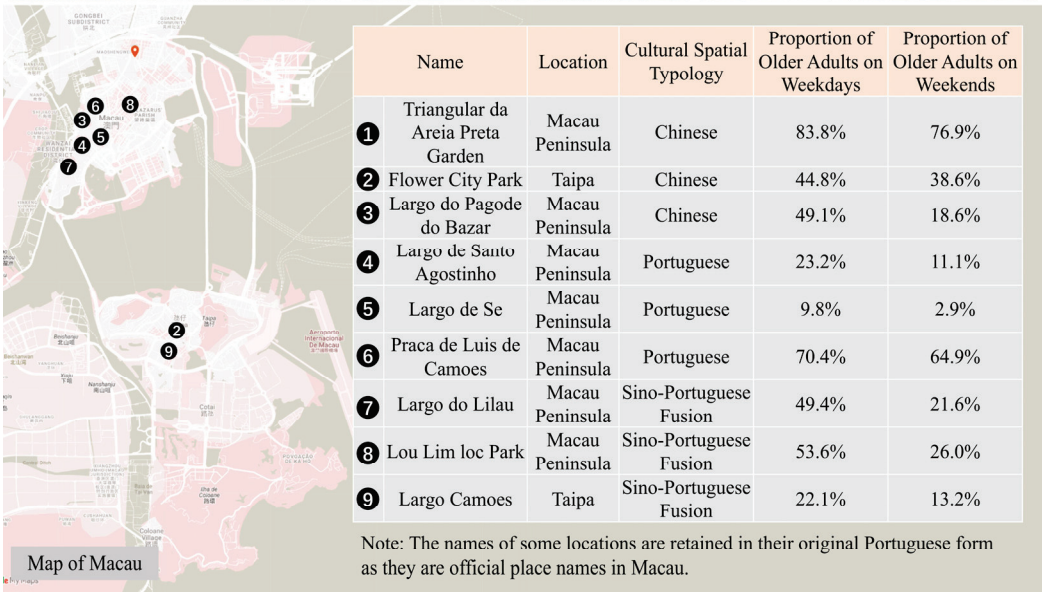
3.1. Research Area and Sample Selection

This study selected nine public spaces in Macau based on their representativeness, diversity, and research feasibility, with the aim of investigating how different outdoor environments influence aging in place and IADL performance. The selection criteria considered factors such as the concentration of elderly residents, cultural and historical context, spatial scale, and functional diversity. Particular emphasis was placed on spaces that are frequently used by older adults, especially those located in districts with a high density of elderly populations, as these environments play a vital role in supporting daily routines, physical activity, and social engagement. The nine selected sites were grouped into three categories based on their cultural characteristics and degree of embeddedness in everyday urban life in Macau: (1) Chinese, (2) Portuguese, and (3) Sino-Portuguese integrated public spaces. This classification reflects key differences in place meaning, social configuration, environmental atmosphere, and levels of local integration, which are critical

for interpreting behavioral outcomes and contextualizing elderly spatial experiences in a historically layered city like Macau. Although the spaces differ in size, their selection was guided by the medium-scale characteristics typical of Macau's largos, which are generally considered suitable for the everyday use of the elderly population.

The spatial distribution and cultural categorization of the nine sites are presented in Figure 1, which maps their locations across various urban districts and typologies. In addition to locational data, Figure 1 includes comparative weekday and weekend observations of the proportion of older adult users in each space. This information helps to quantify site-specific elderly engagement and supports the empirical relevance of each site for analyzing aging-in-place behavior across temporal dimensions.





	Name	Location	Cultural Spatial Typology	Proportion of Older Adults on Weekdays	Proportion of Older Adults on Weekends
1	Triangular da Areia Preta Garden	Macau Peninsula	Chinese	83.8%	76.9%
2	Flower City Park	Taipa	Chinese	44.8%	38.6%
3	Largo do Pagode do Bazar	Macau Peninsula	Chinese	49.1%	18.6%
4	Largo de Santo Agostinho	Macau Peninsula	Portuguese	23.2%	11.1%
5	Largo de Se	Macau Peninsula	Portuguese	9.8%	2.9%
6	Praca de Luis de Camoes	Macau Peninsula	Portuguese	70.4%	64.9%
7	Largo do Lilau	Macau Peninsula	Sino-Portuguese Fusion	49.4%	21.6%
8	Lou Lim loc Park	Macau Peninsula	Sino-Portuguese Fusion	53.6%	26.0%
9	Largo Camoes	Taipa	Sino-Portuguese Fusion	22.1%	13.2%

Note: The names of some locations are retained in their original Portuguese form as they are official place names in Macau.

Figure 1. Nine community public spaces of Macau.

3.2. Composition of Physical Features in Community Public Spaces

The physical features of Macau community public spaces are selected based on the concept of aging in place [3,4], with a focus on how the characteristics of public spaces can support older adults' ability to live independently and engage in daily activities.

To structure the analysis, the study draws on a scoping review of place attachment and aging [47], identifying three key dimensions of public space that contribute to aging in place: Spatial Features, Natural Features, and Elder-friendly and Accessible Features (see Table 1). By examining these three features, the study aims to identify and understand how the physical environment of public spaces in Macau can facilitate IADL performance and may shape their engagement in outdoor activities during aging in place. Table 1 outlines the quantification methods for various environmental elements based on the three core features. Each method was designed to ensure accurate and consistent measurements of the physical features. The sources and references used for these measurements further substantiate the reliability of the methods employed. All physical features were measured through direct field surveys, supplemented where appropriate by local geospatial data. For example, Spatial Enclosure was calculated by combining GIS data from the "Macau Online Map" with on-site verification to determine the ratio between enclosing boundary length and total perimeter. Plant Diversity was derived from direct botanical observation and species counting in the field, followed by application of the Patrick index, which adjusts for site area variation. The measurement results are shown in Table 2.

Table 1. Quantification methods for the physical features of community public spaces (source: authors).

	Environmental Features	Quantification Method	Data Sources	Reference
Spatial Features	Area	Measure the total area of the space in square meters.	Field measurements	[48]
	Percentage of Ground Pavement	The pavement ratio refers to the proportion of the area covered by building materials such as concrete, ceramic tiles, floor tiles, cast-in-place grass bricks, and embossed flooring, relative to the total floor area of the sample space.	Field measurements	[49]
	Spatial Enclosure	Measure the ratio of the enclosing boundary length to the perimeter of the space.	Field measurements	[50]
	Spatial Visual Brightness	the perceived brightness of a space, taking into account the distribution and intensity of light across the area. Measure the luminance and record the luminance values at each point. Represented by the standard deviation of luminance.	Sampling calculation	[51]
Natural Features	Green Coverage Ratio	Measure the proportion of greenery in the space relative to total area.	Field measurements	[52]
	Visible greenery ratio	Calculate the proportion of visible green space within a given area.	Sampling calculation	[53]
	Plant Diversity	Plant diversity (R) was calculated using the Patrick index, where R = S, with S representing the number of plant species in the sample area. To account for variations in the size of the sample space, the formula was adjusted to R = $S/\lg A$, where A is the total area of the sample space.	Field measurements	[54]
	Green Space Ratio	The proportion of green spaces within the sample area—such as ground-level areas suitable for planting trees, shrubs, flower beds, lawns, and groundcover plants, which are used for ecological functions or public recreation—relative to the total site area. Field measurement involves comparing the area of these green spaces to the overall site area.	Field measurements	[55]
Elder-friendly and Accessible Features	Functional Diversity	Functional diversity (F) was calculated using the Patrick index, where F = N, with N representing the number of different facility types within the sample area. Similar to plant diversity, the formula was adjusted to F = $N/\lg A$, where A denotes the total area of the sample space, to account for differences in size.	Field measurements	[56]
	Recreational Facilities	Count the number of recreational facilities (e.g., benches, playgrounds, fitness stations). This indicator is calculated in units of "groups".	Field measurements	[57]
	Density of Resting Facilities	Measure the number of resting facilities per unit area.	Field measurements	[58]
	Pathway Connectivity	The Connectivity Index is calculated by dividing the number of entrances (E) by the total perimeter (P) of the public space, using the formula $C = E/\mathrm{Lg}\ P$. To measure, count the entrances and measure the perimeter, then apply the formula—the higher the value, the better the connectivity.	Field measurements	[59]

Table 2. Physical features of nine community public spaces in Macau.

		Largo do Pagode do Bazar	Flower City Park	Triangular da Areia Preta Garden	Largo do Lilau	Largo Camoes	Lou Lim loc Park	Largo de Santo Agostinho	Praca de Luis de Camoes	Largo de Se
Spatial Features	Area (m^2)	676	5806	1449	576	827	3928	515	4874	1260
	Percentage of Ground Pavement (%)	91.00	36.30	63.67	75.74	69.24	19.34	64.66	63.74	76.43
	Spatial Enclosure (%)	44.44	37.22	7.96	59.10	84.01	27.8	32.32	66.44	78.36
	Spatial Visual Brightness	64.23	61.45	62.01	61.65	65.93	69.36	60.52	69.89	55.96
Natural Features	Green Space Ratio (%)	7.90	35.73	25.80	15.97	5.39	51.16	20.19	31.6	10.16
	Visible greenery ratio (%)	29.33	50.87	41.33	31.29	24.04	43.49	16.64	45.42	7.63
	Plant Diversity	1.06	4.25	2.53	1.81	2.06	5.56	1.48	2.71	0.97
	Green Coverage Ratio (%)	27.50	42.69	86.40	82.51	47.57	75.46	26.58	45.65	12.27
Elder-friendly and Accessible Features	Functional Diversity	0.35	1.86	1.27	0.72	0.69	1.67	1.48	1.63	0.65
	Recreational Facilities (m^2)	32	66	84	15	14	18	9	104	8
	Density of Resting Facilities	0.047	0.011	0.058	0.026	0.017	0.005	0.017	0.021	0.006
	Pathway Connectivity	1.52	1.19	2.63	3.01	1.37	1.13	1.00	1.64	2.27

3.3. Behaviors of Older Adults

Older adults' behaviors were categorized into necessary, optional, and social activities based on Gehl's framework [60]. This study focuses on optional and social behaviors, with optional activities further classified into static and dynamic types. Activities were excluded following the rationale proposed by Gehl and Svarre [61], as these actions are generally less responsive to variations in spatial design and offer limited insight into how physical environments influence voluntary and social use. The behavioral analysis commenced with coding specific action types observed in the field, as follows:

- Social activities refer to interpersonal interactions occurring in public spaces and include conversing, caring for a child, social gathering, playing board or card games, walking together, participating in community volunteer activities, and attending opera or cultural performances. These subcategories were identified through in situ observation and reflect the typological diversity commonly documented in public life studies. While categorized under a general "social" umbrella for analytical consistency, these behaviors involve varying degrees of interactional depth and social meaning, a nuanced acknowledgment, and are recommended for future theoretical refinement;
- Optional static activities involve minimal physical movement and include sitting, eating or drinking, sunbathing, reading newspapers or books, listening to music or watching performances, using a mobile phone, making phone calls, taking photos, viewing natural landscapes, sleeping, and smoking;
- Optional dynamic activities require physical movement and include walking, fitness walking, jogging, exercising alone, using fitness equipment, walking a dog, singing opera or performing traditional arts, engaging in gardening activities, fetching water, and cleaning.

Behaviors of older adults are recorded through non-participant observation, and the six most frequently occurring behavioral categories in each public space are selected to characterize the behavioral patterns of older adults in that specific environment.

3.4. Data Collection and IADL Assessment

The inclusion criteria for participants were (1) aged 65 or older, (2) local older adults in Macau who have used the selected public spaces; (3) able to respond to the IADL

assessment; and (4) voluntary consent to participate. Observations were conducted over a one-month period, during which data collection was distributed across multiple days to constitute a total of four full days of observation. This timeframe aligns with established short-term protocols in public space behavioral research [61–63]. Although effective for identifying typical behavioral patterns, longer observation periods may offer greater insight into seasonal or exceptional variations. To ensure temporal variation in behavior, data collection took place across five distinct time slots each day: 08:30–10:30, 10:30–12:30, 14:30–16:30, 16:30–18:30, and 19:30–21:30. Only behaviors sustained for at least five minutes were included, in order to capture meaningful engagements and exclude incidental or transient activities. While this threshold enhances consistency, it may overlook shorter-duration yet purposeful actions such as jogging or brisk walking, particularly in spatially constrained settings. Future studies may consider adjusting observation thresholds based on activity type and spatial context to better reflect the diversity of older adults' behaviors. The observed behaviors were categorized into the three mentioned types.

For the IADL assessment, older adults engaging in activities within the selected public spaces were randomly invited to participate in an interview or complete a questionnaire based on the IADL scale during December 2024. This scale evaluates an individual's ability to perform a range of daily tasks, including using the telephone, cooking, housekeeping, laundry, shopping, transportation, medication management, and financial management (see Table 3). It is adopted from the Lawton IADL Scale and the China Taiwanese government's "Long-term Care Services Subsidy Measures for Disabled Elderly." The Lawton scale is widely recognized for assessing elderly functional abilities, ensuring comparability, while the Taiwanese model is relevant to Macau's elderly population due to shared cultural and regional factors. IADL scores range from 0 to 24, reflecting levels of independence, with higher scores indicating greater functional ability. Table 3 shows IADL disability levels and scoring. Given that older men in Macau also engage in cooking, housekeeping, and laundry, the same assessment items were used for both male and female participants. Although the primary objective of this study is to obtain IADL assessment scores, efforts were made to minimize behavioral discrepancies among participants by ensuring a balanced distribution of behavioral types, based on the results of non-participant behavioral observation in public spaces. To ensure data representativeness, approximately four participants per time slot were recruited for IADL assessment in each public space.

Table 3. IADL disability levels and scoring criteria *.

Item	Score	Content
A. Ability to Use Telephone	3	Operates telephone on own initiative—looks up and dials numbers, etc.
	2	Dials a few well-known numbers.
	1	Answers telephone but does not dial.
	0	Does not use telephone at all.
B. Shopping	3	Takes care of all shopping needs independently.
	2	Shops independently for small purchases.
	1	Needs to be accompanied on any shopping trip.
	0	Completely unable to shop.
C. Food Preparation	3	Plans, prepares and serves adequate meals independently.
	2	Prepares adequate meals if supplied with ingredients.
	1	Heats, serves and prepares meals, or prepares meals but does not maintain an adequate diet.
	0	Needs to have meals prepared and served.
D. Housekeeping	4	Maintains house alone or with occasional assistance (e.g., "heavy work domestic help").
	3	Performs light daily tasks such as dishwashing, bed making.
	2	Performs light daily tasks but cannot maintain an acceptable level of cleanliness.
	1	Needs help with all home maintenance tasks.
	0	Does not participate in any housekeeping tasks.

Table 3. *Cont.*

Item	Score	Content
E. Laundry	3	Does personal laundry completely.
	2	Launders small items independently but may require assistance with larger laundry tasks.
	1	Can only handle small laundry tasks but cannot manage more significant laundry tasks independently.
	0	All laundry must be done by others.
F. Mode of Transportation	4	Travels independently on public transportation or drives own car.
	3	Arranges own travel via taxi, but does not otherwise use public transportation.
	2	Travels on public transportation when accompanied by another.
	1	Travel limited to taxi or automobile with assistance of another.
	0	Does not travel at all.
G. Responsibility for Own Medications	2	Is responsible for taking medication in correct dosages at correct times.
	1	Takes responsibility if medication is prepared in advance in separate dosages.
	0	Is not capable of dispensing own medication.
H. Ability to Handle Finances	2	Manages financial matters independently (budgets, writes checks, pays rent, bills, goes to bank), collects and keeps track of income.
	1	Manages day-to-day purchases, but needs help with banking, major purchases, etc.
	0	Incapable of handling money.
Disability Level	**IADL Score Range**	**Description**
Level 1	24	No Disability: Fully independent in all IADL tasks (e.g., phone use, shopping, cooking, household chores). No assistance or reminders needed.
Level 2	21–23	Mild Disability: Mostly independent, with occasional minor assistance required (e.g., for shopping or medication).
Level 3	18–20	Mild to Moderate Disability: Independent in most tasks, but needs occasional assistance or reminders (e.g., cooking, shopping, financial management).
Level 4	15–17	Moderate Disability: Requires assistance for most IADL tasks, especially shopping, cooking, and financial management.
Level 5	12–14	Moderate to Severe Disability: Cannot perform many IADL tasks independently and requires regular or full assistance.
Level 6	9–11	Severe Disability: Needs full-time assistance for most IADL activities; unable to independently manage basic daily tasks.
Level 7	6–8	Very Severe Disability: Almost entirely dependent, requiring comprehensive care for all daily activities.
Level 8	0–5	Complete Disability: Totally dependent on others for all activities; requires long-term care with 24-h supervision.

* This table is adopted from the Lawton IADL Scale and the Chinese Taiwanese government's "Long-term Care Services Subsidy Measures for Disabled Elderly".

3.5. Statistical Analysis

Based on the physical characteristics data of public spaces, behavioral data, and IADL statistical data, descriptive statistical analysis was first performed, such as calculating the frequency distribution of behavioral data to understand the basic characteristics of the data. Next, Spearman's rank correlation analysis was used to identify the independent variables that were significantly correlated with the dependent variable and IADL score and to select the most strongly correlated variables. Only variables with statistically significant correlations ($p < 0.05$) to IADL scores were selected as independent variables for regression modeling, in order to maintain model parsimony and avoid overfitting. Subsequently, multiple linear regression analysis was conducted, and collinearity diagnostics were performed using the Variance Inflation Factor (VIF) to identify potential redundant variables. Finally, the regression model was optimized by removing variables with severe multicollinearity, and the model was re-adjusted. The relationship of each independent variable on the IADL score was evaluated using regression coefficients and *p*-values. All statistical analyses were performed with IBM SPSS Statistics (version 26; IBM Corp., Armonk, NY, USA) to ensure the accuracy and reliability of the results.

4. Results

4.1. Percentage of Occurrence for Different Kinds of Behaviors in Nine Sample Spaces

Behavioral data from nine spaces show variation in activity types (see Table 4). Among the optional static activities, sitting (20.63%) was the most common static activity, followed by using a mobile phone (6.28%) and eating or drinking (2.13%). When it comes to optional dynamic activities, walking emerged as the most prevalent behavior, occurring in 7.6% of the observed spaces. Exercising alone followed closely with 4.58% of occurrences. Social activities represented a significant portion of the behaviors observed in these spaces, particularly conversing (18.3%) and playing board or card games (26.10%). These activities highlight the importance of interaction and communal engagement among older adults in public spaces. The high frequency of these behaviors indicates that these spaces serve as important social hubs for older adults, facilitating their need for connection and leisure.

Table 4. Statistical analysis of the percentage of occurrence for different behaviors.

Behavioral Types		Working Day	Weekend	Frequency	Occurrence Percentage
Optional static activities	Sitting	182	225	407	20.63%
	Eating or Drinking	25	17	42	2.13%
	Sunbathing	17	12	29	1.47%
	Reading Newspapers or Books	1	1	2	0.10%
	Listening to Music or Watching Performances	2	2	4	0.20%
	Using a Mobile Phone	52	72	124	6.28%
	Making Phone Calls	4	4	8	0.41%
	Taking Photos	5	2	7	0.35%
	Viewing Natural Landscapes	2	0	2	0.10%
	Sleeping	3	3	6	0.30%
	Smoking	6	14	20	1.01%
Optional dynamic activities	Walking	75	75	150	7.60%
	Fitness Walking	11	22	33	1.67%
	Jogging	1	1	2	0.10%
	Exercising Alone	48	52	100	5.07%
	Using Fitness Equipment	6	13	19	0.96%
	Walking a Dog	2	0	2	0.10%
	Singing Opera or Performing Traditional Arts	1	0	1	0.05%
	Fetching Water	1	0	1	0.05%
	Cleaning	4	2	6	0.30%
Social activities	Conversing	201	160	361	18.30%
	Caring for a Child	25	7	32	1.62%
	Social Gathering	20	17	37	1.88%
	Playing Board or Card Games	250	265	515	26.10%
	Walking Together	14	0	14	0.71%
	Participating in Community Volunteer Activities	8	1	9	0.46%
	Attending Opera or Cultural Gatherings	17	23	40	2.03%

Therefore, the occurrence probabilities of six behaviors, like playing board or card games, conversing, sitting, walking, using a mobile phone, and exercising alone, will be used to represent the behavioral patterns of the selected public spaces (see Table 5). For accuracy, this study adopts a ranking system to replace the raw behavior data with ordinal values: "High = 3", "Medium = 2", and "Low = 1". This approach converts the continuous variables into ordered variables, which will be adapted for the physical features of public space and used for subsequent data analysis. The reason for converting continuous variables of spatial and behavioral data into ordinal variables is to address the uncertainty and randomness within the data, thereby better reflecting general trends in reality. Through this ranking system, the overall impact of spatial forms and behavioral characteristics on IADL scores can be identified, rather than relying solely on the specific values of individual

sample spaces. This approach enables a deeper understanding of the potential role of different spatial and behavioral features on older adults' IADL performance.

Table 5. Behavioral activity distribution across selected public spaces.

	Sitting	Using a Mobile Phone		Walking	Exercising Alone	Conversing	Playing Board or Card Games
SPACE 1	Largo do Pagode do Bazar	2.4%	10.2%	10.3%	0.0%	5.3%	0.0%
SPACE 2	Flower City Park	9.5%	8.2%	8.8%	2.3%	7.4%	2.4%
SPACE 3	Triangular da Areia Preta Garden	32.5%	26.5%	16.2%	9.3%	35.3%	73.6%
SPACE 4	Largo do Lilau	6.5%	6.1%	0.0%	2.3%	7.9%	0.0%
SPACE 5	Largo Camoes	1.2%	0.0%	1.5%	0.0%	3.2%	0.0%
SPACE 6	Lou Lim loc Park	9.5%	18.4%	23.5%	53.5%	14.2%	0.0%
SPACE 7	Largo de Santo Agostinho	0.6%	2.0%	0.0%	2.3%	3.2%	0.0%
SPACE 8	Praca de Luis de Camoes	33.1%	22.4%	36.8%	25.6%	23.7%	24.0%
SPACE 9	Largo de Se	4.7%	6.1%	2.9%	4.7%	0.0%	0.0%

4.2. Associations of Physical Features and Behavioral Patterns on IADL Scores

The IADL assessment collected a total of 289 samples from 9 public spaces (see Tables 6 and 7). Among these participants, 78.5% scored 18 or higher, with a mean IADL score of 19.85. These results indicate that most older adults active in public spaces have an IADL rating above LEVEL3. Moreover, the median score of 21, corresponding to LEVEL 2, suggests a relatively high level of independence.

Table 6. Frequency distribution of participants across public spaces.

	Frequency	Percent
Flower City Park	37	12.8
Largo Camoes	31	10.7
Largo de Santo Agostinho	19	6.6
Largo de Se	18	6.2
Largo do Lilau	33	11.4
Largo do Pagode do Bazar	40	13.8
Lou Lim loc Park	31	10.7
Praca de Luis de Camoes	40	13.8
Triangular da Areia Preta Garden	40	13.8
Total	289	100.0

Table 7. Distribution of IADL scores and frequency.

IADL Score	Frequency	Percent	Cumulative Percent
7.00	1	0.3	0.3
10.00	1	0.3	0.7
11.00	2	0.7	1.4
12.00	8	2.8	4.2
13.00	3	1.0	5.2
14.00	7	2.4	7.6
15.00	11	3.8	11.4
16.00	15	5.2	16.6
17.00	14	4.8	21.5
18.00	22	7.6	29.1
19.00	30	10.4	39.4
20.00	28	9.7	49.1
21.00	34	11.8	60.9
22.00	44	15.2	76.1
23.00	41	14.2	90.3
24.00	28	9.7	100.0
Total	289	100.0	
Mean	19.85		
Median	21		

Spearman's rank correlation was performed to examine the relationships between various physical features, behaviors, and IADL scores (see Table 8). The results revealed several correlations:

(1) Visible greenery ratio and recreational facilities showed strong positive correlations with IADL scores (r = 0.239, r = 0.251, $p < 0.001$);
(2) The density of resting facilities also demonstrated a positive correlation (r = 0.211, $p < 0.001$), suggesting that spaces with more resting facilities promote better IADL outcomes;
(3) Conversing (r = 0.211, $p < 0.001$) and playing board or card games (r = 0.153, $p = 0.009$) were positively correlated with IADL scores.

Table 8. Correlation analysis between physical features, behavior, and IADL scores.

		IADL_Score	
		Pearson Correlation	**Sig. (2-Tailed)**
1	Area (m^2)	0.118 *	0.045
2	Percentage of Ground Pavement (%)	−0.125 *	0.034
3	Spatial Enclosure (%)	−0.140 *	0.017
4	Green Space Ratio (%)	0.129 *	0.029
5	Visible greenery ratio (%)	0.239 **	0.000
6	Recreational Facilities (m^2)	0.251 **	0.000
7	Density of Resting Facilities	0.211 **	0.000
8	Conversing	0.211 **	0.000
9	Playing Board or Card Games	0.153 **	0.009
10	Pathway Connectivity	0.103	0.081
11	Using a Mobile Phone	0.102	0.082
12	Walking	0.102	0.082
13	Functional Diversity	0.101	0.087
14	Plant Diversity	0.099	0.092
15	Sitting	0.094	0.111
16	Green Coverage Ratio (%)	0.05	0.399
17	Spatial Visual Brightness	0.043	0.472
18	Exercising Alone	−0.021	0.719

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

In contrast, Spatial Enclosure and Percentage of Ground Pavement exhibited weak negative correlations with IADL scores (r = −0.140 and r = −0.125, respectively; $p < 0.05$), suggesting that spaces with higher enclosure or more paved surfaces may be less conducive to maintaining functional independence in older adults.

The low r value suggests that the model may not have explained all the variations in the IADL scores, possibly because IADLs are influenced by multiple factors, including other unaccounted variables such as the most significant factors: personal health and chronic diseases, among others. The statistically significant p-value of less than 0.05 indicates that there is indeed a relationship between these independent variables and IADL scores, further demonstrating the contribution of these variables in predicting IADL scores. Subsequently, a multiple linear regression analysis was performed to evaluate the influence of the independent variables on the IADL score. The initial regression model yielded an R^2 value of 0.136, but several variables exhibited high Variance Inflation Factors (VIFs), suggesting substantial multicollinearity. Specifically, the variables Area (m^2) (VIF = 54.196), Green Space Ratio (%) (VIF = 61.777), Recreational Facilities (m^2) (VIF = 74.075), and Percentage of Ground Pavement (%) (VIF = 32.335) exhibited excessive multicollinearity. To address this, these four variables were removed from the model, and a revised regression analysis was conducted.

A refined regression analysis was subsequently conducted. The adjusted model, incorporating five predictors, yielded an R^2 of 0.125 and an adjusted R^2 of 0.109, indicating

that approximately 10.9% of the variance in IADL scores can be explained by the retained variables (see Tables 9 and 10). The model was statistically significant (F = 8.079, $p < 0.001$), and all remaining VIF values were below five, confirming that multicollinearity had been effectively addressed. Although the R^2 value decreased slightly from 0.136 to 0.125 following the removal of multicollinear variables, the resulting model is more parsimonious and statistically robust. This trade-off enhances the interpretability and stability of the regression coefficients, thereby improving the reliability of the findings.

Table 9. Initial model and optimized model summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Initial model	0.368 [a]	0.136	0.111	3.105
	a. Predictors: (Constant), Playing Board or Card Games, Spatial Enclosure (%), Density of Resting Facilities, Visible Greenery Ratio (%), Conversing, Recreational Facilities (m^2), Area (m^2), Green Space Ratio (%)			
Optimized model	0.353 [b]	0.125	0.109	3.107
	b. Predictors: (Constant), Playing Board or Card Games, Spatial Enclosure (%), Density of Resting Facilities, Visible Greenery Ratio (%), Conversing			

Table 10. Optimized multiple linear regression results for IADL score prediction.

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
	B	Std. Error	Beta			Zero-Order	Partial	Part	Tolerance	VIF
(Constant)	17.903	0.951		18.827	0.000					
Spatial Enclosure (%)	−0.251	0.156	−0.111	−1.605	0.110	−0.140	−0.095	−0.089	0.650	1.538
Visible greenery ratio (%)	1.161	0.269	0.499	4.311	0.000	0.239	0.248	0.240	0.231	4.325
Density of Resting Facilities	0.737	0.163	0.341	4.520	0.000	0.211	0.259	0.251	0.544	1.839
Conversing	−0.870	0.495	−0.204	−1.758	0.080	0.211	−0.104	−0.098	0.229	4.374
Playing Board or Card Games	−0.944	0.354	−0.252	−2.663	0.008	0.153	−0.156	−0.148	0.345	2.897

(a) The optimized regression model identified several significant predictors of IADL scores;
(b) Visible Greenery Ratio (%): Exhibited the strongest positive association with IADL scores (B = 1.161, β = 0.499, $p < 0.001$), suggesting that greater visual access to green spaces is significantly linked to higher functional independence;
(c) Density of Resting Facilities: Also showed a significant positive effect (B = 0.737, β = 0.341, $p < 0.001$), indicating that an increased availability of resting areas is beneficial for maintaining independence;
(d) Playing Board or Card Games: Revealed a significant negative effect on IADL scores (B = −0.944, β = −0.252, $p = 0.008$), which implies that frequent participation in such sedentary social activities may be associated with reduced functional independence;
(e) Conversing: Although it showed a negative relationship with IADL scores (B = −0.870, β = −0.204, $p = 0.080$), this effect did not reach statistical significance;
(f) Spatial Enclosure (%): Had a minor negative impact (B = −0.251, β = −0.111, $p = 0.110$), but this relationship was not statistically significant.

Overall, the results suggest that green space visibility and the availability of resting facilities are positively linked to IADL performance, while sedentary social activities such as board or card games may contribute to reduced functional independence. Other factors, including spatial enclosure and conversing, did not show significant effects in this model.

5. Discussion

This section interprets the key empirical findings on how public space features and behavioral patterns are associated with older adults' IADL performance. It evaluates the implications of these results in relation to prior research, highlighting theoretical contributions, practical relevance, limitations, and directions for future inquiry.

5.1. Exploratory Insights into the Associations Between Physical Features, Behavioral Patterns, and IADL Performance

This study aimed to explore the associations between physical features and behavioral patterns in community public spaces and their relationship with IADL performance in older adults in Macau. The results provide valuable insights but also highlight the complexity of the relationship between the physical environment and IADL performance. IADL performance is influenced by multiple factors, including health status, cognitive ability, social support, and so on. The relatively low Pearson correlation coefficients (r values between -0.3 and 0.3) and the R^2 value of 0.125 in the regression model suggest that while there are statistically significant relationships between certain physical features, behavioral patterns, and IADL scores, these factors alone explain only a small portion of the variation in IADL performance: approximately 10.9%. These findings align with prior research acknowledging that IADL performance is a multifaceted issue influenced by a range of internal and external factors [64]. This relatively low explanatory power indicates a limitation in capturing the full complexity of IADL performance through environmental and behavioral variables alone. Prior studies have also reported limited effect sizes in similar contexts. For instance, Saelens and Handy [65] noted that built environment attributes typically account for a small proportion of variance in walking behavior, and Ewing and Cervero [66] observed similar patterns in travel behavior studies. The results support the hypothesis that the physical environment does play a role in supporting older adults' independence but also reinforce the need for a more comprehensive understanding of the factors at play. The significant predictors identified still provide valuable insights for policy and urban design, demonstrating that even incremental improvements in the built environment can have meaningful impacts on older adults' independence and cognitive well-being.

5.2. Key Observations on Visible Greenery Ratio, Resting Facilities, and Sedentary Activities

This study identified notable associations between physical space features, behaviors, and IADL performance. One of the most significant findings was the positive association between the visible greenery ratio and IADL scores, supporting the notion that natural elements in public spaces foster mental restoration and physical engagement. Previous studies have emphasized that greenery supports not only psychological well-being but also promotes outdoor activity [41,52], which in turn can preserve functional capacities and other daily tasks [21]. In this context, green visibility serves as a facilitator for cognitive health, which is critical for IADL performance. Natural elements, therefore, play a direct role in promoting independence by supporting cognitive recovery and engagement in functional activities.

The density of resting facilities correlated positively with IADL scores, supporting previous research on the importance of seating areas [67]. These spaces help reduce fatigue, allowing older adults to stay outdoors longer and engage in activities such as walking, shopping, and socializing—critical tasks for maintaining independence. The presence of resting areas also allows for a balanced pacing of activities, helping older adults mitigate physical strain and increase their ability to perform IADLs [22]. In this way, resting facilities

function as crucial transitional spaces in the public environment, directly contributing to older adults' functional independence.

In contrast, there is an observed negative correlation between playing board or card games and IADL performance. Although these activities offer cognitive and social benefits, their sedentary nature may limit physical engagement and contribute to a decline in physical function, especially when they dominate older adults' routines [68]. While these games can foster cognitive engagement and social bonding, their predominantly sedentary nature may limit opportunities for the moderate physical exertion that supports performing IADL tasks. Thus, although social activities generally have beneficial psychosocial and cognitive aspects, an overemphasis on sedentary pursuits could inadvertently undermine physical robustness and daily functional capacity.

The underlying mechanisms through which physical features and behavioral patterns may contribute to IADL performance can be understood through a more integrated perspective that considers the interaction of cognitive, physical, and behavioral dynamics. In the study, green visibility and resting facilities are not only correlated with IADL performance but may also play a role in IADL completion by supporting cognitive recovery and reducing fatigue. Similarly, social activities such as playing board games indirectly may reflect functional decline. These findings suggest that behavioral choices in public spaces are influenced by individual health conditions, underscoring the complexity of these relationships.

It is important to recognize that the interaction between the built environment and individual health factors complicates direct interpretations of the relationship with IADL performance. While visible greenery and resting areas may contribute to cognitive and physical well-being, their potential benefits could vary depending on individuals' health conditions, such as chronic illnesses, cognitive impairments, or mobility limitations. These factors may moderate the extent to which older adults benefit from environmental features, highlighting the need for a more integrated approach that considers both environmental design and personal health when planning for functional independence in older adults. This complexity suggests that the built environment interacts with personal health and activity choices in ways that are not fully captured by surface-level correlations.

5.3. Variations in the Impact of Static, Dynamic, and Social Activities on IADL Performance

IADL tasks require both physical and cognitive abilities [33]. Social interactions stimulate cognitive function and maintain mental agility, which are crucial for completing complex daily tasks. Although conversing showed a positive correlation in simple analyses, its effect may be overshadowed by other cognitively related variables, such as playing board or card games, in multivariate regression models. Additionally, the quality and depth of conversations vary greatly in different contexts, potentially reducing their statistical significance when other factors are controlled for. While playing board or card games can promote cognitive exchange in social interactions, they are inherently sedentary and lack the necessary physical activity. Over-involvement in such activities may lead to insufficient physical exercise, negatively associated with IADL tasks that require physical endurance. Therefore, frequent engagement in these activities is associated with lower IADL scores, reflecting a decline in functional independence that prompts individuals with reduced functionality to choose such low-intensity activities.

This study highlights the limitations of static and dynamic activities. Optional static activities such as sitting or using a mobile phone may facilitate rest or information acquisition to some extent, but they generally do not provide enough physical or social stimulation to directly enhance or maintain IADL performance. Prolonged sitting may result in muscle

atrophy and endurance decline, but the frequency and duration of sitting or phone use in our sample may not have reached thresholds that may impact functional independence. While optional dynamic activities like walking and exercising may enhance physical health, their direct influence on IADLs is less clear, as IADLs also require cognitive processing, decision-making, and multitasking. These findings suggest that activity choices may reflect individuals' functional status, with those experiencing greater functional decline being more inclined to engage in sedentary behaviors.

5.4. Policy and Design Implications for Aging in Place in High-Density Asian Cities

This study highlights several actionable insights for enhancing aging in place strategies in high-density Asian cities. Findings from Macau indicate that even subtle adjustments to public space design, such as improving greenery visibility and increasing the availability of resting facilities, may support older adults' functional engagement and independence.

Visible greenery was found to be positively associated with IADL performance, echoing prior research on its restorative and mobility-supportive effects [41,69]. In compact urban settings, micro-greening strategies like vertical planting and pocket parks can serve as effective interventions. Similarly, a higher density of resting points contributes not only to physical support but also to social connection and spatial inclusion [59,67]. These elements should be integrated into transit nodes, walking routes, and gathering areas frequented by older adults. At the same time, this study cautions that not all social activities are equally beneficial. Frequent sedentary engagement, particularly low-intensity games, may be associated with functional decline. Urban designs should therefore encourage environments that foster both social interaction and light physical activity.

These implications align with the WHO's age-friendly cities framework, emphasizing accessible, inclusive, and health-supportive spaces [15]. Embedding empirical tools—such as behavioral observation and IADL assessments—into planning processes can help cities tailor interventions to local aging needs. As aging accelerates across Asia, creating flexible evidence-based public environments will be vital to supporting autonomy and well-being in older populations.

5.5. Limitations

This study has several limitations. First, the cross-sectional design limits the ability to draw causal conclusions. Longitudinal studies would provide more insights into whether specific interventions, such as increasing green visibility or adding resting facilities, lead to sustained improvements in IADL performance over time. Second, while non-participant observations captured a broad overview of behavioral patterns, self-reported data on the frequency and duration of specific activities could offer a more nuanced view of how these behaviors evolve. Third, although the observation period aligns with short-term protocols [61–63], its limited duration may not fully capture seasonal or event-based behavioral variations. Additionally, the five-minute observation threshold may not be equally appropriate across all activity types. For example, transient behaviors like jogging or brisk walking may last less than five minutes in compact spaces, potentially leading to the underestimation or misrepresentation of such activities in the dataset. This limitation suggests the need for future research to adapt temporal thresholds based on behavior-specific and spatial contexts. Furthermore, while this study groups all observed interpersonal actions under the "social" category, it is recognized that such activities differ in function, frequency, and depth of interaction. Future research should adopt a more stratified and theory-driven framework to distinguish between casual encounters, organized group actions, and emotionally meaningful exchanges, thereby improving analytical precision and

policy relevance. Finally, this study did not control for potential confounding factors such as individual health status, cognitive ability, or socioeconomic background, which may also influence IADL performance and enhance the model's explanatory power.

These limitations underscore the need for more comprehensive study designs that account for temporal variability and a broader range of influencing factors. Expanding the scope of data collection, incorporating longitudinal approaches, and leveraging advanced analytical techniques could further refine and strengthen the findings of this study.

6. Conclusions

This study explored how physical features and behaviors in Macau's public spaces are associated with older adults' IADL performance. By combining spatial measurements, non-participant observations, and IADL assessments, the findings provide valuable insights into the role of public space design in supporting older adults. Even though the model explains only a small portion of the variation in IADL performance, the evidence from this study underscores the practical importance of physical space features and behavioral patterns in older adults' functional engagement. The main findings and contributions are summarized as follows:

(1) Associations Between Physical Features and Behavioral Patterns: The R^2 value of 0.125 from the regression model suggests that physical features and behavioral patterns together account for approximately 10.9% of the variance in IADL scores. This suggests that while other factors, such as personal health and chronic conditions, play a critical role in determining IADL performance, the physical features and behavioral patterns of public spaces may also relate to IADLs. Although the current model explains only a limited portion of IADL variance, it aligns with effect sizes found in similar exploratory studies and provides foundational insights for evidence-based design of age-friendly public environment;

(2) Greenery Visibility: A higher visible greenery ratio was positively associated with IADL scores. This finding suggests that exposure to green spaces may contribute to older adults' functional engagement, underlining the potential role of natural elements in promoting cognitive health and well-being;

(3) Resting Facilities: The density of resting facilities, such as benches and shaded seating areas, showed a positive association with IADL scores. Spaces with abundant resting opportunities may facilitate prolonged physical activity and social interactions, which are important for maintaining independence;

(4) Sedentary Activities: Although playing board or card games can encourage social interaction, their frequent engagement was negatively associated with IADL scores. This highlights the need to further explore the relationship between sedentary behaviors and functional independence, particularly in the context of public space usage;

(5) Bridging Urban Design and Gerontological Health: By integrating on-site spatial measurements, non-participant observation, and a standardized IADL assessment, this study contributes to the intersection of urban design and health research. This mixed-method approach offers an exploratory perspective on how environmental factors may relate to older adults' functional well-being;

(6) Empirical Insights for Age-Friendly Design: This study provides preliminary evidence that physical elements may play an important role in older adults' daily functioning. These findings offer insights for policymakers and urban designers aiming to create environments that support aging in place, particularly in dense urban contexts like Macau.

In summary, this study suggests that strategic public space design and behavioral engagement may be linked to IADL performance in older adults. It underscores the need for a holistic approach in urban planning, integrating spatial design with an understanding of individual health conditions and activity patterns. By combining gerontological insights with urban planning principles, this study contributes to the discourse on creating inclusive health-supportive environments in rapidly aging cities. Future studies could build upon these findings by incorporating longitudinal data, AI-driven behavioral analysis, and cross-cultural comparisons to further refine strategies for designing age-friendly urban spaces that enhance the independence and well-being of older adults.

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GIS-Based Analysis of Elderly Care Facility Distribution and Supply–Demand Coordination in the Yangtze River Delta

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Abstract: This study addresses the challenges related to the distribution of elderly care facilities in the Yangtze River Delta (YRD) region, which is experiencing a rapidly aging population. With over 176 million people aged 65 and above in China as of 2019 and the elderly population in the YRD continuing to grow, the study analyzes the spatial distribution, evolution, and supply–demand balance of elderly care facilities. Using GIS technologies, multi-source data analysis, and spatial autocorrelation techniques, the research identifies key regional patterns. Shanghai exhibits a clear hierarchical distribution of facilities, Jiangsu shows a "south strong, north weak" trend, while Zhejiang and Anhui demonstrate the opposite. The study also highlights a shift towards smaller, community-based care facilities, reflecting the growing demand for more localized services. It uncovers significant spatial mismatches and low coordination between supply and demand, particularly in rural and urban fringe areas, indicating the need for better regional coordination and more balanced resource distribution. To address these challenges, the study recommends (a) establishing cross-regional elderly care resource-sharing mechanisms; (b) promoting the development of small, community-based facilities; (c) integrating urban and rural services; and (d) leveraging technology for smart elderly care, including the use of big data and AI to optimize service delivery. These strategies aim to improve the equity and accessibility of elderly care services, ensuring that underserved areas receive better support. The findings provide a comprehensive framework for elderly care policies, offering valuable insights for other rapidly urbanizing regions and countries facing similar demographic challenges.

Keywords: Yangtze River Delta; population aging; elderly care facilities; spatiotemporal evolution; equilibrium analysis; coupling coordination model

1. Introduction

Population aging is one of the major challenges facing modern societies and represents an inevitable trend accompanying social development [1]. This demographic shift is a global phenomenon affecting both developed and developing countries. According to the United Nations, the global population aged 60 and above has more than doubled over the past 30 years, and it is projected to nearly triple by 2050, reaching 2.1 billion people [2]. The rapid aging of the population places immense pressure on healthcare systems, pension schemes, and social services while also influencing economic productivity and intergenerational relationships [3–5]. Addressing the challenges posed by aging societies requires comprehensive

strategies to ensure that elderly individuals receive adequate medical care, social welfare, and support systems, enabling them to live independently and with dignity [6,7].

As the world's most populous developing country, China faces significant challenges related to population aging. According to the 2020 National Population Census released by the National Bureau of Statistics of China, the old people (aged 60 and above) had reached 264 million, accounting for 18.7% of the total population—an increase of 5.5 percentage points compared to 2010. At this rate of growth, China is expected to enter a "super-aged society" by 2035, with individuals aged 65 and above exceeding 20% of the total population [8]. In response to these demographic changes, the Chinese government has actively aligned with the United Nations' 2030 Agenda for Sustainable Development, incorporating "ensuring healthy lives and promoting well-being for all at all ages" (Goal 3) [9] and "building sustainable cities and communities" (Goal 11) [10] into its national strategic priorities. In recent years, policy frameworks such as the Medium- and Long-Term Plan for Actively Responding to Population Aging (2019) [11] and the report from the 20th National Congress of the Communist Party of China [12] have been issued, outlining key policy pathways for strengthening elderly care services, promoting the development of the aging industry, optimizing resource allocation, and enhancing the quality of care services.

At the regional level, aging-related challenges are particularly pronounced. The Yangtze River Delta (YRD), one of the first regions in China to enter an aging society, has experienced one of the most rapid demographic shifts, placing significant pressure on elderly care services [13]. The YRD region, covering Shanghai, Jiangsu, Zhejiang, and Anhui provinces, spans approximately 350,000 square kilometers and is home to over 200 million people [14]. As a region characterized by high population density and advanced economic development, the continuous improvement of economic conditions and healthcare services has led to an increase in life expectancy and a significant rise in the number of old people. Recent statistical data indicate that the proportion of the population aged 65 and above in Shanghai, Jiangsu, Zhejiang, and Anhui has reached 16.28%, 16.20%, 13.27%, and 15.01%, respectively [15]. With the exception of Zhejiang, the other provinces have already entered a moderately aged society. However, significant disparities exist in aging patterns between urban and rural areas and among cities within the YRD region [16,17]. Furthermore, the escalating demand for elderly care services is exerting tremendous pressure on the regional public service system. Particularly in terms of elderly care facilities, the YRD faces structural issues such as unbalanced facility distribution, resource misallocation, and mismatches between urban and rural service demands [18,19]. These challenges necessitate a spatially oriented, data-driven research approach to identify the distribution patterns and dynamic evolution of elderly care facilities across different geographical areas, thereby supporting evidence-based policymaking and targeted interventions.

This study focuses on the spatial distribution and supply–demand imbalance of elderly care facilities in the Yangtze River Delta. By integrating information geography, web scraping techniques, geographic information systems (GISs), and statistical modeling, this research constructs a comprehensive dataset of elderly care facilities in the YRD region. It analyzes spatial distribution patterns, temporal trends, and the alignment of facility supply with population needs. The findings of this study not only contribute to enhancing the scientific precision of local government decision-making in elderly care service provision but also provide an analytical framework applicable to the global discourse on aging. This research offers insights into promoting equity in elderly care services and advancing sustainable urban development in the context of global population aging.

2. Literature Review

With the growing severity of population aging, elderly care facilities have become crucial components in ensuring the quality of life and well-being of old people [20,21]. These facilities play a key role in urban sustainable development strategies, serving not only as places for caregiving [22], rehabilitation [23,24], and psychological support [25,26] but also directly influencing the convenience of daily life and the social participation of elderly populations [27]. Therefore, the spatial configuration and service equity of elderly care facilities have become critical topics in the field of aging studies. Many countries are now focusing on integrating elderly care facilities into broader territorial planning strategies. Urban and regional policies are increasingly addressing the need for equitable access to care services by ensuring that facilities are strategically located to serve both urban and rural populations. The overlap between territorial planning and elderly care facility policies is particularly evident in efforts to improve accessibility, integrate services across regions, and create environments that support aging in place, all while balancing the distribution of resources to meet the growing demands of an aging population.

Existing research primarily focuses on identifying the spatial distribution characteristics of elderly care service facilities. Descriptive statistical and visualization techniques are commonly used to reveal the density, spatial clustering, and dispersion patterns of various types of facilities. Frochen et al. [28] applied the Getis-Ord Gi* index to conduct spatial clustering and hotspot analysis, revealing significant spatial aggregation of elderly care facilities in the Los Angeles area. Huang [29] utilized kernel density estimation (KDE) to systematically explore the spatial distribution and clustering characteristics of eight types of elderly care facilities, highlighting notable spatial imbalances in facility layouts. Tan et al. [20] analyzed the spatial pattern of elderly care facilities in Tianjin using Moran's I, identifying significant spatial clustering in central urban areas. Most studies widely apply Geographic Information System (GIS) techniques for spatial visualization, employing methods such as standard deviational ellipse (SDE) [30–32], kernel density estimation (KDE) [33–35], and Moran's I [20,36,37] to examine the spatial aggregation and evolutionary trends of elderly care facilities, providing essential technical support for optimizing facility layouts.

As research progresses, scholars have shifted from focusing solely on "spatial visualization of facility distribution" to analyzing "service accessibility," emphasizing the spatial interactions between elderly care facilities and aging populations. Accessibility analysis has become a core research focus, with commonly used methods including Euclidean distance, network distance, and population demand-weighted models [38–40]. Among these, the two-step floating catchment area (2SFCA) method has been widely adopted for assessing the accessibility of elderly care facilities. Cheng et al. [41] utilized the 2SFCA method to analyze the geographic accessibility of multi-tiered healthcare services for the old people, emphasizing the importance of improving elderly healthcare accessibility in optimizing public health resource allocation. Guida and Carpentieri [42] further refined the 2SFCA model by incorporating a distance decay function and multimodal transportation network modeling. By integrating pedestrian pathways, bus routes, and urban rail transit, they developed a more realistic accessibility evaluation system.

In recent years, with the advancement of the "aging-in-place" concept and age-friendly city initiatives, research has expanded to regional-scale analyses of service supply–demand equity. Scholars have begun examining the spatial disparities in elderly care resources across different administrative units, such as streets, communities, and districts. For example, Ellen et al. [43] conducted a systematic evaluation of 86 types of elderly care services in Australia, assessing their effectiveness in meeting the needs of aging populations. Higgs [44] analyzed the spatial disparities in social care service provision using the Welsh

national database of residential and care home beds, focusing on localized resource allocation challenges. Sagara [45] investigated the employment mechanisms and structural challenges faced by elderly care assistants in nursing institutions through fax surveys and questionnaires. The study found that large institutions generally provide more comprehensive training and support systems, whereas small- and medium-sized institutions suffer from workforce shortages, exacerbating structural imbalances within the elderly care service system.

Despite the theoretical foundations and methodological advancements provided by existing studies, several key gaps remain in the spatial analysis of elderly care facilities. First, most current research relies on static cross-sectional data, lacking systematic tracking and quantitative analysis of the dynamic evolution of elderly care facility distribution over time. This limitation hinders the accurate depiction of spatial changes in facility layouts in the context of urban development and demographic aging. Second, while accessibility and equity have become central research themes, the coordinated mechanisms underlying supply–demand matching remain underexplored. Additionally, in terms of data acquisition, traditional government statistical data often suffer from delayed updates and insufficient spatial resolution, limiting the real-time applicability and granularity of research findings.

3. Methodology

Given the existing research gaps in the dynamic evolution of elderly care facilities and the coordination mechanisms of supply and demand, this study focuses on the YRD region and constructs a comprehensive analytical framework integrating "spatial distribution–evolutionary characteristics–supply–demand coupling." By leveraging web scraping and geocoding techniques, a spatial database of elderly care facilities is established. The study employs Moran's I, nearest neighbor index, kernel density analysis, and standard deviational ellipse to analyze the spatial evolution of these facilities. Additionally, a coupling coordination model and the entropy weight method are utilized to assess the spatial matching between facilities and elderly people. The objective is to comprehensively depict the spatiotemporal evolution patterns and supply–demand equilibrium of elderly care facilities in the YRD region, thereby providing theoretical support and empirical insights for optimizing regional elderly care service systems. The research methodology consists of three main aspects.

3.1. Development of a Regional Elderly Care Facility Dataset Based on Web Scraping and GIS Technology

This study selected elderly care facility data published by the Integrated Civil Affairs Service Platform as the baseline dataset. Based on this, web scraping and relevant GIS analysis methods were utilized to spatially locate and enrich the attributes of the elderly care facilities, ultimately constructing a spatial distribution dataset. The dataset fields include information such as institution name, credit code, number of beds, and address. The data processing workflow is as follows (Figure 1):

(1) Based on the elderly care facility data provided by the Integrated Civil Affairs Service Platform, the facility directory was cleaned and verified. Given the limitations in attribute information, such as the lack of time-based data, additional information was gathered from civil affairs bureaus (departments) of the three provinces and one municipality, as well as from corporate data sources like Qichacha, Tianyancha, and various elderly care websites to enrich the dataset.

(2) The enhanced elderly care facility data were then geocoded to convert the addresses into geographic coordinates, which were imported into the GIS for spatial visualization.

(3) For quality control, regional Points of Interest (POI) data products, maps, and remote sensing imagery were used, along with official data on elderly care facilities and statistical

yearbooks published by provincial (municipal) civil affairs bureaus (departments), to verify the spatial locations and attribute information.

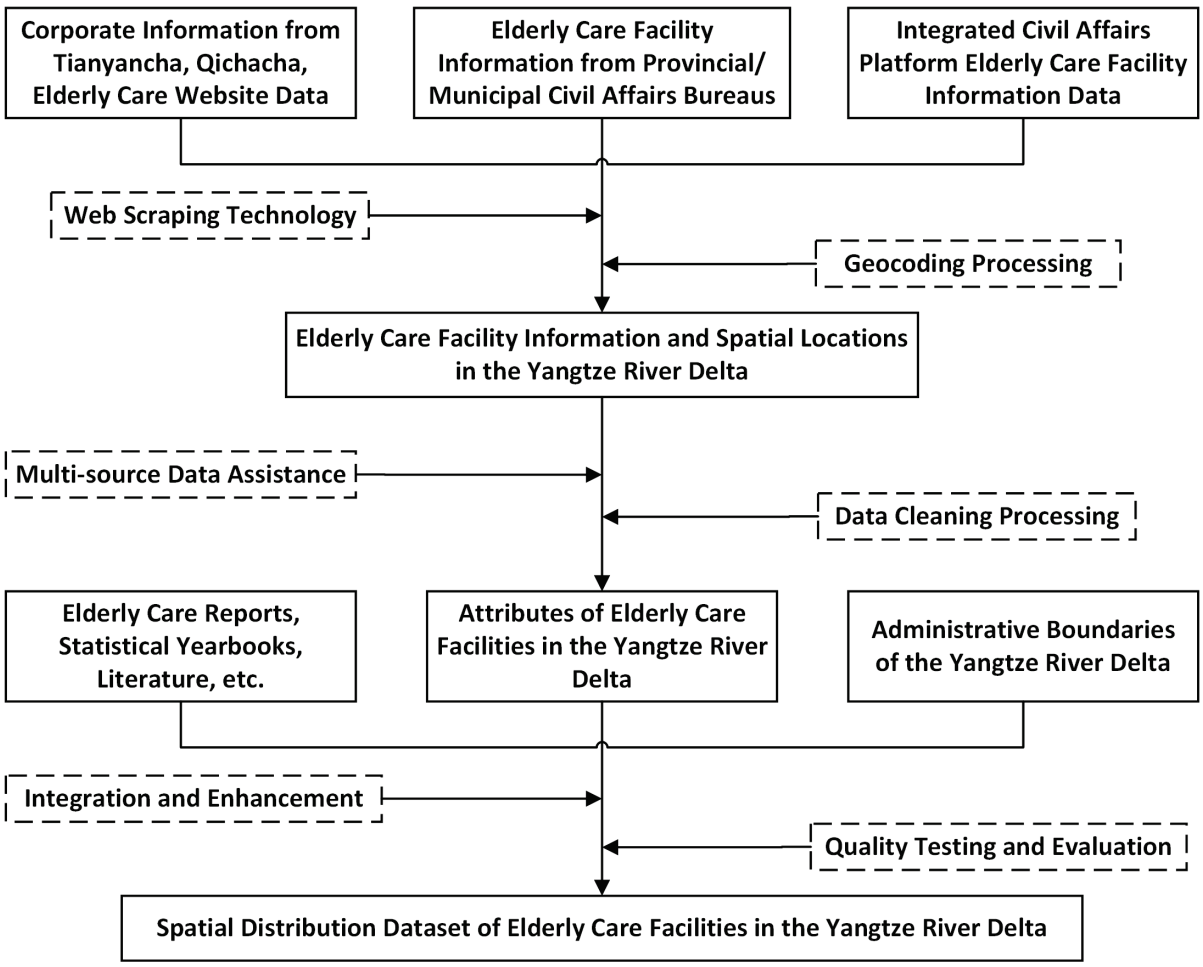


Figure 1. Data development process.

This study focuses on elderly care service facilities, encompassing both public and private institutional care facilities as well as community-based elderly care facilities. These facilities provide comprehensive services for people aged 60 and above, including daily living support, health care, recreational activities, and more. The types of facilities include nursing homes, elderly care homes, senior apartments/elderly apartments, care homes, dementia care institutions, small-scale community institutions, and retirement communities [46]. Moreover, the study uses Python's Requests and Beautiful Soup libraries for web scraping, adheres to legal and ethical standards, and complies with the requirements of the website's robots.txt file.

The other data sources are as follows. The transportation network data were derived from the National 1:1,000,000 Basic Geographic Information Data (2021) from the National Geomatics Center of China (https://www.ngcc.cn/, accessed on 12 July 2024). Information on elderly care facilities, related attributes, and Points of Interest (POI) data were sourced from the Yangtze River Delta Data Center (http://nnu.geodata.cn/, accessed on 18 July 2024).

3.2. Spatiotemporal Pattern Evolution Analysis

To better analyze the distribution and evolution trends of regional elderly care facilities, this study analyzes by calculating the global Moran's index and nearest neighbor index, detecting whether the current layout of elderly care facilities exhibits spatial clustering or

dispersion within the study area and examining the evolution of distribution characteristics. Additionally, kernel density estimation is employed to analyze the development trends and characteristics of elderly care facilities at different stages, while the standard deviation ellipse (SDE) is used to observe their expansion direction and range trends (Figure 2).

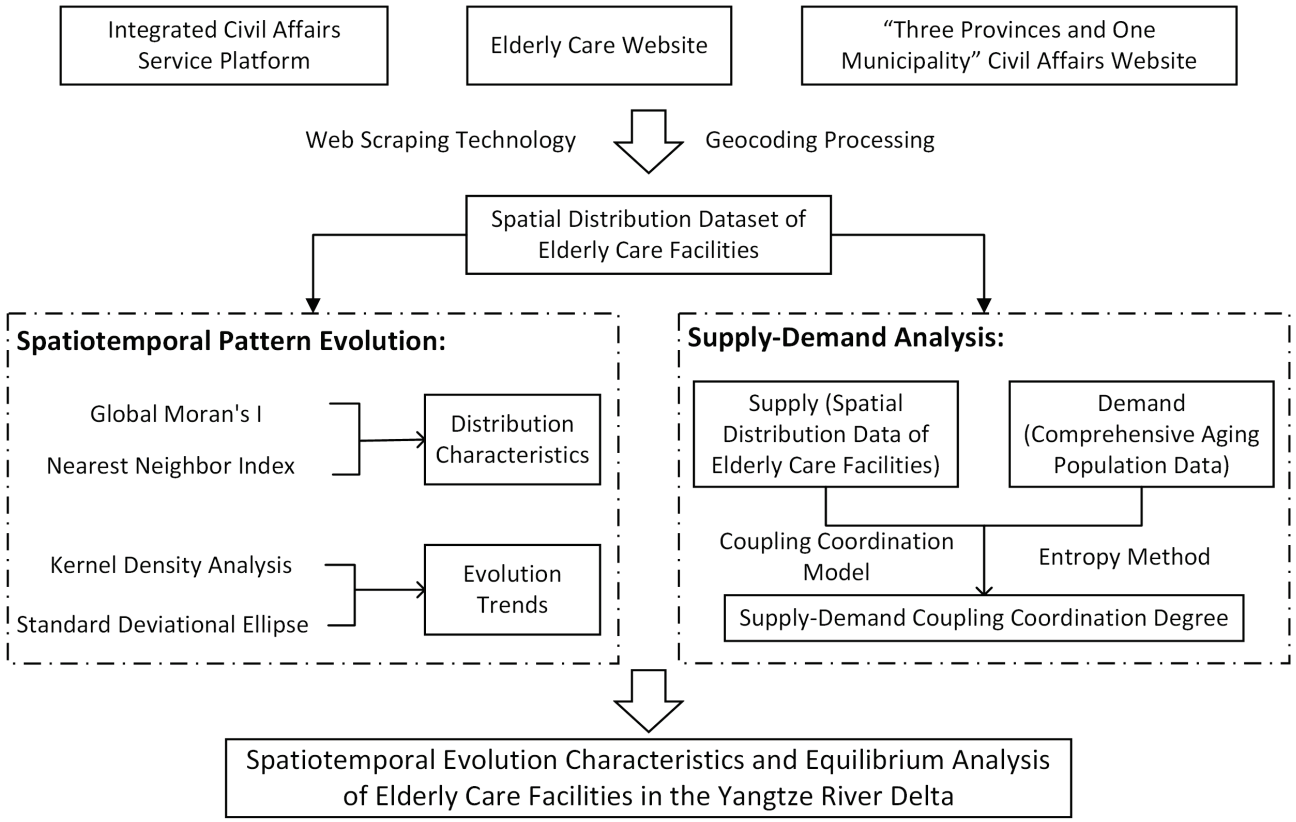


Figure 2. Methodological framework.

Global Moran's Index

Global Moran's I is used to analyze the overall spatial distribution trends of a given attribute within a specific region. It plays an important role in understanding the spatial distribution patterns and spatial interactions of geographic phenomena [47]. This index reflects whether spatial data exhibit clustering or dispersion trends, as well as the strength and significance of these trends. Based on previous research [48], this study uses the Global Moran's I to analyze the spatial clustering of elderly care facilities and determine whether these facilities are clustered or dispersed in geographic space. Moran's I value ranges between $[-1, 1]$, where positive values indicate clustering, negative values indicate dispersion, and zero represents no spatial autocorrelation. The calculation formula is presented in Equation (1).

$$I = \frac{n}{S_0} \cdot \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \cdot (x_i - \bar{x}) \cdot (x_j - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \quad (1)$$

where n is the total number of observations, x_i and x_j are the attribute values of regions i and j, $\bar{x}$ is the mean of observed values, w_{ij} represents the spatial weight between i and j, S_0 is the sum of all spatial weights.

Nearest Neighbor Index

The nearest neighbor index (NNI) [49] is a spatial statistical method commonly used to analyze the spatial distribution characteristics of point patterns (such as the distribution of buildings or facilities in a city or the distribution of plants and animals in nature). It is widely used in fields like geography, ecology, and urban planning. The NNI analyzes the distance between a specific point and its nearest neighboring point to determine whether the distribution tends toward randomness, clustering, or uniformity.

$$NNI = \frac{r_{obs}}{r_{exp}} \tag{2}$$

where r_{obs} is the observed average distance between each point and its nearest neighbor, and r_{exp} is the expected nearest neighbor distance for a randomly distributed set of points, calculated as:

$$r_{exp} = \frac{1}{2\sqrt{\frac{n}{A}}} \tag{3}$$

where n is the number of points (sample size) in the study area, A is the area of the study region.

Kernel Density Estimation

Kernel density estimation (KDE) is a non-parametric spatial analysis method often used to analyze areas of spatial concentration [50]. The kernel function can take various forms, such as triangular, quadrilateral, Gaussian, and Epanechnikov kernel [51]. Referring to previous studies [52], this paper uses the Gaussian kernel function to study the dynamic evolution trend of elderly care facility distribution. The formula is:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \tag{4}$$

where n is the number of observations, h is the bandwidth, K is the kernel function, $x - x_i$ is the distance from the estimation point to the observation point.

Standard Deviation Ellipse

The SDE [53] is mainly used to quantify and visualize the spatial distribution patterns of geographic data. By calculating the center of geographic point data, distribution directionality, and dispersion (standard deviation), the spatial distribution is represented as an elliptical shape. This ellipse intuitively reflects the spatial range, trends, and directionality of data distribution. Referring to previous studies [54], this method is applied to observe the spatial range and directional trends in the distribution of elderly care facilities. Assume there are n elderly care facilities with coordinates (x_i, y_i). The main calculation formulas are as follows:

Center point:

$$x = \frac{1}{n}\sum_{i=1}^{n} x_i, \quad y = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{5}$$

Axis lengths:

$$\sigma_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}, \quad \sigma_y = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{6}$$

Ellipse rotation angle:

$$\theta = \frac{1}{2}\arctan\left(\frac{2\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2 - \sum_{i=1}^{n}(y_i - \bar{y})^2}\right) \tag{7}$$

3.3. Supply–Demand Equilibrium Analysis

Coupling Coordination Degree Model

The coupling coordination model [55] is specifically designed to analyze the relationship between supply and demand systems, assessing the degree of matching and coordination between them. This model is widely used in fields such as ecological environment coordination [56], tourism resource management [57], and the layout of public service facilities [58], making it an effective tool for evaluating balanced regional development. Drawing on previous research [57,59], this study uses the coupling coordination model to calculate the coupling coordination degree between the supply and demand of elderly care facilities across counties and districts. The specific formulas are as follows:

1. Calculation of the Comprehensive Evaluation Index for Supply and Demand:

$$u(X_i) = \sum_{j=1}^{m} W_j \times X_{ij} \tag{8}$$

where W_j represents the weight of each indicator (calculated using the entropy weight method), X_{ij} is the j-th indicator of the i-th sample, m is the total number of indicators.

2. Calculation of development level, reflecting the overall situation of supply and demand:

$$T = \alpha u_1(X_i) + \beta u_2(X_i) \tag{9}$$

where α and β represent the weights of supply and demand, generally taken as equal.

3. Calculation of the coupling degree, which measures the strength of the interaction between the supply and demand systems. A higher coupling degree indicates a more significant supply–demand relationship:

$$C = 2 \times \frac{u_1 \times u_2}{(u_1 + u_2)^2} \tag{10}$$

where u_1 and u_2 are the comprehensive evaluation functions of the supply and demand systems, respectively.

4. Calculation of the coupling coordination degree:

$$D = C \times T \tag{11}$$

4. Study Area

The study area for this paper is located in the Yangtze River Delta (YRD) of China (Figure 3). According to the Development Plan Outline for the Integrated Development of the YRD, approved by China's State Council in 2019, the YRD includes Jiangsu, Zhejiang, Anhui, and Shanghai [60]. This region consists of 41 cities, spans an area of 358,000 square kilometers, and is home to more than 200 million people. The YRD is distinguished by its advanced economy, geographical proximity, close social connections, and shared cultural heritage. As one of the most densely populated regions in China, the YRD has a significant aging population, with challenges associated with aging becoming increasingly prominent. The growing trend of population aging in recent years has resulted in a continuous rise in the demand for elderly care services, making elderly care facilities a focal point of social attention. According to the Overview of the Elderly Care Industry Development in the Yangtze River Delta Region (2021), the national strategy of YRD regional integration has encouraged the three provinces and one municipality to actively establish institutional environments conducive to the development of the elderly care industry. This strategy has fostered innovation in the sector, positioning the YRD as a leading region for elderly

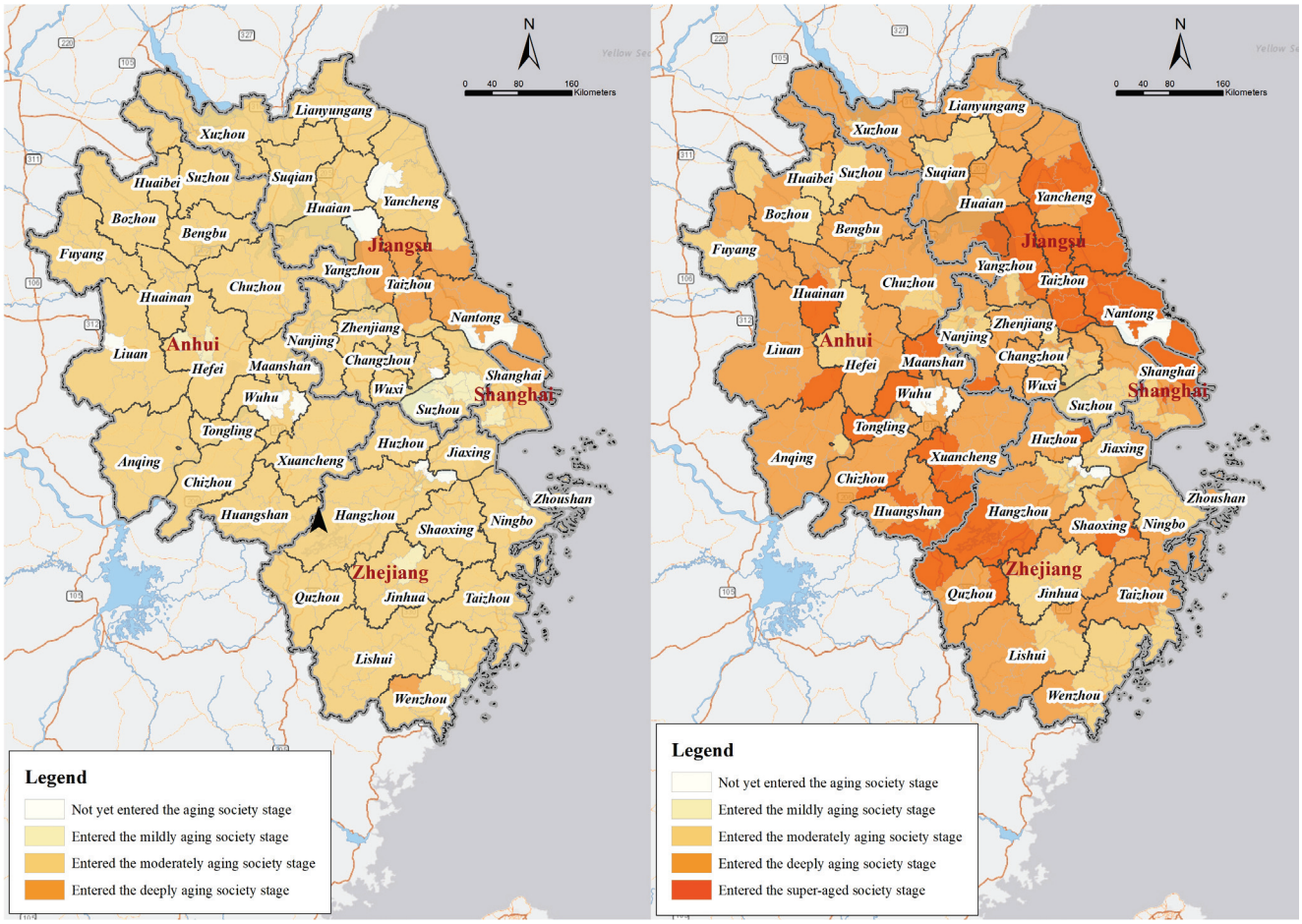
care industry development in China. In China's administrative hierarchy, the highest level includes provinces and municipalities. Below this are prefecture-level cities. These cities are further divided into counties and districts. Counties are generally rural administrative units, while districts are urban subdivisions within prefecture-level cities or municipalities.



Figure 3. Map of the Yangtze River Delta study area (based on National 146 1:1,000,000 Basic Geographic Data) (https://www.getwemap.com, accessed on 18 July 2024).

China's population census data are systematically collected by the National Bureau of Statistics to provide comprehensive insights into the country's demographic characteristics, structure, distribution, and socio-economic features [61]. Since the first national census in 1953, China has conducted seven censuses, typically every ten years, with the 2000, 2010, and 2020 censuses being particularly notable. Population censuses are essential for accurately understanding the demographic status of China and addressing population-related and socio-economic challenges. They also serve as a critical data source for addressing population aging and supporting the country's high-quality development strategy. According to the latest data from the seventh national census, the proportion of people aged 65 and older in Shanghai, Jiangsu, Zhejiang, and Anhui provinces are 16.28%, 16.20%, 13.27%, and 15.01%, respectively. Compared to the 2010 census, the proportion of people aged 65 and older increased by 6.20%, 5.32%, 3.93%, and 4.78%, respectively. Figure 4 illustrates the aging trends in each district and

county within the YRD region, categorized into five stages (Table 1) based on the proportion of individuals aged 65 and above.



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

Figure 4. Degree of population ageing in various districts and counties in the Yangtze River Delta: (**a**) 2010 census data; (**b**) 2020 census data.

Table 1. Aging society stages.

Stage of Aging	Percentage Range
Not Yet Entered the Aging Society Stage	0–7%
Entered the Mildly Aging Society Stage	7–10%
Entered the Moderately Aging Society Stage	10–14%
Entered the Deeply Aging Society Stage	14–20%
Entered the Super-Aged Society Stage	20% and above

5. Analysis and Results

5.1. Analysis of the Spatial Distribution of Elderly Care Facilities in the Yangtze River Delta

This study employs ArcGIS to conduct a comprehensive spatial visualization analysis of elderly care facilities and their bed capacities across counties in the YRD region. Utilizing the Natural Breaks (Jenks) classification method, we stratify these indicators into five distinct levels, providing a nuanced cartographic representation that reveals subtle spatial variations in elderly care infrastructure (Figure 5). The results reveal significant inter-provincial and regional disparities in the allocation of elderly care resources. Shanghai, as the core city of

the region, exhibits a marked advantage in this regard, with the highest number of facilities and bed capacities, characterized by a concentric spatial distribution where resources are more concentrated in the central urban areas, gradually decreasing toward the outer suburbs. Jiangsu Province shows a "South Strong, North Weak" pattern, with the southern cities like Suzhou, Wuxi, and Nantong having a high density of elderly care facilities and beds, while the northern cities such as Xuzhou, Suqian, and Lianyungang have fewer facilities and beds, reflecting regional developmental imbalances. This highlights the dominance of southern Jiangsu in elderly care resource allocation while also underscoring the internal disparities within the province. In Zhejiang and Anhui, elderly care resources follow a "North Strong, South Weak" distribution. In Zhejiang, northern cities such as Hangzhou and Ningbo have a high concentration of facilities and beds, while regions like Lishui and Quzhou in the west are comparatively underdeveloped, aligning with the province's regional economic disparities. Similarly, in Anhui, the northern cities such as Suzhou, Fuyang, and Bozhou have relatively dense elderly care resources, while the southern cities like Huangshan, Chizhou, and Anqing face a scarcity of such resources.

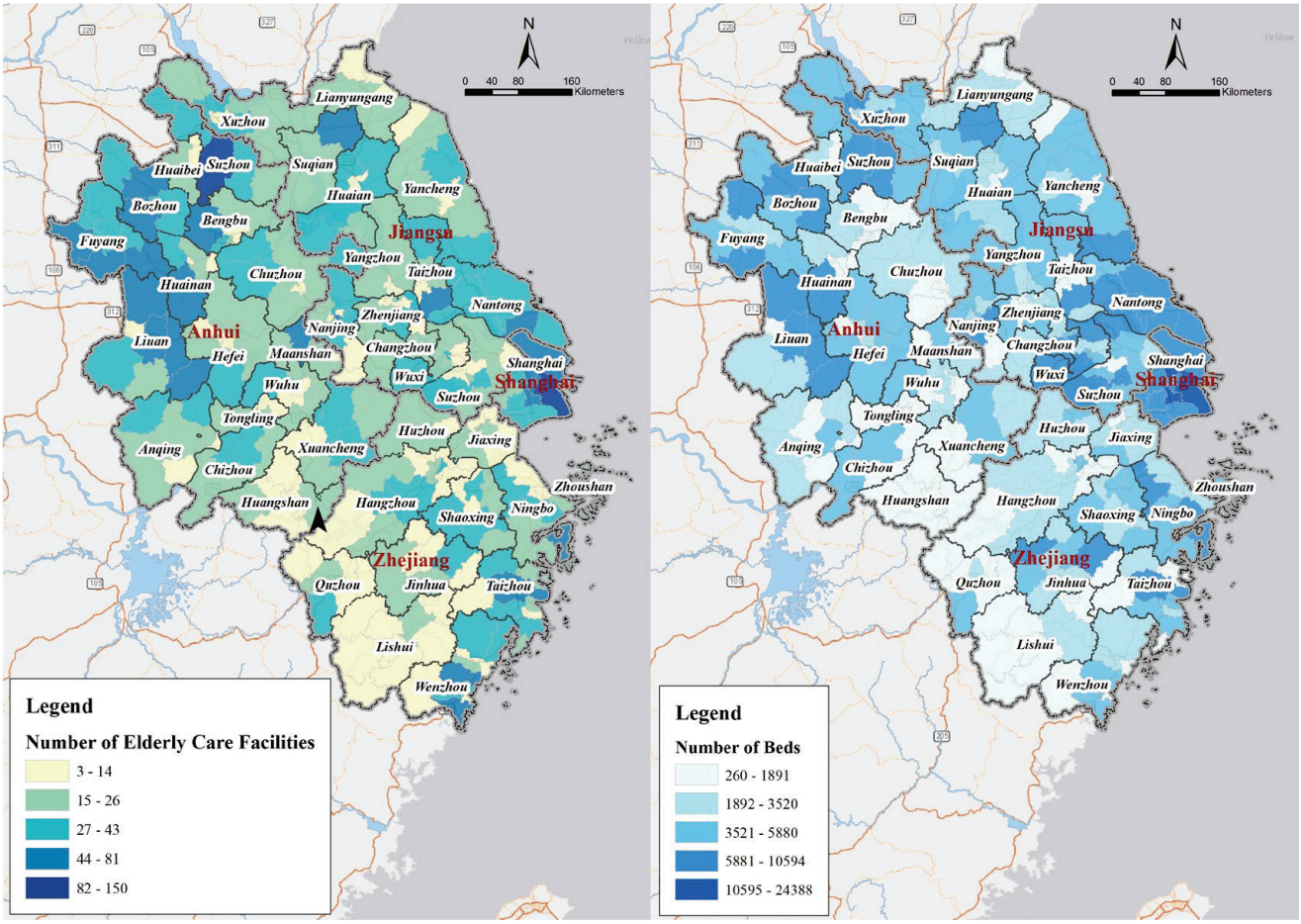


Figure 5. Spatial distribution of the number of elderly care facilities (ECF) and beds in the Yangtze River Delta in 2020: (**a**) Spatial distribution of the number of elderly care facilities in the Yangtze River Delta, (**b**) spatial distribution of the number of beds in the Yangtze River Delta.

Further analysis of the spatial distribution of elderly care resources across 41 cities in the region (Figures 6 and 7) reveals marked urban–rural disparities. In Shanghai, elderly

care resources are predominantly urban-oriented, with a concentration of facilities in central and suburban urban areas where individual facility sizes are larger, while rural areas in the outer suburbs have fewer and smaller facilities. In Jiangsu, the southern region is dominated by urban facilities, while the northern region exhibits a more balanced urban–rural distribution, with smaller facilities overall. Zhejiang displays a regional gradient in resource allocation, with developed cities like Hangzhou and Ningbo leading in the number and size of elderly care facilities, while less developed areas like Lishui and Quzhou have more rural facilities, though their scale is smaller. Anhui's distribution is notably rural-centric, with rural elderly care facilities predominating in cities such as Lu'an, Wuhu, Anqing, and Huangshan, and in some areas, rural bed numbers even exceed those in urban areas.

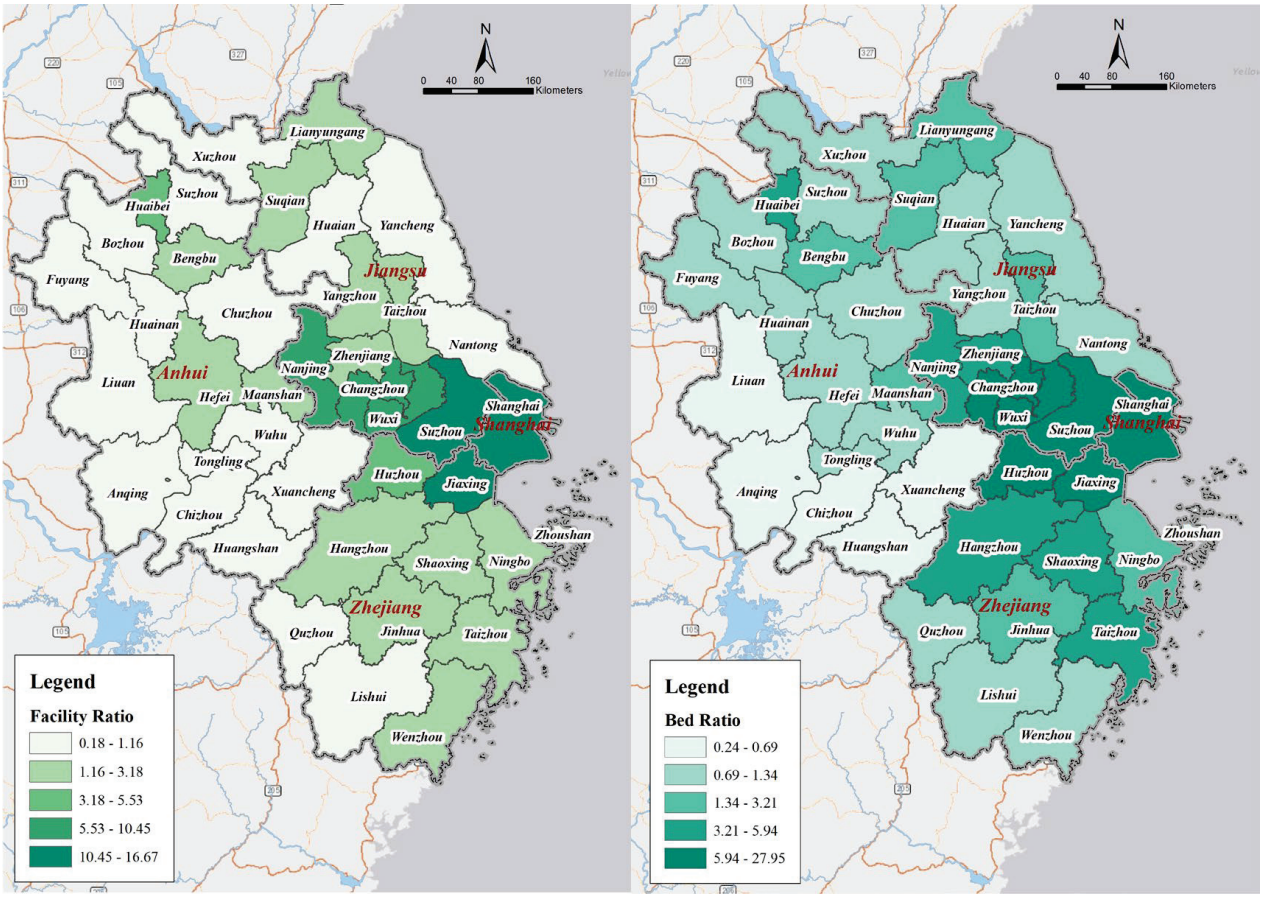


Figure 6. Spatial distribution of urban–rural ratios of elderly care facilities and beds in the Yangtze River Delta: (**a**) Elderly care facilities, (**b**) beds.

To further explore the spatial distribution and development characteristics of elderly care facilities in the YRD from a macro perspective, global spatial autocorrelation and nearest neighbor index analyses were conducted. As shown in Table 2, the global Moran's I index is 0.51, statistically significant at the 99% confidence level, indicating a spatial clustering pattern of elderly care facilities. To examine changes in clustering or dispersion over different time periods, the spatial distribution data of elderly care facilities were extracted based on the timing of three population censuses, focusing on 2000, 2010, and 2020. Nearest neighbor index analysis was performed for each of these years (Table 3). From 2000 to 2010, the nearest neighbor index rose from 0.86 to 0.89, indicating

a trend toward greater dispersion of elderly care facilities during this period. However, from 2010 to 2020, the nearest neighbor index decreased from 0.89 to 0.76, showing a shift toward greater clustering. By 2020, the nearest neighbor index further dropped to 0.76, suggesting that elderly care facilities began to concentrate significantly in certain areas.

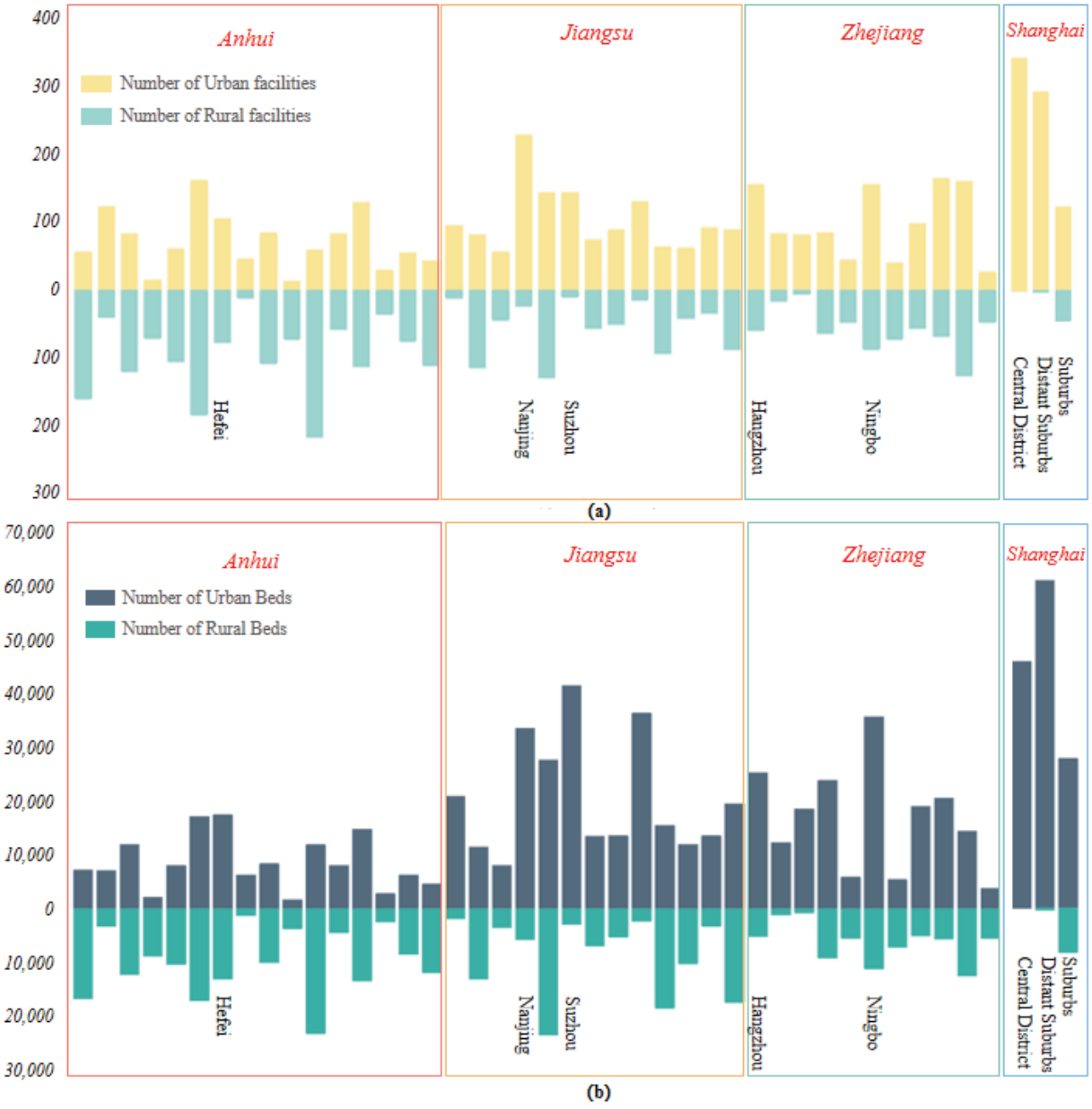


Figure 7. Comparison of urban–rural elderly care facilities and beds in the Yangtze River Delta: (**a**) Elderly care facilities, (**b**) beds(each rectangle corresponds to a specific second-tier administrative division, such as cities or districts, depending on the provincial structure).

Table 2. Global Moran's Index calculation results (99% confidence level).

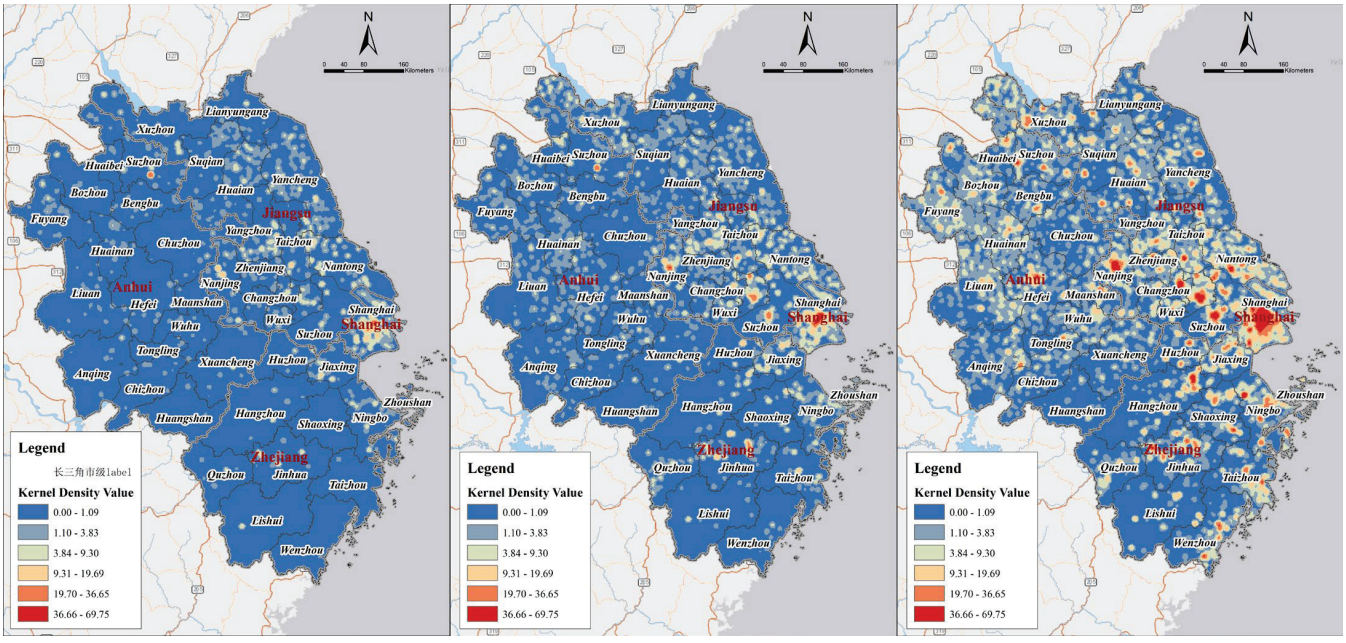
Category Value	Value
Moran's I	0.51
Z-Value	11.99
p-Value	<0.001

Table 3. Nearest neighbor index for different years.

Year	NNI	Z-Value	*p*-Value
2000	0.86	−8.61	<0.001
2010	0.89	−10.49	<0.001
2020	0.76	−38.90	<0.001

5.2. Analysis of Spatiotemporal Evolution Trends of Elderly Care Facilities in the Yangtze River Delta

Employing a Gaussian kernel function for kernel density estimation, this study meticulously analyzes the spatiotemporal dynamics of elderly care facility development, revealing the evolution and migration of hotspots across different periods. The results of the kernel density analysis are shown in Figure 8. From 2000 to 2020, the spatial distribution of elderly care facilities experienced a significant evolution. In 2000, high-density areas for elderly care facilities were mainly concentrated in Shanghai and its surrounding areas. By 2010, elderly care facilities began to expand to other cities in the YRD, especially in cities such as Suzhou and Nanjing, where the density increased. By 2020, the spatial distribution of elderly care facilities had further expanded, with high-density areas no longer limited to Shanghai and its surrounding cities. More cities in the YRD, such as Hefei and Nanjing (provincial capitals), as well as the Su-Xi-Chang metropolitan area (the urban agglomeration centered around the cities of Suzhou, Wuxi, and Changzhou in Jiangsu Province, China, which are closely interconnected in terms of economic, transportation, and social activities), had developed high-density zones. The distribution in northern Anhui and coastal areas in eastern Zhejiang had also increased significantly. Although the distribution improved, imbalances remained, with some remote areas, such as Huangshan and Lishui in Zhejiang, still facing insufficient elderly care services.



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

Figure 8. Kernel density analysis of elderly care facilities from 2000 to 2020: (**a**) 2000, (**b**) 2010, (**c**) 2020.

To better understand the expansion range and evolutionary direction of elderly care facility distribution, this study uses the standard deviation ellipse method to analyze elderly care facilities between 2000 and 2020. As shown in Figure 9, the region has undergone a

significant spatial restructuring. In terms of the evolution of the spatial center of gravity, the center point of facilities shows a clear trend of southeastward migration. From 2000, when the facility center was around the Nanjing area, it gradually moved southeastward, and by 2020, it had shifted to the Zhenjiang–Changzhou urban belt. This migration reflects the development trend of the core region of the YRD and also demonstrates how the spatial layout of elderly care facilities responds to regional socio-economic development levels. From the shape changes of the standard deviation ellipse, the range of the ellipse shows a continuous contraction from 2000 to 2020, but it has always maintained a northwest–southeast-oriented axis. The distribution range was widest in 2000, with a high elongation ratio of the ellipse, indicating a more scattered spatial distribution of elderly care facilities in the early period. The ellipse area gradually shrank over time, and by 2020, a more concentrated spatial pattern had formed. This evolutionary feature reveals that the spatial organization of elderly care facilities is shifting from a dispersed model to a more concentrated one, gradually forming an intensive layout centered around regional core cities.

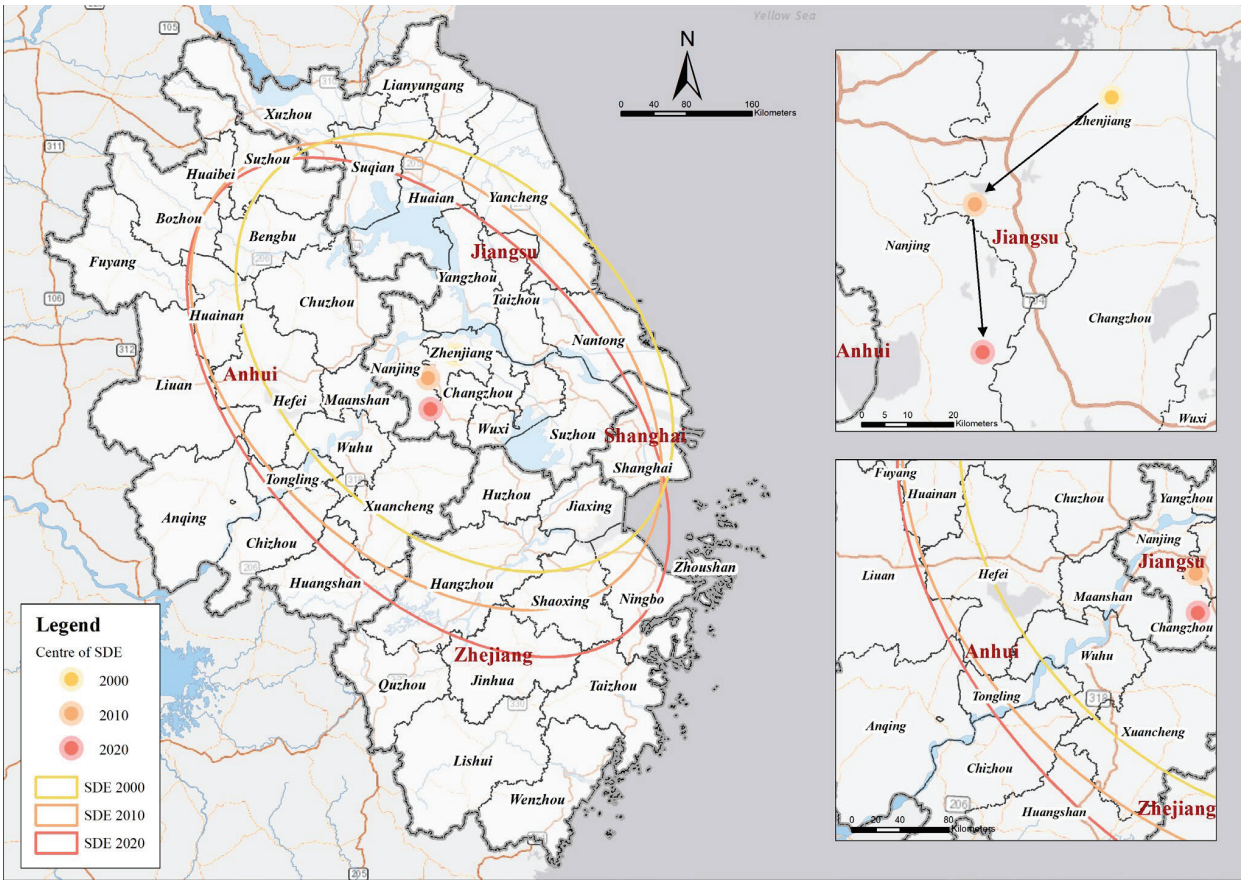


Figure 9. Standard deviation ellipse analysis of elderly care facilities from 2000 to 2020.

The study also provides a statistical analysis of elderly care facilities of different scales over time (Figure 10). The data show significant changes in the scale structure of elderly care facilities in the YRD between 2000 and 2020. The proportion of small-scale elderly care facilities (0–99 beds) increased from about 33% in 2000 to around 42% in 2020, a rise of 9 percentage points. The proportion of medium- and large-scale facilities (200 beds and above) remained relatively stable, maintaining around 25% over the 20-year period. Meanwhile, the proportion of medium- and small-scale facilities (100–199 beds) decreased

from about 32% in 2000 to around 26% in 2020, a decline of 8 percentage points. This shift indicates a structural adjustment in the elderly care facilities in the YRD, transitioning from large institutions dominating the sector to a greater prevalence of smaller facilities.

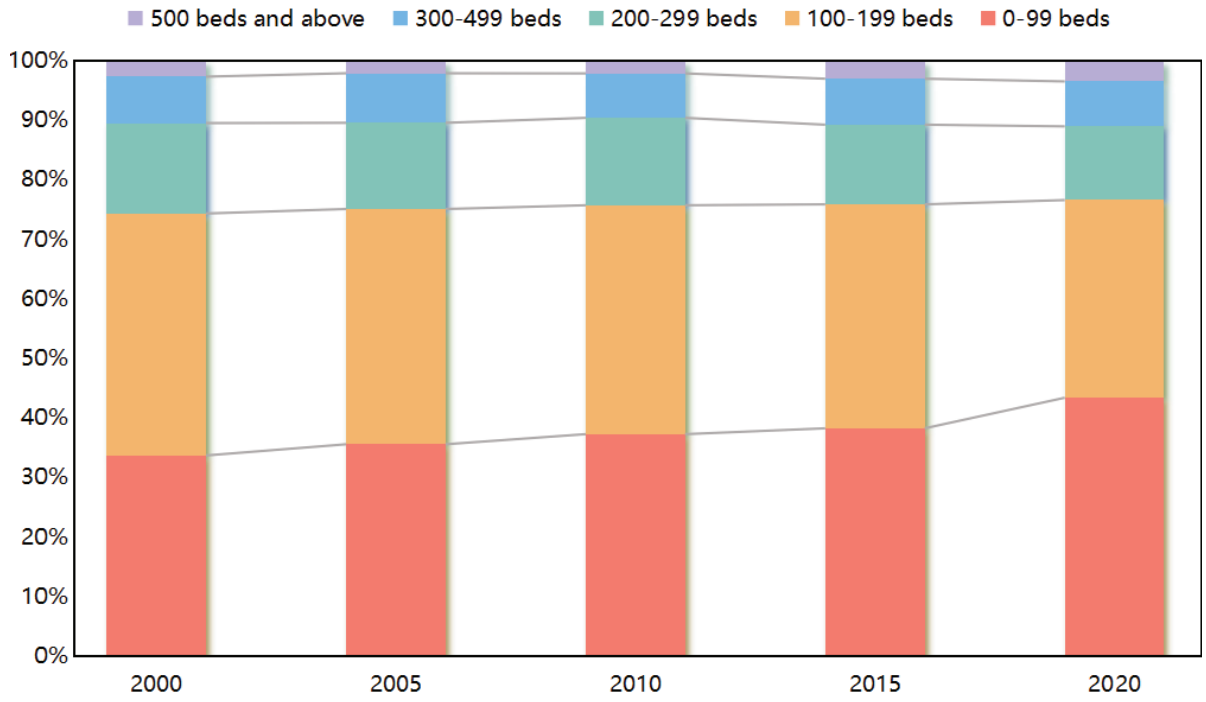


Figure 10. Changes in the percentage of elderly facilities by size.

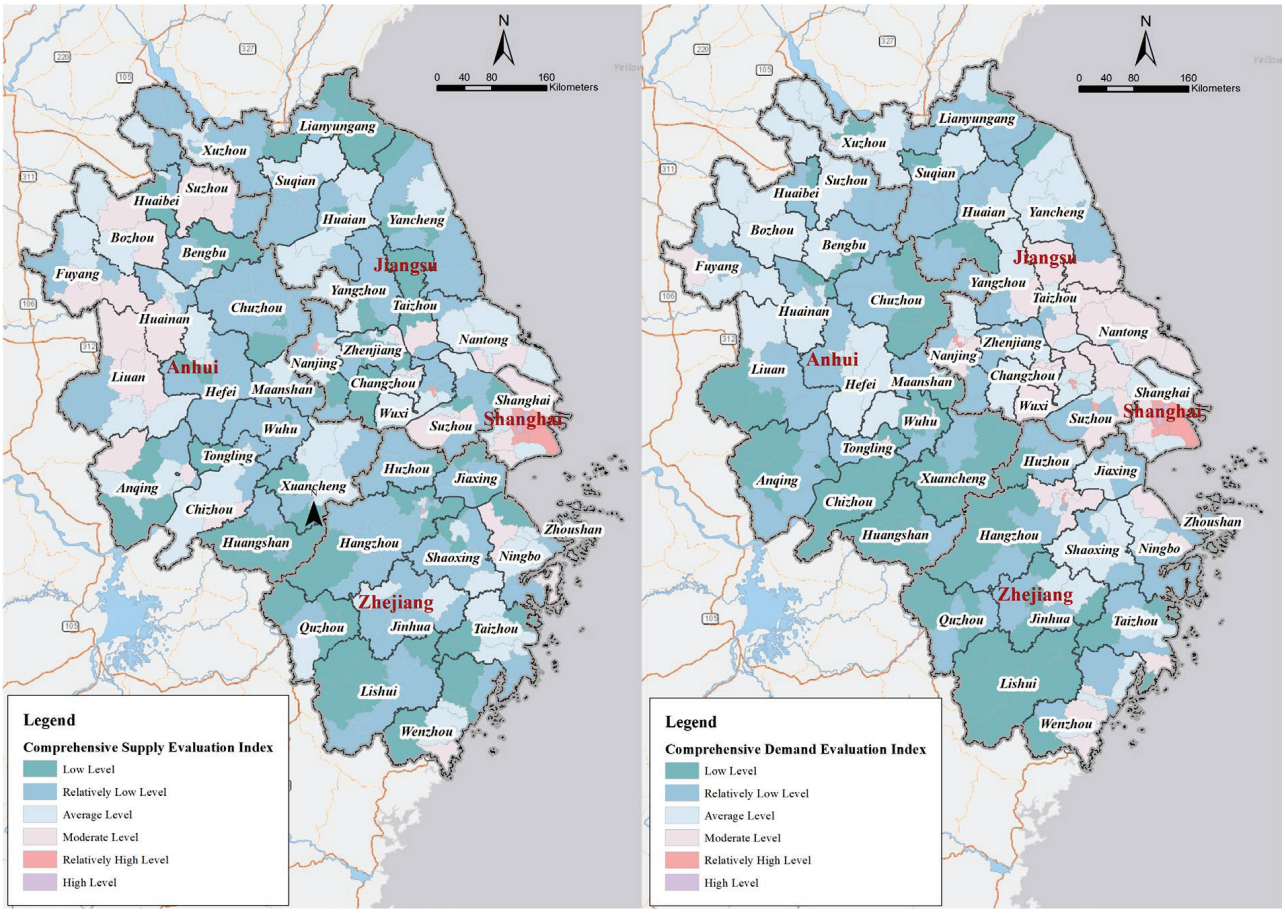
5.3. Discussion-Coupling Coordination Degree of Supply and Demand for Elderly Care Services in the Yangtze River Delta

To investigate the balance between the supply and demand of elderly care facilities in the YRD, this study conducts a supply–demand matching analysis of these at the county level for the year 2020. The evaluation indicators were divided into two subsystems: supply and demand. Using the entropy method to determine the weight of each indicator and following principles of scientific validity, data availability, and systematization, a coupling evaluation index system for the supply and demand of elderly care services in the YRD was constructed, as shown in Table 4. The coupling coordination model was employed to calculate the comprehensive evaluation indices of elderly care service supply and demand levels, as well as the coupling coordination index for 306 counties and districts in the YRD. This model provides a quantitative measure of the degree of coordination between the supply and demand for elderly care facilities across the region.

Table 4. Supply and demand indicators for elderly care facilities services.

System Layer	Primary Indicator	Secondary Indicator	Indicator Attribute	Weight
Supply	Elderly Care Facilities	Number of Elderly Care Facilities	+	0.12
		Number of Elderly Care Beds	+	0.12
		Number of Elderly Care Beds per 1000 People	+	0.07
		Density of Elderly Care Facilities	+	0.69
Demand	Elderly Care Facilities	Elderly Population	+	0.13
		Proportion of Elderly Population	+	0.06
		Density of Elderly Population	+	0.72
	Traffic	Road Network Density	+	0.09

The spatial distribution of the comprehensive supply and demand indices for elderly care facilities in the YRD reveals significant disparities in supply–demand matching across the region (Figure 11). Overall, the level of elderly care service supply is relatively low and unevenly distributed. High supply index areas are primarily concentrated in the northern Anhui region and a few economically developed cities and their surrounding areas along the southeastern coast, with scattered distribution in central areas. Most regions exhibit relatively low supply indices. In comparison, high-demand index areas are more concentrated, especially in the eastern coastal and certain inland regions, where the demand for elderly care services is higher and more concentrated.

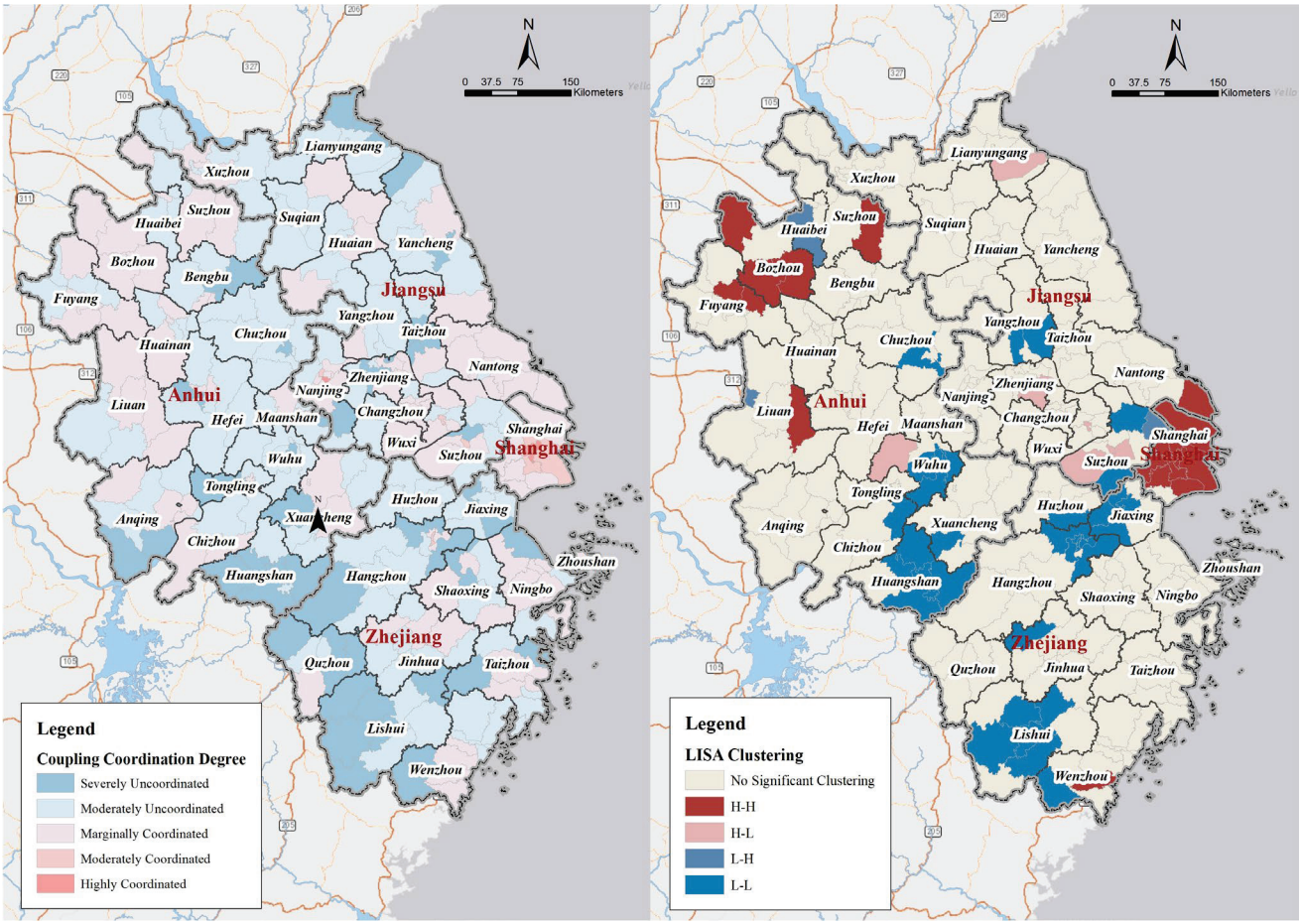


(**a**) (**b**)

Figure 11. Supply and demand index of elderly care facility services in the Yangtze River Delta: (**a**) Comprehensive supply evaluation index (CSEI), (**b**) comprehensive demand evaluation index (CDEI).

From the perspective of supply–demand coupling coordination, the overall coordination degree of elderly care facilities in the YRD is relatively low, with significant spatial variation in the types of coupling coordination between elderly care demand and facility supply (Figure 12). Severely uncoordinated areas are concentrated in the southwestern part of the region, forming a band-like pattern, particularly in western Huangshan (Anhui) and western Lishui (Zhejiang), which are characterized by mountainous terrain and poor transportation. Moderately uncoordinated areas are more widespread, primarily located in central parts of the YRD. Marginally coordinated areas are mainly concentrated in the southeastern coastal region and the northwestern part of the YRD. The southeastern coastal areas include cities like Nantong and the Suzhou-Wuxi-ChangzhouSu-Xi-

Chang metropolitan area, while the northwestern areas include southern Bozhou, southern Fuyang, and northern Lu'an. Moderately coordinated areas are relatively few and scattered, mainly found in urban districts such as Pudong, Baoshan, and Minhang in Shanghai; Gulou in Nanjing; Gusu in Suzhou; Liangxi in Wuxi; and Shangcheng and Xiacheng in Hangzhou. Highly coordinated areas are sparsely concentrated in the core region of Shanghai. Based on local autocorrelation analysis, it can be observed that both H-H and L-L clusters exhibit significant spatial agglomeration characteristics. H-H clusters are primarily concentrated in the entire Shanghai area and the core of Nanjing, forming contiguous clusters. These regions are economically developed, have convenient transportation, and exhibit a well-coordinated development of elderly care services and demand. In contrast, L-L clusters are relatively concentrated in peripheral areas with relatively underdeveloped economies, poor transportation, and a location far from the center of the YRD, such as Huangshan and Lishui. H-L (high-low) and L-H (low-high) clusters are relatively rare and do not form significant spatial clusters, mainly appearing near the H-H and L-L cluster areas.



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

Figure 12. Coupling coordination of supply and demand for elderly care facility services and LISA clustering in the Yangtze River Delta in 2020: (**a**) Coupling coordination of supply and demand, (**b**) LISA (Local Indicators of Spatial Association) clustering.

6. Discussion

The spatial distribution of elderly care facilities in the YRD exhibits significant regional differentiation, reflecting disparities in regional economic development as well as

inefficiencies in elderly care resource allocation. The metropolitan cluster centered around Shanghai demonstrates a notable concentration of elderly care resources, driven primarily by the city's role as a national economic center, enhancing its capacity for population aggregation and service provision. However, such a concentrated distribution pattern also reveals a pronounced "Matthew Effect" [62] in resource allocation, whereby economically developed areas attract a disproportionately high share of high-quality elderly care resources, leaving less-developed regions unable to effectively meet the growing service demands. Addressing this imbalance necessitates systematic adjustments through regional coordination strategies aimed at optimizing elderly care service allocation on a broader spatial scale. From an urban–rural perspective, the elderly care facility distribution presents a clear dual structure, with distinct development pathways emerging across provinces and cities. Shanghai and southern Jiangsu primarily feature urban-oriented elderly care facilities, indicative of a highly urbanized area's preference toward institution-based elderly care service systems. In contrast, Anhui Province exhibits a higher proportion of rural elderly care facilities, reflecting the continuation of traditional family-based and rural collective care models. These urban–rural differences illustrate not only varying stages of socio-economic development but also underscore the diversity in elderly care provision shaped by regional cultural traditions, lifestyles, and institutional practices. Therefore, future elderly care service planning should adhere to the principle of localized adaptation, balancing urban–rural developmental stages and integrating local cultural traditions to foster differentiated and specialized care models.

From a temporal perspective, the spatial evolution of elderly care facilities in the YRD demonstrates distinct developmental phases. Between 2000 and 2010, elderly care facilities exhibited a dispersed spatial pattern, reflecting widespread initial investment and broad infrastructure establishment in elderly care service development. Between 2010 and 2020, however, the distribution shifted toward increasing centralization within urban core areas, indicating an advanced stage characterized by resource integration and efficiency enhancement. This evolutionary trajectory aligns with general developmental logic observed in public service facilities and highlights an ongoing trend towards the professionalization and scaling-up of elderly care services. Nevertheless, excessive centralization may inadvertently exacerbate regional disparities in resource redistribution, underscoring the necessity for policies to enhance service protection mechanisms targeting peripheral areas and vulnerable populations, thus balancing efficiency-driven goals with equity-oriented objectives. Additionally, shifts in the scale and structure of elderly care facilities highlight transitions in service models. The rising prominence of small-scale and community-based elderly care facilities reflects the increasing popularity of the "aging-in-place" concept and growing demand for personalized, refined elderly services. While this trend enhances accessibility and convenience for elderly residents, it also poses new challenges, such as reduced operational efficiency and increased difficulties in standardizing service quality. Consequently, future optimization of elderly care systems must carefully balance intimacy and accessibility of community-based care with operational efficiency and service standardization through targeted policy guidance and technological support.

Examining supply–demand relationships, significant regional disparities characterize the spatial match between elderly care facility supply and elderly population demand in the YRD region. High-supply areas are concentrated in economically developed southeastern coastal regions and parts of northern Anhui; the former benefit from abundant financial and human resources, while the latter enjoy preferential policy support and local investments. In contrast, demand for elderly care services is primarily concentrated in eastern coastal regions and certain inland areas with high aging populations, closely linked

to demographic characteristics and urbanization processes. This study identifies three distinct patterns of spatial coordination between elderly care facility supply and demand. Severely unbalanced areas mainly occur in remote mountainous or peripheral regions with poor transportation infrastructure, highlighting the constraint of infrastructure limitations on service accessibility. Moderately unbalanced areas are widespread across the region, indicating an ongoing developmental phase of the elderly care system, with significant potential for improvement in overall coordination efficiency. Highly coordinated areas, meanwhile, are primarily centered around major urban cores like Shanghai, reflecting the institutional and systemic advantages possessed by economically advanced regions in integrating and optimizing elderly care services.

Further analysis using local spatial autocorrelation reveals significant clustering in supply–demand coordination. High-High (H-H) clusters—areas characterized by both high supply and high demand—predominantly occur in economically developed, well-equipped regions, effectively meeting diverse elderly care needs. Conversely, Low-Low (L-L) clusters—areas with both low supply and low demand—are typically found in resource-deficient regions with lower rates of aging, facing dual pressures from insufficient resource investment and gaps in service coverage. The interwoven distribution of High-Low (H-L) and Low-High (L-H) clusters illustrates transitional spatial mismatches in supply–demand relationships. These "potential mismatch zones" suggest that targeted policy interventions are necessary to enhance service efficiency and spatial equity in elderly care provision precisely.

7. Conclusions

This study, based on the perspective of information geography, takes the YRD region as the research subject. Using methods such as information collection, GIS spatial analysis, and statistical modeling, the study systematically analyzes the spatial distribution characteristics, evolution path, and supply–demand matching pattern of elderly care facilities in the YRD. It constructs a comprehensive analysis framework integrating "spatial differentiation–evolution characteristics–supply–demand coupling." The study finds that elderly care facilities in the YRD exhibit significant regional differences and stage-specific evolution characteristics. There is a spatial mismatch and uneven coordination between supply and demand, providing empirical evidence for regional elderly care policy formulation and optimization of elderly care resource allocation. Based on the findings and theoretical framework, we propose the following conclusions and policy recommendations:

1. Uneven spatial distribution of elderly care facilities and significant regional differences: Elderly care facilities in the YRD region exhibit a clear urban–rural dual distribution, with a high density in urban areas and a shortage in suburban and rural areas. This creates a "center-periphery" spatial structure, reflecting the imbalances in resource distribution observed globally and regional development theories on resource tilt and policy selectivity. To address this spatial imbalance, we recommend implementing targeted policy interventions including (a) establishing financial incentives and subsidies specifically for rural elderly care facility development; (b) creating cross-regional elderly care service networks that enable resource sharing between urban and rural areas; and (c) developing integrated transportation systems to improve accessibility to existing facilities for rural elderly populations. Additionally, the observed shift toward smaller, community-based facilities represents a positive development that can partially mitigate the center-periphery imbalance by bringing care services closer to where elderly people live.

2. Spatial mismatch and coordination imbalance between supply and demand of elderly care facilities in the YRD: There is a significant spatial misalignment between the high-demand elderly population areas and the supply of elderly care facilities, particularly

in urban–rural fringe and rural areas with severe aging. This mismatch reduces service efficiency and exacerbates accessibility issues for elderly groups. To address this challenge, we recommend implementing a multi-scale precise allocation and supply–demand matching mechanism to optimize resource distribution. Specific measures include establishing a real-time monitoring system for elderly population density and care demand to dynamically guide facility layout optimization, formulating differentiated regional elderly care policies to prioritize resource allocation in severely aging areas, and introducing intelligent demand forecasting models to enable proactive allocation of elderly care resources, thereby enhancing service accessibility and equity.

From an international perspective, the findings of this study align with the welfare geography views proposed by Pinch [63] and Smith [64] and the spatial justice theories of Soja [65] and Harvey [66], which state that the distribution of public service facilities is often positively correlated with socio-economic status, resulting in unequal spatial distribution of resources. The observed phenomenon of elderly care facility agglomeration in urban core areas is consistent with these theories, and the uneven distribution of elderly care facilities reflects inequality in spatial resource allocation. This theoretical framework helps explain why elderly care services are more advanced in economically developed areas. By drawing on the path dependency theory of Martin and Sunley [67], we find that the spatial distribution pattern of elderly care facilities in the YRD is profoundly influenced by historical development trajectories and institutional inertia, explaining why the supply model is slow to adjust despite changes in demand.

Based on the research findings, the following recommendations are proposed to address the issues of large-scale aging and supply–demand imbalance in the Yangtze River Delta region. Firstly, it is crucial to strengthen regionally coordinated development by establishing a cross-regional elderly care resource-sharing mechanism, focusing on supporting the construction of elderly care facilities in underdeveloped areas to reduce provincial and urban–rural gaps. This could be achieved by learning from the EU's regional balanced development policies [68] and Australia's cross-regional resource-sharing models [69]. Secondly, the elderly care service system should be improved by promoting the professionalization and scaling-up of services while also actively supporting the development of small, community-based elderly care facilities and enhancing the integration of urban and rural services. This can be achieved by adopting the Nordic "continuum of care" [70] model and Japan's "community-inclusive care system" [71] to build a multi-level elderly care network covering community, home, and institutional services. Finally, technology should be leveraged to enhance elderly care services by establishing a smart elderly care platform that integrates big data, the Internet of Things, and artificial intelligence. Drawing on Singapore's "smart nation" [72] initiatives and South Korea's remote care systems [73], information technology should be deeply integrated into elderly care to address spatial distribution gaps and improve both temporal and spatial accessibility of services.

As one of the six globally recognized world-class metropolitan areas, the elderly care service system and development model in the Yangtze River Delta region provide diverse solutions for global aging governance, especially suitable for densely populated and rapidly urbanizing Asian countries and developing countries undergoing economic transformation. In the future, its regional collaboration mechanism and smart elderly care model can be further promoted, offering a Chinese solution to the global challenge of aging.

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Towards Equitable Representations of Ageing: Evaluation of Gender, Territories, Aids and Artificial Intelligence

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Abstract: There are few studies on the representation of older people regarding aids and assistive devices and even fewer that incorporate more inclusive views (gender, emotions, anti-ageist, territorial or land approach) as well as virtual or land ethnography or artificial intelligence. The general objective was to evaluate digital images of aids and assistive aids in the older population, from the perspectives mentioned above. Method. A descriptive and cross-sectional study that searched, observed and analyzed images. An evaluation of intentionally selected images from Freepik, Pixabay, Storyblocks, Splitshire, Gratisography and ArtGPT, included in an original database constructured by several authors of this article, was carried out in the context of the ENCAGEn-CM project (2020–2023, financed by the CAM and FSE). This base was updated and expanded in October and November 2023. In addition, an image generation process was carried out using artificial intelligence, and this was also part of the analysis (ArtGPT). Finally, algorithms were used to solve and retrain with the images. Results. Of the total final images included in the expanded database until November 2023 (n = 427), only a third (28.3%, 121/427) included the aids and assistive aids label. Representations of mixed groups predominated (38.8%) and, to a lesser extent, those of women. A large proportion of the devices were 'glasses' (74.6%) and the 'use of a cane' (14.9%). To a lesser extent, 'wheelchairs' (4.4%) or 'hearing aids' (0.9%) and the presence of more than one device (simultaneously) (5.3%) were noted. The main emotions represented were 'joy' (45.6%) and 'emotion not recognized' (45.6%), with, to a lesser extent, 'sadness' (3.5%), 'surprise' (4.4%) and 'anger' (0.9%). Differences by sex were found in the represented emotions linked to aids and assistive aids. The representation of images of the built environment predominated significantly (70.2%), and it was observed that older women were less represented in natural environments than men. Based on the previous findings, a method is proposed to address stereotypes in images of older individuals. It involves identifying common stereotypical features, like glasses and hospital settings, using deep learning and quantum computing techniques. A convolutional neural network identifies and suppresses these elements, followed by the use of quantum algorithms to manipulate features. This systematic approach aims to mitigate biases and enhance the accuracy in representing older people in digital imagery. Conclusion. A limited proportion of images of assistive devices and older people were observed. Furthermore, among them, the lower representation of images of women in a built environment was confirmed, and the expressions of emotions were limited to only three basic ones (joy, sadness and surprise). In these evaluated digital images, the collective imagination of older people continues to be limited to a few spaces/contexts and emotions and is stereotyped regarding the same variables (sex, age, environment). Technology often overlooks innovative support tools for older adults, and AI struggles in accurately depicting emotions and environments in digital images. There is a pressing need for thorough pretraining analysis and ethical considerations to address these challenges and ensure more accurate and inclusive representations of older persons in digital media.

Keywords: older people; aids and assistive devices; technologies; artificial intelligence; quantum computing; image evaluation; land; environment/space; gender; intersectionality; ageism; emotions

1. Introduction

According to the latest World Population Prospects report, it is estimated there were 771 million people aged 65 or over worldwide in 2022. Moreover, the proportion of the world population in this age range will increase from 10% in 2022 to 16% in 2050 [1], which constitutes both a social success and a future challenge for current policies. Moreover, this demographic change and the factors contributing to it require attention in terms of developing public and social policy within this paradigm. How can we maintain healthy and active lifestyles for people during the ageing process? This continues to be one of the basic pillars in the development of public and social policy [2] for the older population with the maximum quality of life (QoL) and for society. Moreover, there are variations between continents, but, in terms of life expectancy, older women globally outnumber men in almost all populations [1], which is impacting social roles and policies, leading to a more inclusive vision with a gender and anti-ageist perspective. The factors that have mainly contributed to this demographic change and healthy ageing are progress in research in health sciences and biotechnology; greater knowledge of diseases and the drugs and therapies used to treat them; and the latest advances in technology and health devices. However, it should not be ignored that older women continue to be largely forgotten in terms of the roles and stereotypes that are common in this population group. This is mainly because they represent a social group with biased roles in caring for family members, and, because of technology, there is still an incipient digital divide in those who are older or very old. This bias remains latent in society.

In the context of technology, there are hundreds of devices and products focused on improving the QoL and well-being of people. However, many of these products present significant difficulty for older people—on the one hand, in relation to their cost–benefit ratio, and, on the other, in terms of accessibility and usability. This is in addition to the incipient digital divide within the older and very old population. For these reasons, even today, common aids and assistive devices usually cover a wide range of devices and tools designed to assist individuals in various aspects of daily living, mobility and health management—for example, walking sticks, wheelchairs, glasses and earphones. These types of aids are a focus point in public policy guidelines, since they can provide improvements in different QoL dimensions [3], which should be evaluated from a comprehensive, accessible, inclusive and intergenerational perspective. Therefore, new and emerging technologies that enhance ageing are designed mainly for activities of daily living, personal health or safety, mobility, communication and physical activity, which can facilitate independence in the home [4].

However, the use of the phrase 'health support technology' is often confused with the use of mobile phones and apps, which do not always effectively compensate for or alleviate illnesses or disabilities. This confusion can lead to unrealistic expectations about the capabilities of such technologies. Moreover, recent advancements in artificial intelligence (AI) have expanded its application in various fields. AI is now used to generate algorithms for aids and assistive devices, as well as to create chatbots designed to assist individuals and generative AI models that provide information about the ageing process. While these technologies may not always have a direct focus on health, they significantly influence health representation and can contribute to stereotyping [5]. For instance, AI-driven tools might inadvertently reinforce negative stereotypes about ageing by portraying older adults in a limited or negative light. This can shape public perception and contribute to a more negative collective imagination about ageing and older persons. Addressing these issues requires a careful, inclusive approach to designing and implementing health support technologies, ensuring that they promote positive and accurate representations of ageing and support the diverse needs of older adults.

Specifically, the way in which older people and their environment are represented through social images constitutes a central axis in reflections on old age and impacts the formation of stereotypes and generalized discrimination against older people. This representation is crucial because it shapes societal perceptions and attitudes towards older adults. When media and social images predominantly depict older individuals as frail, dependent and disengaged from society, these portrayals reinforce negative stereotypes and contribute to ageist attitudes. Such stereotypes can lead to generalized discrimination, marginalizing older adults and affecting their access to opportunities and resources.

Furthermore, age discrimination is a psychosocial problem that negatively impacts the health and well-being of older people (see [6], among other studies). Research has shown that experiencing ageism can lead to increased stress, reduced self-esteem and poorer mental and physical health outcomes. Ageist attitudes and stereotypes are pervasive across various media, with social networks being particularly influential. Social media platforms often amplify these negative portrayals, presenting older people as a homogeneous, vulnerable and powerless group [7,8]. This widespread stereotyping fosters an environment where ageist discourses thrive, further entrenching discriminatory attitudes and behaviors towards older adults.

This stereotyping not only shapes public perception but also influences policy and social attitudes towards older adults. Therefore, addressing these issues requires a careful, inclusive approach to designing and implementing technologies [5]. These technologies should promote positive and accurate representations of ageing and support the diverse needs of older adults, ensuring that they are seen as capable, diverse and valuable members of society. Furthermore, the intersection of gender perspectives with images and technologies plays a crucial role in shaping these representations. AI technologies, for instance, increasingly influence how older women are portrayed in digital media.

From a gender/sex perspective in older people, such as concepts linked to identity and how they are represented [5,9], there are antecedents based on data from digital images that have made it possible to study the presence of stereotypical images of old age with the greater presence of women [5]. These findings underscore the importance of examining how older women are depicted and the impact of these portrayals on societal perceptions and gender-based stereotypes.

The imbalance that appears in the activities attributed to men and women is notable, where women continue to appear within stereotyped roles in indoor spaces, carrying out care activities, while men carry out leisure activities in open spaces and are visible outside (see [5], among other studies). A recent review has shown the important gaps in knowledge about the representation of older people in the digital world in terms of love and sexuality, and diversity has rarely been addressed [10]. It is suggested to explore the terminology from a classic perspective, through collective or social imagination [11,12], with a positive representation of, for example, gender and older people. Although this study does not focus on exposure to social networks, there is literature on the population of older people in which the gender inequalities related to them are shown. For example, stereotypical representations and the invisibility of older people according to gender have been observed in Edström's study, which analyzes the media with the greatest presence in three different decades (1994, 2004 and 2014), indicating that men and women become almost invisible as they age, being more pronounced in older women [13]. Recently, in the case of social networks and digital platforms, discrimination against older people has also been detected in previous studies [14,15].

How older people are represented and the emotions that they express is a crucial basis on which to understand the psychosocial dimension of ageing, which has been identified by different authors, classic and recent, from the field of social psychology [16,17] with links to gender [18]. Here, significant numbers of images had no emotions represented, and, to a lesser extent, the emotions detected were sadness, surprise and anger [5]. It was also observed that there was physical contact and relational gestures in the representation of such people and the emotional states of older people [5].

The representation of older people and gender in images within a specific environment/space is of vital importance, since ageism is most manifested through the invisibility of old age, both in family and social contexts, as well as in other areas, such as nursing homes and households [19]. Furthermore, studies have shown that older people prefer their typical environments, but, when their care needs increase, they consent to be transferred to nursing homes [19] with aids and assistive aids. In this context, there is not much similar research available, with some exceptions [5,14,15,19,20] that investigate the representation of older people with health support technologies and health devices and incorporate inclusive perspectives—such as the gender, space and age approach from virtual ethnography and AI [21–23]. Moreover, digital images of older people often carry negative connotations, characterized by minimal diversity and a lack of emphasis on the positive aspects of ageing. This tendency is particularly relevant in media and advertising contexts, where depictions of old age tend to focus on negative stereotypes and aspects associated with the loss of physical and cognitive abilities [15]. This lack of diversity and the prevalence of negative representations can have a significant impact on the public perception of ageing and on the self-esteem of older persons. This means that digital images representing older people exhibit bias in aspects related to demographic shifts, disparities and equity. The latter is linked to the concepts of 'equity' and 'technology', implying an inclusive and intersectional approach in the application of technology analysis (see Figure 1).



Figure 1. Representation of concepts used to evaluate ageing images. Note: own figure.

The main objective of this study is to evaluate digital images of aids and assistive devices in the older population, from the perspectives of gender, age and location, as well as from AI. It is expected that digital representations of aids and assistive devices in the older population reflect gender and age stereotypes and that their use and accessibility vary according to the geographical location. Regarding the 'age perspective', this study specifically examines how different age groups within the older population (e.g., those in their 60s, 70s, 80s, etc.) may be portrayed differently in digital images and how these representations can reinforce or challenge existing age-based stereotypes. Regarding 'location', the research analyzes how the availability, design and depiction of aids and assistive devices vary across different geographical regions, highlighting the disparities that may exist between urban and rural areas or across different countries. Additionally, it is proposed that AI may provide new perspectives and approaches in the analysis of these images, thus contributing to a deeper understanding of the representations and needs of the older population in relation to emerging technologies.

This study is imperative due to the significant demographic shift towards an ageing population worldwide. With the number of individuals aged 65 and above projected to increase substantially by 2050, there is a pressing need to address the challenges and opportunities associated with ageing. Furthermore, the gender disparities in life expectancy and societal roles underscore the importance of adopting a more inclusive perspective that

considers the unique experiences and needs of older women. Additionally, the influence of technology, including both aids and assistive devices and emerging AI applications, on the lives of older adults cannot be overstated. However, the current landscape of technological development often overlooks the diverse needs of older individuals, perpetuating ageist stereotypes and limiting their access to beneficial resources. Therefore, a comprehensive analysis of digital images of aids and assistive devices, considering gender, age, location and AI perspectives, is essential to promote a more inclusive and accurate representation of ageing and to address the evolving needs of older populations in the digital age. By exploring these dimensions, this study aims to shed light on the existing disparities and pave the way for more equitable and effective technological solutions tailored to the diverse needs of older adults.

2. Materials and Methods

This section comprises three parts: the study design and criteria for data collection; the method; and sampling.

2.1. Study Design and Criteria for Data Collection

This descriptive and cross-sectional study was carried out from a virtual ethnography approach [21–23], based on digital images, and the dimensions and categories were explored from a gender, spatial and anti-ageing perspective, linked exclusively to aids and assistive aids [5,9,24]. This work was designed as an ad hoc study within the framework of the ENCAGEn-CM program (2020–2023) [25] to promote a positive image of old age and ageing and combat ageism.

The search and inclusion criteria used to define the analysis database were based on variables that were related to gender/sex, age, representations of images in the environment, the presence of aids and assistive devices and emotions. They were labeled according to sex, i.e., 'man' and 'woman', with a combination of groups of people where at least one man and one woman appeared or multiple people of different sexes appeared. It was also noted when the sex was not recognized. If there were more than two people of different genders/sexes in the same image, the category of 'mixed group' was assigned; when there was an image of two people, one older and one younger, the sex was recorded for both people. The inclusion criteria and a brief description are given in Table 1.

Table 1. Inclusion criteria used to select images and representations of older people and their descriptions.

Criterion	Description
Representations of the environments of older people within different spaces	The definition of the natural and built environment was taken and the categories reported in the previous literature were adapted [26,27]. Within the built environment, specific categories were defined (residential, commercial, industrial, recreational, public services, transportation, green space with human intervention, work, others), as well as for the natural environment (agricultural areas, green areas without human intervention, and aquatic spaces). In the natural dimension, meteorological data categories (sunny, cloudy, rainy, windy) were also investigated. In all cases, the category of 'not recognized' was also added.
Presence of types of aids and assistive devices	Categories related to the use of aids linked to technology were selected from 'The Survey of Health, Aging and Retirement in Europe' (SHARE). This is an international and interdisciplinary project, with the application of rigorous common procedures and protocols [28]. This variable was applied only to older people represented in the images. When two older people who had different devices were found in the same image, both or a single person were recorded, but, in the presence of more than one device, it was recorded as a combined category. The categories from the aforementioned survey were based on the following: cane, Zimmer frame/walker, manual wheelchair, electric wheelchair, stroller/scooter, special eating utensils, personal alarm, bars/grips/rails, toilet seat (raised), pads for urinary incontinence, robots, tablets, mobile phones, electric scooters. There was also the possibility for emerging categories, such as glasses or hearing aids, or combined categories, such as canes and glasses or canes and manual wheelchairs.

Table 1. *Cont.*

Criterion	Description
Emotions	Basic emotions were selected and emerging categories were possible. When the emotion could not be identified precisely, the category of 'not recognized' was assigned (for example, when a mask was worn). In the case of identifying more than one person in an image who shared the same emotion, it was recorded as one; if there were different emotions in each person but only one had a support device, the emotion linked to said device was recorded. When different emotions were perceived with the presence of devices, only in this case was it recorded as a combined emotion category. The categories of emotions that were included to be explored were the same as those followed in the previous study [5] and the previous scientific literature [16–18], and they were anger, joy, surprise, disgust, sadness and fear and an additional category of 'not recognized'.

2.2. Method

The study consisted of two stages. Stage 1 started from an original database generated by several authors of this work [5] in the context of the ENCAGEn-CM program [25] until February 2022. For this work, the database was expanded and updated until November 2023 with the inclusion of images collected in different digital repositories. Open-access databases were considered: Canva, Freepik, Gratisography, OpenPhoto, Pexel, Pinterest, Pixabay, SplitShire, Storyblocks, Unsplash and Envato. Moreover, images were generated through artificial intelligence (AI). We used the free program ArtGPT.

2.2.1. Data Collection

Overall, until November 2023, all digital images that presented any element related to age or older persons were added and other types of media, such as illustrations or videos, were excluded. A subsample was intentionally selected in which some elements linked to aids and assistive devices had been detected, which, in this work, were the central units of analysis. It should be noted that the data collection was based on free and open-access websites, i.e., those that allowed images to be viewed and downloaded and that were free of rights (Creative Commons).

For the image search, a systematic process was implemented where keywords in English and Spanish were used to generate the searches. They were the following: 'personas mayores', 'vejez', 'edadismo', 'tercera edad', 'anciano' and 'anciana', 'jubilado' and 'jubilada', 'viejo' and 'vieja', 'edad', 'envejecimiento', 'elderly, 'ageism', and 'retired people'. The same criteria as for the original database search were used [5].

The selected images were downloaded and archived in secure folders, with the purpose of mitigating the 'ephemeral' process and the risk of obtaining information that had circulated through digital environments. Moreover, the systematization of these images was carried out in a database designed for this purpose. Corresponding links and other information related to metadata and descriptive information were included.

In addition, during this process, the analysis of the individually selected images was implemented. The previously defined categories were coded through the manual technique and then analyzed quantitatively. In this classification and coding process, visual elements, images, expressions and context, among other elements, were selected.

The inter-coder reliability measure for 'emotions' was Cohen's kappa coefficient. This coefficient is commonly used to assess the degree of agreement between two or more coders when categorizing or classifying data, such as the emotions portrayed in images. Cohen's kappa coefficient helps to determine whether there is significant agreement beyond chance agreement among the coders, thus providing a measure of the reliability of the collected data. The Cohen's kappa results are also included with the results of the emotions.

For example, Figure 2 provides an example of the dataset used and shows an older woman in the foreground, in a wheelchair, with a non-recognized emotion. It is worth noting that we focused on basic and primary emotions (4, 6 or 8, according to different authors). However, if we had used secondary or advanced ones, the list would have been expanded to dozens (different numbers depending on the authors consulted). For example,

we could have included calm or tranquility (or a lack of expression, depending on how it is interpreted), and we could have assigned this to many of the images of older people. The lack of expressiveness and calmness is sometimes difficult to differentiate with only a still image. This needs to be investigated further (e.g., evaluation of videos or audiovisual media). However, this was beyond the main study's objective, which focused on still images, and remains a challenge.



Figure 2. Image of an older woman with a wheelchair in an environment shared with other people. Source: https://lc.cx/xVIuxv. Accessed on 12 August 2024.

In the case of images generated by AI, the process was carried out by a researcher trained on the ArtGPT platform during the month of November 2023, and the procedure followed the introduction of keywords of interest related to older people, gender, emotions and support devices, to generate different tests. These keywords were 'older people', 'older women', 'older men', 'older people and happiness', 'older people and quality of life', 'older people and joy', 'older people and fear, 'older people and sadness' and 'older people and technologies', among others.

Different search combinations were implemented with the aforementioned terms and it was observed that the GPT generated six images with each one (in total, 22 intersections were generated, resulting in 132 images, in two phases or batches). Several tests were carried out and in no case were they repeated.

The final combinations, which gave rise to the 10 images that were included in the database for analysis, were generated from the following 5 intersections:

- Aids and assistive devices and older people and emotions;
- Aids and assistive devices and older people and emotions/joy;
- Aids and assistive devices, technologies and older people and emotions/sadness;
- Aids and assistive devices and older people and emotions/fear;
- Aids and assistive devices and older people and emotions/anger.

To report the results, the two images that appeared first were selected (of the 5 generated by each intersection, 10 images from the previous intersections), except when the image appeared distorted. With this, the combination of the terms used was applied to obtain images generated by AI. For each combination, AI generated a total of six images, and, from these intersections, they included aids and assistive devices and older people and emotions (null or joy/sadness/fear/anger or annoyance).

During the fieldwork for this study, each search combination consistently generated 6 images, regardless of the number of variables introduced. Therefore, although a total of 30 images was produced, only the first two images from each combination were selected, resulting in a total of 10 images evaluated for the five final intersections mentioned.

The images generated through AI were obtained using two email accounts, since a maximum number of images was allowed per account. It should be noted that there was a limit to the number of images that could be accessed free of charge. In the case of exceeding this number, the AI requests a paid subscription.

From each combination of keywords, only the first two output images (of the initial six) were included since they were the ones that were most relevant to this study, and the distorted images were not included.

Another aspect to highlight is that while general criteria were used for the images from the digital repositories and when reproducing the searches of a previous study [5], more specific criteria (as mentioned above) were included in the case of AI-generated images.

2.2.2. Data Analysis

To reduce information bias, all images were reviewed at least twice by two independent researchers [22] and discrepancies were reviewed in virtual meetings within the working group.

The analysis of the final database was carried out through a descriptive analysis (absolute and relative frequencies), and a narrative analysis of the results was included to generate some initial ideas about the image generation process using AI. Images were selected to illustrate some of the dimensions of the analysis.

This study was based on an analysis of freely available digital images in web repositories, so it did not require evaluation by an ethics committee.

The total number of images included in the secondary database was n = 427 (300 initial + 117 new from the selected repositories + 10 generated by AI).

Finally, 121 images were evaluated, amounting to 28.3% of the total of 427, consisting of those where the image identified or referred to aids and assistive devices (n = 121 images) (Figure 3). The study included a descriptive statistical analysis of the images, where the results were expressed as the frequency of the number of images and their percentages.

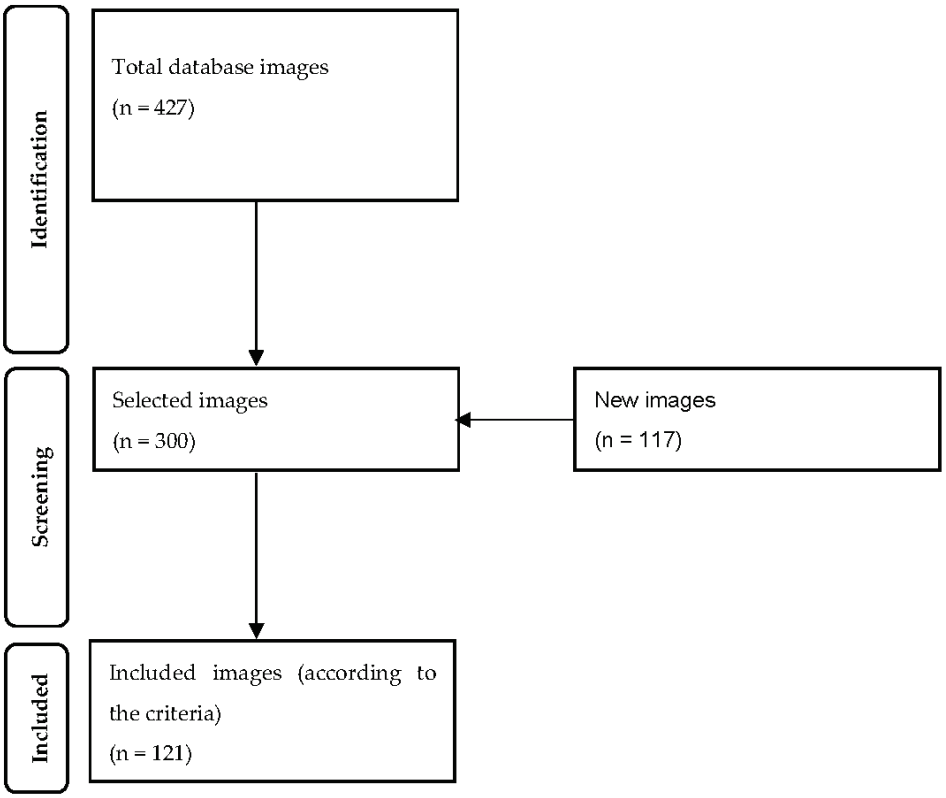


Figure 3. Data collection process according to inclusion and exclusion criteria. Note: own figure.

2.2.3. Power Analysis

The databases used had more than 11 million downloadable images. This means that if a confidence or security level (1-α) of 95% was applied, precision d = 5%, proportion p = 0.4 and expected proportion of losses R = 13.7%, the expected sample would be n = 427 images.

The minimum detectable difference between the scores was also estimated, given a sample of 300 subjects (images in this study) and power of 90%. To calculate the standardized difference between the scores, or the effect size, both the power is specified as the power (30, 40, 50, 60, 70, 80) and the sample size has the range n (100, 200, 300, 400), and both the G Power and the effect were analyzed (27). With this, the minimum detectable standardized difference given the requested power and the sample size was 0.16, which corresponded to an average score of approximately 536 and a difference between the scores of 17.

In short, a selection of 1000 images was obtained, for which it was proposed to measure the G Power and sample power [29]. To do this, the power obtained was analyzed for sample sizes from 100 to 427 when the scores increased to 100, 200, 300, 400 and 500, with a standard deviation of 117 images (Figure 4).

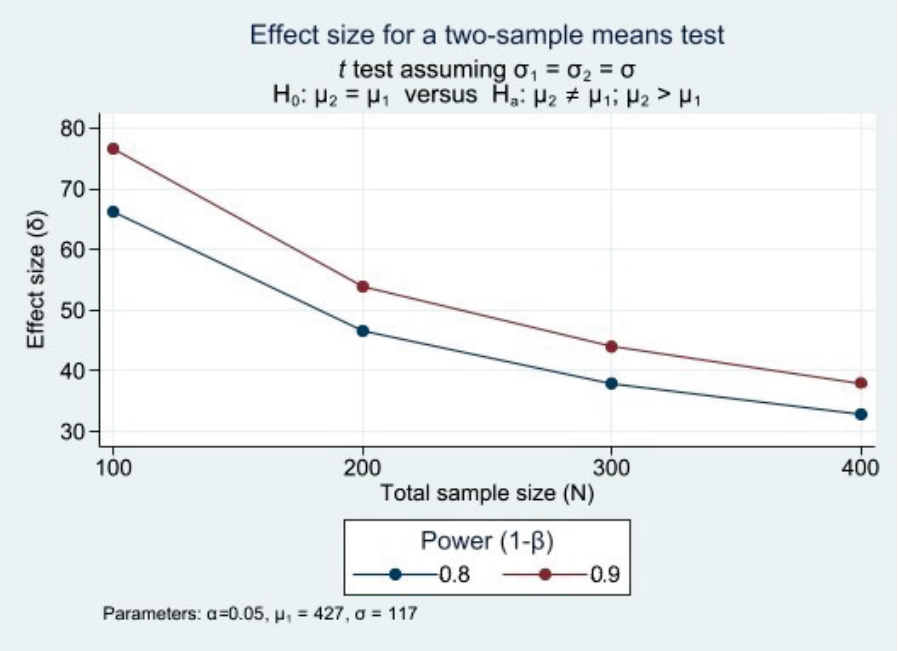


Figure 4. Estimated experimental group mean for a two-sample means test. Note: own figure. Created with Stata version 17.

2.2.4. Proposed Algorithms to Solve and Retrain Images

By employing a blend of advanced methodologies, this research also explored methods to enhance the images' comprehension and manipulation. This experiment enabled us to detect and address potential biases and stereotypes present within the visual data. This endeavor combined two technologies: deep learning, which aids computers in learning from patterns and examples, and quantum computing (QC), harnessing the principles of quantum mechanics.

In this pursuit, a sophisticated tool known as a convolutional neural network (CNN) served as a key component, analyzing the images to extract stereotyped features. Subsequently, these features underwent manipulation using quantum algorithms (QAs), leveraging quantum phenomena to streamline and accelerate the processing.

3. Results

The results for the analyzed images are divided into four different sections: the presence of aids and assistive devices; emotions and gender; the built and natural environment and sex; and digital images generated by AI.

3.1. Presence of Aids and Assistive Devices

Table 2 indicates the distribution of the types of aids and assistive devices linked to older people. Most of the devices were 'glasses' (74.4%) and 'canes' (14%). To a lesser extent, they included 'wheelchairs' (4.9%) or 'hearing aids' (0.8%) and the presence of more than one device simultaneously (5.8%).

Table 2. Distribution of types of aids and assistive devices in images of older people.

Aids and Assistive Devices	N	%
Walking stick	17	14.0
Wheelchair/walker	6	4.9
Glasses	90	74.4
Earphones	1	0.8
Cane and glasses	1	0.8
Cane and manual wheelchair	1	0.8
Medications/others	2	1.6
Crutches and glasses	2	1.7
Manual wheelchair and glasses	1	0.8
TOTAL	121	100

Representations of mixed groups predominated (38%), 31.4% were men, and the lowest representation was found for women (25.6%); sometimes, the gender/sex in the image was not recognized (4.9%). Furthermore, no images were found that represented gender diversity.

3.2. Emotions and Gender

The main emotional states represented were 'joy' (44.6%) and 'the emotion is not recognized' (44.6%). In a smaller proportion, 'sadness' (4.9%), 'surprise' (4.9%) and 'anger' (0.8%) were detected.

Differences were found in the gender/sex analysis in the represented emotions linked to aids and assistive devices. For example, as Figure 5 shows, although the categories of 'not recognized' (37%) and 'joy' (56.3%) predominated in the group of women and men, the emotion of 'sadness' had a greater presence in the group of women (12.9%). This result confirms, once again, some of the gender stereotypes observed in this virtual context.

Finally, the calculated Cohen's Kappa coefficient (-0.0608) suggested that the agreement between these emotions was very low. This could indicate that there was little consistency in how the emotions were labeled among the observers or that there was significant random disagreement in emotion classification. However, since the p-value was very high (1.0000), there was not enough evidence to conclude that the Kappa coefficient was significantly different from zero.

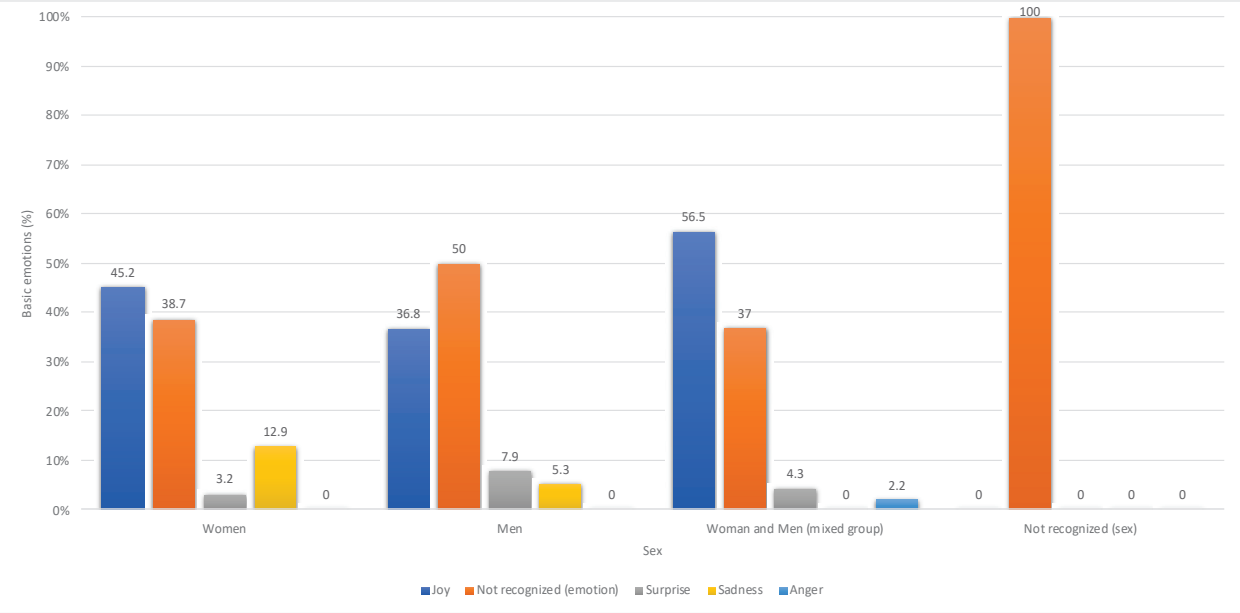


Figure 5. Analysis of basic emotions according to sex subgroups.

3.3. Analysis of the Built and Natural Environment

In the total images of older people linked to assistive technologies, 71.9% presented a built environment (87/121) and 10.7% a natural environment (13/121); in 17.4%, the environment was not recognized (21/121). Table 3 shows, in detail, the distribution of the types of built environment.

Table 3. Distribution of the types of built environment linked to aids and assistive devices in images of older people.

Built Environment	N	%
Commercial	13	4.9
Green space	20	23.0
Work/office	2	3
Not recognized	8	9.2
Technological space with screens	3	3.4
Others	5	5.7
Recreational (for example, park, square, playground, sports spaces)	9	10.3
Residential (refers to spaces in houses or urban buildings, both inside and outside)	22	25.3
Public services (e.g., police station, hospital)	4	4.6
Transport	1	1.1
TOTAL	87	100.0

When analyzing the natural environment (only identified in 13 of 121 images), it was observed that 66.7% were represented in aquatic spaces and 33.3% in green spaces, with the predominance of sunny meteorological conditions (9/13) and, to a lesser extent, cloudy conditions (3/13). Figure 6 shows a group of older people performing exercises in a closed environment, where one can see the outside space in the background. Despite exercising, all of the people appear sitting in chairs, which is also characteristic of the 'collective imagination' of passiveness regarding older people and old age within a built environment.



Figure 6. Image of a group of older people with wheelchairs, exercising in a closed environment with views of the outside. Source: https://www.pexels.com/es-es/foto/hombre-gente-mujer-nina-12085633/. Accessed on 12 August 2024.

For instance, as illustrated in Figure 7, although the categories of 'not recognized' and 'joy' were predominant in the groups of both women and men, the emotion of 'sadness' was more frequently observed in the group of women. This result reinforces the presence of gender stereotypes even within this virtual context. However, as the graph shows, most images (blue bars) depict built spaces, reaching over 70% for both men and women.

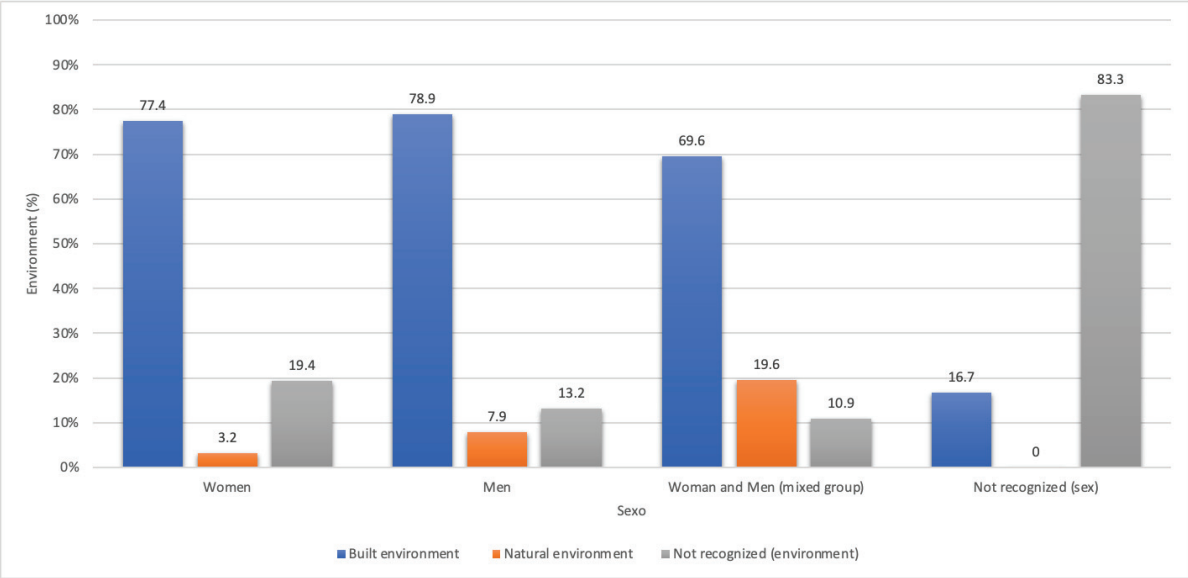


Figure 7. Analysis of the type of environment according to sex subgroups.

3.4. Digital Images Generated by AI

Below are some examples of digital images generated using the combination of all terms of interest in this work, namely 'aids and assistive devices', 'older people', 'emotions' (differentiating among joy, sadness, fear and anger, as shown in the images below), and

observations about this process. In Figure 8, there is a 'happy' older woman and three others where the type of emotion or a sense of 'calm' or 'tranquility' cannot be differentiated. The AI has not been able to determine whether the setting is mostly indoors or outdoors and whether the image depicts green land or another type of space/environment.



Figure 8. Various images generated with AI. From left to right: two older women (**a**,**c**,**d**) and one older man (**b**) in different spaces. Source: images generated by https://facet.ai/artgpt. accessed on 12 August 2024.

3.5. Bridging Stereotype Identification and Manipulation in Images through Advanced Technologies

According to the results obtained in the previous sections, there are two prevalent features regarding stereotypes of older people. On one hand, it is common to find older people wearing glasses, and, on the other hand, hospital and nursing home environments

are depicted. The following outlines a framework spanning from the identification of stereotypical characteristics to their manipulation using techniques from deep learning and QC. Through this process, the aim is to mitigate biases and enhance the fairness and accuracy of image analyses, leveraging advancements in both artificial intelligence and quantum technologies. Based on the previous results, a working method is proposed to eliminate stereotypes in databases focusing on these two main characteristics. The following conditions enable the identification of common characteristics indicating stereotypes about older people:

- X is the set of features extracted from the images;
- Y is the set of labels indicating the presence of stereotypes about older people;
- Common characteristics xi are identified such that xi $\in$ X and yi = 1, where yi $\in$ Y.

The application of a CNN model enables the identification and suppression of such elements in the images:

- Let fCnn(I) be the function representing the convolutional neural network, where I is an image;
- The output of the CNN is a modified image Imod = fCnn(I).

The image features are exported: Xmod is the set of features extracted from the modified images. Image manipulation is applied by using QCA:

- fQC(Xmod) is the function representing the quantum algorithms applied to the features of the modified images;
- The output of the QA is a set of manipulated features Xmanip = fQC(Xmod).

4. Discussion

The analysis of digital images depicting older adults revealed several critical insights across various categories. Firstly, the representation of aids and assistive devices predominantly featured 'glasses' (74.4%), with less frequent portrayals of 'canes' (14%) and 'wheelchairs' (4.9%). 'Hearing aids' and the use of multiple devices simultaneously were rare, indicating the limited portrayal of the full spectrum of assistive technologies available. The gender representation in these images was skewed, with men depicted more frequently (31.4%) compared to women (25.6%) and a notable portion of images (38%) showing mixed gender groups.

This representation is significant given that assistive devices are crucial for the daily lives of many older adults. According to data, approximately 70% of older adults utilize at least one type of assistive device. The disparity between this statistic and their depiction in digital imagery underscores the substantial gap in how these technologies are represented. The underrepresentation of hearing aids and other assistive technologies not only neglects the variety of aids used by older adults but also reinforces a narrow view of ageing that fails to acknowledge the diversity of the assistive tools available.

The gender representation in these images was skewed, with men depicted more frequently (31.4%) compared to women (25.6%) and a notable portion of images (38%) showing mixed gender groups. This imbalance points to a lack of gender inclusivity in digital portrayals of older adults. Furthermore, the absence of diverse gender identities in these images highlights a broader issue of inclusivity.

The emotions portrayed in these images predominantly included 'joy' and 'unrecognized emotions', each at 44.6%, while other emotions, such as 'sadness', were less common. Gender differences were evident in the emotional representation, with women more frequently associated with 'sadness' compared to men, suggesting a potential gender bias in the depiction of emotions. The Cohen's Kappa coefficient for emotion agreement was very low (-0.0608), indicating significant variability in emotion classification among the observers and highlighting the inconsistency in the portrayal of emotions.

Regarding the environment depicted in the images, there was a strong bias towards built environments (71.9%), with natural environments represented in only 10.7% of the images. The built environments included residential and commercial spaces, while natural

settings were primarily aquatic or green spaces. This overrepresentation of built environments may contribute to a stereotypical view of ageing as confined to institutional or controlled settings.

Challenges with AI-generated images were also significant. AI systems often struggled to accurately depict emotions and environmental contexts, resulting in images with neutral or ambiguous expressions and idealized or futuristic settings that did not accurately reflect real-life scenarios. This discrepancy underscores the need for improved training data and more nuanced approaches to AI-generated imagery to better represent older adults.

These findings collectively highlight ongoing issues in the representation of older adults in digital imagery, including the prevalence of stereotypes, gender biases and limitations in emotional and environmental depiction. Addressing these issues through more inclusive and diverse visual content is essential in creating a more accurate and respectful portrayal of ageing.

4.1. Social Representation Theory and Its Impact on the Perception of Older Adults in Digital Images

Émile Durkheim, a pioneer in the study of collective representation, laid the groundwork for an understanding of how shared ideas and beliefs within a society influence social cohesion and the ways in which individuals perceive reality. Durkheim posited that these representations are social constructions that emerge from communal life and, in turn, shape the actions and thoughts of a society's members [30]. His approach profoundly influenced subsequent studies on the formation and function of social representations. A notable example is the work of Lévy-Bruhl, who, prior to Moscovici, explored the pre-logical mindsets of primitive societies, suggesting that forms of collective thought influence the perception of reality [31].

To better understand the implications of this study, the theory of social representation, developed by Serge Moscovici, has been adopted as the conceptual framework. This theory posits that social representations are systems of values, ideas and practices that are shared by the members of a community, which allow persons to interpret reality and communicate about it. These representations are generated and transmitted through media, discourses and cultural practices and have a significant impact on the formation of collective perceptions and attitudes [32–34].

In the context of this analysis, digital images representing older adults and assistive technologies not only reflect preexisting social perceptions but also play an active role in constructing and perpetuating these perceptions. For example, the recurrent depiction of older adults in stereotypical settings or with limited emotional expressions reinforces reductive and often negative views of ageing, which can influence how society as a whole perceives and values older adults and how they perceive their environments [35,36].

This theoretical framework allows for the understanding that the lack of diversity and the presence of stereotypes in digital images are not merely visual shortcomings but manifestations of a broader system of social representation that can perpetuate inequities and limit inclusion. Furthermore, these representations have the power to shape individual and collective expectations and behaviors, affecting how older adults see themselves and how they are viewed by others.

The socio-genetic perspective, which builds upon Moscovici's foundational concepts, extends this understanding by considering how biological factors might interplay with social processes in the formation of these representations. While Moscovici emphasized the social and cultural dimensions of representation, the socio-genetic approach adds a layer of complexity by exploring how inherent biological traits might influence or interact with the social construction of reality. This perspective enriches the original theory by integrating insights from genetics and biology into the analysis of how social representations are formed and sustained [37].

Thus, this study not only identifies technical shortcomings in the creation and selection of digital images but also highlights the need for a more nuanced approach to visual content

creation. By addressing both the social and biological dimensions of representation, and striving for more equitable and diverse depictions, it is possible to challenge and transform the prevailing social narratives. This comprehensive approach aims to foster a more inclusive and respectful portrayal of ageing and the technologies that support older adults, ultimately contributing to a more balanced and fair societal view.

Following this, Deborah Lupton has examined how social representations are being transformed in the digital age, particularly in the realm of health and the body. Lupton argues that information technologies and the proliferation of personal data are reshaping perceptions of identity and well-being, while also influencing social narratives about what is considered normal or desirable in terms of health. Her work highlights how digital representations not only reflect preexisting social realities but also actively shape them, promoting new discourses and practices in everyday life. These ideas are particularly relevant in understanding how digital images and other forms of visual content can affect collective perceptions and, ultimately, influence social attitudes and behaviors [38].

This study, therefore, not only exposes technical issues in the generation and selection of images but also underscores the need for a more critical and conscious approach to the creation and distribution of visual content in the digital era and AI-driven environments. AI-driven environments are contexts where artificial intelligence algorithms are used to generate, curate and analyze visual content. These systems can influence the types of images produced and how they are presented, often reflecting and amplifying existing biases. In this context, Ruha Benjamin explores how such technologies can perpetuate social and racial biases, highlighting the importance of addressing these issues to foster more equitable and inclusive digital spaces [39]. By addressing these biases and working towards more equitable and diverse representation in digital media, the dominant social narratives can be challenged and transformed, promoting a more inclusive and respectful view of ageing and the technologies that support this demographic group.

4.2. Challenges and Stereotypes in Digital Imagery

In the case of the presence of aids and assistive devices, the results were based on images that mostly represented glasses, canes and wheelchairs. In sum, gaps in the genders, emotions, and environments that were represented, as well as aids and assistive devices, were found. Furthermore, technological devices applied to health were not represented, which reflects a double stereotype. On the one hand, older people are represented with devices related to disabilities or mobility problems, and, on the other, they are not observed using innovative support technologies, as already mentioned in a previous study by some of the authors [40]. However, it seems that there is currently a trend towards the development of increasingly wearable devices and products for daily and everyday use, including more innovative ones, such as robots or digital solutions [4], but these were not yet visible in the images that were analyzed.

The absence of representation extends to innovative health technologies, revealing a double stereotype: older persons are depicted mainly with devices related to disabilities or mobility issues, while innovative solutions like wearable devices or robots remain largely absent. This disparity highlights persisting stereotypes within digital imagery and its portrayal of older adults and their assistive needs. The persistence of stereotypes in the representation of older adults in technology and assistance could be linked to the existence of a digital divide that, while narrowing, has not been fully accepted by society. This contradicts new understandings of adulthood and old age, which advocate for active participation and full integration into the digital age. The reluctance to recognize and adequately represent innovative technologies and assistance needs in old age reflects a disconnect between the changing realities and entrenched perceptions about ageing.

This study revealed several key findings. First, predominant emotions such as 'joy' were observed, along with cases where emotions were unrecognizable, with variations based on gender. This lack of emotional clarity varied by gender, suggesting that the representation of emotions may be influenced by gender biases or stereotypes. For example,

women may be depicted with less expressive emotional states compared to men, which could reinforce traditional gender norms. Second, most images depicted older adults in built environments, with few representations in natural settings. This reflects a lack of diversity in the contexts of representation that does not fully capture the reality of older adults' experiences. Third, AI-generated digital images presented challenges in accurately representing emotions and environmental contexts. AI-generated images often exhibited neutral or ambiguous expressions, and the environments were frequently idealized or futuristic, rather than reflecting real-life scenarios. This discrepancy between AI-generated images and real-world experiences highlights the need for more nuanced and diverse training data to improve the representation of older adults. In other words, for older adults to continue to be part of the silver economy and to adopt emerging technological devices, social images and their perceptions of themselves are vital. One way to address this challenge is to promote inclusive digital education for older adults and involve older adults in the process of creating and evaluating digital images. Their perspectives and experiences can provide valuable insights into how to enhance representation and inclusion in digital media. Additionally, it is important to encourage the more diverse and accurate representation of older adults in media and advertising, highlighting their active participation in society and their ability to adopt technology meaningfully. By showcasing positive and empowering examples of older adults using advanced technology effectively, it is possible to change public perceptions and foster a more positive attitude towards ageing and technology adoption in older people. To address this challenge, a generative AI algorithm with machine learning could be implemented to digitally analyze images of older individuals and assistive devices. This algorithm could be trained using a diverse and representative dataset including images of older individuals in various environments and situations, as well as a variety of assistive devices. Employing deep learning techniques, the algorithm could identify specific patterns and features in the images that are related to accurate representation of age, gender and the environment. Additionally, the algorithm could be designed to generate new and realistic images that reflect a range of contexts and emotions associated with ageing. This would help to improve the accuracy and diversity of representations of older individuals in digital media, thus reducing stereotypes and promoting a more accurate and positive image of ageing. The lack of diversity and the need for more positive and realistic representations of ageing across all realms, including media, advertising and popular culture, to foster a more inclusive and enriching view of the ageing process is still unresolved matter among digitalized societies [15,20,40]. This research also emphasizes stereotypes regarding aids and spaces, as the predominant types were glasses and hospitals/older residence spaces. Through the fusion of advanced methodologies, this research endeavors to enhance the comprehension and manipulation of images, aiming to detect and mitigate biases and stereotypes inherent in visual data. Integrating deep learning and quantum computing (QC), it leverages convolutional neural networks (CNNs) to analyze images for stereotypical features, followed by manipulation using quantum algorithms (QAs) to expedite their processing. This process includes identifying stereotypical features (X) and their labels (Y), modifying the images using a convolutional neural network (CNN) to produce altered images, and applying quantum algorithms to these modified features to generate manipulated features. The aim is to reduce the biases and enhance the fairness and accuracy in image analysis through these advanced technologies.

Among the other possibilities that quantum technology could offer is the optimization of AI algorithms used to analyze images of older adults and assistive devices. Quantum computing has the potential to significantly accelerate the calculations required to train and execute these algorithms, which could dramatically improve the efficiency and accuracy of image analysis. Moreover, QA is capable of handling large datasets more effectively, enabling a more comprehensive and detailed analysis of representations of older adults in digital media. One of the approaches that we could use to develop this algorithm is the adiabatic algorithm. The adiabatic algorithm relies on the controlled manipulation of a quantum physical system to find optimal solutions to optimization problems. It utilizes

the concept of adiabatic transitions to find the ground state of a quantum system, which corresponds to the solution of the optimization problem. By harnessing the quantum properties of the system, such as superposition and entanglement, the adiabatic algorithm can rapidly explore the solution space and efficiently find optimal solutions. On the other hand, a quantum annealer could be another option. A quantum annealer is a quantum device specifically designed to solve combinatorial optimization problems. It utilizes the phenomenon of quantum tunneling to find bit configurations that minimize an energy function associated with the optimization problem. Thus, quantum annealers are particularly effective in finding solutions close to global optima in complex optimization problems. Globally, quantum technology could help to enhance the quality and diversity of representations of older adults in digital media, thereby contributing to reducing stereotypes and promoting a more accurate and positive image of ageing.

Regarding emotions and gender, images were observed that showed mostly joy and a lack of recognition of emotion, especially in women. In general, it is observed that digital images linked to the use of aids and assistive devices among women are underrepresented. Evidence shows that while older people, especially older women, tend to be less represented in digital media [13], the differences become more acute when investigating how they are represented in a differential and stereotypical way in digital images [5].

The limitation of this study from a gender and feminist perspective has also been noted. In this context, a previous study showed that sexual and gender minorities face several challenges, especially in the use of digital platforms related to identity [41]; in another work, the author even concluded that digital images present a limited view of old age, excluding homosexual couples and non-binary people [5].

Although older people become 'invisible' in digital media [13], it is noted that men are more visible than women. The data also show marked differences in older people's use of media (traditional and digital), even among high-income countries (Canada, the Netherlands, Romania, Spain and Finland) [42]. In the same sense, the results of this work show the presence and co-existence of scenarios of gender/sex inequality and ageism in the representation of older people in this collective digital imagination.

Regarding the representation of the natural environment, in digital images, an excess of this appears, particularly emphasizing sunny weather, which is even visible in closed spaces. This emphasizes that, where older people appear, the idealization of the natural space is visible, which, according to García Monteagudo, could make it difficult '*to understand their social environment*' [43] and hides the reality or challenges that are emphasized in the present study. Older people using aids and assistive devices were predominantly represented in built environments (for example, nursing homes) and scarcely in natural environments, with a balance being necessary in the representation of these spaces. As evidenced by a previous study from the perspective of older people, the physical, social and nature-based qualities of everyday environments are important with regard to good ageing [44]. This also highlights the role of connecting with nature, both inside and outside built environments, in promoting healthy ageing [45]. This result is key, particularly in regard to the representation of women in the built environment (such as nursing home environments), as has been shown by previous work on digital images, where older women are largely linked within the home with care roles [5].

From the above, the representation in digital media (images) of the older adult population from an inclusive and intersectional perspective (gender, age, space) is crucial. For example, as suggested in a study conducted during the COVID-19 pandemic, problematic representations of older people in the media could evoke or amplify age discrimination [46]. In short, the stereotypes observed in this work are accentuated when an intersectional approach is considering involving age and sex, among other aspects, also highlighting the environment [47–50].

Regarding the images analyzed by AI, expressions are observed that evoke predominantly neutral emotions, as well as futuristic environments. This leads to the suggestion that AI, as noted for built environments, shows an idealized and stereotyped environment,

which can also make it difficult for older people to understand the importance of innovative technology. In the studied digital images, the presence of faces where the expression could not be detected was frequent, which suggests that more research should be conducted into the identification of emotions to allow the assessment of the degree of acceptance of the technology by the users themselves regarding the adoption of new technologies. With this, it is possible, in turn, to apply agent-based models (computational simulations) to test stochastic process algorithms so as to address the 'technological divide' that is still present in older people [51].

In the images not generated by AI, limited emotions beyond joy stand out, as the authors have already indicated in a previous study [5], which suggests that the wide range of emotions that could be expressed is not being recognized. Furthermore, as stated in a previous review [52], when older people are represented in the media (both digital and non-digital), they are largely represented as a homogeneous group and without individual differentiation, even from an exaggeratedly positive perspective. However, it can be highlighted that, in a significant proportion of images, the emotion could not be recognized (due to neutral or ambiguous expressions, an absent gaze, a lack of reaction or a state of peace/tranquility, depending on how it is interpreted, as we have noted previously).

4.3. Limitations and Strengths

In this work, limitations related to the virtual ethnography method itself can be identified, such as access to resources in specific databases and the 'ephemeral' nature of the data. However, all of the images were downloaded and the functioning of the links was reviewed on more than one occasion and at different times, finding, at the time of the last consultation, a small proportion of images that were no longer available online (only one of 114 images and their respective links).

There could have been information bias or under-recording (for example, we limited ourselves to a certain number of databases and assigned the categories of interest within a limited period), although, as indicated in the Materials and Methods section, different measures were taken to mitigate this.

Moreover, the initial analysis of Cohen's kappa showed some discrepancies in the emotion labeling, which we view as an opportunity for improvement rather than a limitation. It was expected due to the limited number of individuals involved in the labeling process. These findings emphasize the importance of refining and further validating the methods to ensure reliable results in the future. By implementing targeted enhancements, such as standardizing the labeling criteria, expanding the pool of labelers and conducting qualitative analyses, the future analysis of the database of images can achieve improved accuracy and consistency in emotion labeling. This iterative approach not only enhances the study's validity but also deepens our understanding of emotional nuances. Thus, while the initial results may indicate areas for improvement, they signify the beginning of an enriching journey towards more nuanced and insightful findings in emotional image codification.

Moreover, the images analyzed in this study included a significant proportion of promotional material. This aspect should be considered when interpreting our findings. Promotional images are often designed to capture attention and promote specific products or services, which can influence how older adults are represented, often focusing on aspects that resonate with the target audience's expectations and marketing ideals. This promotional orientation can contribute to the perpetuation of stereotypes by depicting older adults in ways that align with prevailing social perceptions and expectations. However, the fact that these images come from promotional contexts does not invalidate their relevance in the discussion about public perception and stereotypes associated with ageing. On the contrary, it underscores the need for greater critical reflection on how visual representations influence social perceptions and the acceptance of emerging technologies among older adults. This study aimed not only to describe the content of the images but also to understand how these representations may reflect and, in turn, reinforce certain social perceptions and expectations. Future work would benefit from combining image analysis

with additional research on how social perceptions and market expectations influence the representation of older adults. This would provide a more comprehensive and critical view of the impact of promotional images on the construction of identity and the social integration of older adults.

In addition, there were limitations in the use of AI, as stated in the Materials and Methods, but it was possible to verify, in the generated images, the representation of expressions related to emotions. In older people, they are 'neutral', or, if possible, they convey absence (gaze lost or fixed on the horizon) or inexpression (or 'calm' or 'tranquility', depending on how it is interpreted). Regarding health and environmental support technologies, although representations that resemble reality are displayed, they usually present older people within 'futuristic' and 'unrealistic' contexts.

In relation to the initial and exploratory use of AI in this area, and due to the limitations found and already stated (in comparison with images retrieved from digital repositories), it is possible to highlight the quality of the images provided (the distortion of some images when several terms are introduced at the same time) and also the subscription. These aspects remain a future challenge, and a more in-depth analysis is required in light of the ethical aspects related to algorithmic discrimination and data bias [53]. Moreover, stock images or AI are pervasive on the web and apps are increasing in number. There is a blind spot in the ethics of stock images regarding the use of such images without training [54], which is a complex and relevant aspect to be analyzed when implementing AI. However, these aspects are beyond the scope of this work and may be explored in future studies that explore image databases and apply the ethics approach.

The main limitation of this study in this regard is the consideration of an app to generate images, as it used mainly images from the Low-Rank Adaptation of Large Language Models AI (LoRA AI) [55]. The LoRA AI utilizes large-scale language models like the Low-Rank Adaptation (LoRA) model, which has been widely employed to generate digital images with a wide range of features. The LoRA AI has the potential to significantly contribute to diversity and inclusion in visual representation, as it can generate images depicting people of different ages, abilities, cultural backgrounds and genders. However, it is important to recognize that the quality and representativeness of AI-generated images may be influenced by biases present in the datasets used to train these models. Therefore, addressing these ethical concerns and ensuring that AI-generated images accurately and equitably reflect societal diversity is crucial.

The quality and representativeness of AI-generated images, including those produced by models like the LoRA AI, still require further evaluation. Issues such as image distortion and a lack of diversity, as highlighted in this study, emphasize the need for additional research to assess the reliability and accuracy of these generated images. Variability in image quality and potential biases in training data can affect how emotional images are interpreted, which could have significant implications for inclusion and accuracy in emotion coding. In addition to concerns specific to the LoRA AI, it is crucial to consider broader challenges associated with AI-generated imagery. For instance, the training datasets used to develop these models often contain inherent biases that may perpetuate stereotypes or underrepresent certain groups. This is particularly important when evaluating emotional and social representations in images. Furthermore, the algorithms themselves may struggle in accurately depicting nuanced emotional expressions, particularly in diverse populations or complex contexts. Addressing these issues requires not only optimizing the AI models but also conducting comprehensive studies that examine the broader implications of these technologies. This includes ensuring that AI-generated images accurately reflect societal diversity, as well as exploring how different AI models handle various emotional and contextual nuances. By tackling these challenges, future research can contribute to more inclusive and precise representations in AI-generated imagery.

4.4. Future Directions and Ethical Considerations

Future studies need to focus more on the LoRA AI instead of the training images. Although this study did not analyze the LoRA AI, the academic literature on this subject, to our knowledge, is lacking. Therefore, it is worth highlighting that this is an important approach that should be applied in the representation of images in future works, in addition to the virtual ethnographic evaluative method on which this study focused.

It is worth highlighting some observations related to AI when applying the terms of interest (older people, women/men and aids/assistive devices). In most cases, the use of the variable 'older people' causes AI to generate images of older women, while older men are represented only when they are directly specific. One reason for this finding could be that older women are directly linked to old age and to assistive technologies or that AI takes into account life expectancy according to sex. However, a more comprehensive analysis of these ideas, as well as new tests and the standardization of procedures, is needed to establish a conclusion in this regard. Another issue is the limited representation of aids/assistive devices and older people, suggesting that they are not yet fully included in AI. Some AI difficulties have also been observed in understanding other concepts, such as 'ageism' and the spatial/contextual aspects of this. Finally, confirming the need for specific and more standardized searches in the future in the field of images obtained from AI, the ethnic, racial and sexual diversity was poor (almost all images were of white individuals with a normative appearance). This last aspect is partly consistent with some findings from the analysis of digital images in repositories.

For this evaluative study, and as a general conceptual framework, our work was based on previous ones, such as [56–59].

There are studies regarding image evaluation guidelines from a social and/or gender perspective [24,60] but few on the evaluation of digital images according to age, space/land and gender. There are already hundreds of works on evaluation and gender [61] but very few on evaluation, images and gender (and less with a feminist approach) or on older people and the environment/land.

Moreover, advancements in AI have both positive and negative implications for these representations. AI technologies are increasingly used to generate and analyze digital images, including those of older adults. While AI has the potential to create more inclusive and diverse representations by recognizing and mitigating biases in image datasets, it can also perpetuate existing stereotypes if not carefully managed. For instance, AI algorithms trained on biased data can inadvertently reinforce negative stereotypes about ageing and gender, leading to the greater presence of stereotypical images of older women. Therefore, AI-generated images are not aware of and do not actively counteract these biases. This involves curating diverse and representative datasets, implementing fairness and bias detection mechanisms and promoting ethical guidelines in AI development. In this way, AI can help to foster more accurate and positive representations of older adults, particularly women, contributing to a more inclusive and equitable society. In the future, generative AI should serve as an ally for the evaluation of images and for social evaluation and research as a whole, as well as, more specifically, in the areas addressed here.

On the other hand, AI images are currently trained with datasets such as CIFAR-10 [1], MNIST [2] and COCO [3], which are not specifically designed in consideration of social concepts such as inclusion and contain implicit biases and stereotypes [62,63]. In this context, apps play an interesting role in research and could be used to pursue objectives related to inclusion. For example, the project FAT/Lm explores databases with training images applying ethical and inclusion concepts. In the case of this study, ArtGPT provided images for a wide range of individuals, including those with different abilities and cultural backgrounds, ethnicities and ages, by engaging artistic expression. ArtGPT could contribute to inclusion by giving a voice to those who may have traditionally been marginalized in conventional artistic circles.

This point is very important as it is an emerging finding and it is necessary to foster positive attitudes towards older persons and their use of technologies.

However, it is also important to consider how the underlying artificial intelligence model behind ArtGPT is trained and utilized. If the data used to train the model are biased or represent only certain artistic styles, genders or cultures, the responses generated by the application could reflect and perpetuate these biases, which could have a negative impact on inclusion and diversity in the art field. Thus, a social perspective is needed to support greater representation in apps such as ArtGPT, enabling them to generate representations inspired by diverse groups of older people, using technological devices, in realistic environments and with differentiation by gender, contributing to reducing ageism and fosting more inclusive and intersectional views in general. Regarding this study and its method, it cannot be inferred that the results obtained from the digital images reflect real representations of the elderly. Therefore, future studies that also include the perspectives of older people themselves are needed.

Additionally, the representation of older adults in digital images reveals a series of persistent stereotypes and a lack of diversity in the depiction of technologies and environments. These observations have significant implications for policy formulation and spatial planning. The prevalence of stereotypical representations, such as the predominant use of basic assistive devices and the exclusion of advanced technologies, underscores the need for policies that promote more inclusive and accurate representation. Public policies should encourage the integration of diverse representations in digital media and educational campaigns to adequately reflect the realities of older adults. Additionally, urban planning should consider the inclusion of both natural and built spaces that meet the needs of older adults, promoting active and healthy ageing. Collaboration between policymakers, technology developers and older adult communities is essential to ensure that environments and technologies are accessible and representative.

In this context, emotional intelligence becomes relevant. The ways in which emotions are represented in digital images and, especially, with artificial emotional intelligence technology can exert a social impact [39] on how older adults and society in general experience and manage their own and others' emotions. Limited or stereotypical emotional representations can contribute to a lack of empathy towards older adults, perpetuating a one-dimensional and limited understanding of their experiences. On the other hand, a more diverse and emotionally rich representation could foster greater empathy and understanding, which is crucial for more equitable representation and inclusion.

5. Conclusions

This study revealed that digital imagery of older adults frequently perpetuates stereotypes and age discrimination. Notably, gender disparities were evident, with older women being less represented and portrayed in more traditional and limiting roles compared to their male counterparts. This finding is particularly relevant given the demographic shift towards an increasingly older population, where gender inclusivity in representation is a relevant factor. The disproportionate representation of older women and the reinforcement of reductive stereotypes in digital media contribute to the persistence of ageist attitudes and fail to capture the diverse experiences of ageing. These results highlight the urgent need for more nuanced and equitable portrayals that accurately reflect the complexity and vitality of the ageing population.

The evaluation of the final images confirmed the lower representation of women and limited emotional expressions in images of older people, highlighting the persistent stereotypes and biases in digital imagery. Despite technology's omnipresence, images often overlook innovative support technologies for older people. Moreover, AI struggles to accurately depict emotions and environments in digital images, indicating the need for thorough pretraining analysis and ethical considerations.

The analysis revealed predominant emotions such as 'joy' and the greater representation of older people in built environments compared to natural settings. Gaps were identified in gender representation, emotional expression, environmental depiction and the representation of assistive devices. Additionally, innovative health technologies were

notably absent, perpetuating stereotypes of older adults with disability-related devices. The persistence of such stereotypes may stem from the digital divide and societal reluctance to fully embrace ageing and technological advancement. There is still a challenge regarding the promotion of inclusive digital education and the accurate representation of older adults in media and advertising. By showcasing positive examples of older adults using technology effectively, public perception can be shifted towards a more positive attitude towards ageing.

Generative AI algorithms and quantum technology offer solutions to enhance the accuracy and diversity of representations of older adults in digital media. Furthermore, combining convolutional neural networks with quantum computing algorithms could offer a powerful approach to reducing biases and improving both fairness and precision in image analysis. These advancements have the potential to significantly enhance the efficiency and accuracy of image analysis, but ethical considerations are paramount. Future research should prioritize inclusivity and explore older adults' perspectives to ensure a comprehensive understanding and representation in digital imagery.

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Notes

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Optimizing the Layout of Service Facilities for Older People Based on POI Data and Machine Learning: Guangzhou City as an Example

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Abstract: Population aging is a global issue. China is facing the same challenge, especially in its megacities, with more than 10 million permanent urban residents. These densely populated cities urgently need the scientific planning and optimization of the layout of service facilities for older people. Taking Guangzhou, a megacity in China, as an example, this study uses point-of-interest (POI) data and the ID3 machine learning decision tree algorithm to train a site selection model for service facilities for older people. The model can help to select appropriate locations for new service facilities for older people more scientifically and accurately, and it can provide targeted suggestions to optimize the layout of the service facilities for older people in Guangzhou. First, Guangzhou city is divided into 29,793 grids of 500 m × 500 m based on the range of activities of older people, and 985 grids are found to contain service facilities for older people. Then, the POI data of the grid are fed into the ID3 algorithm for training to obtain a prediction model for the selection of sites for service facilities for older people. The effective prediction rate of the model reaches 87.54%. Then, we apply the site selection model to predict the whole city of Guangzhou, and 4534 grids are suitable for service facilities for older people. In addition, considering the degree of concentration of the elderly population in each street, we further filter out 1066 priority grids as the final site selection. Finally, taking into account the situation of the streets in different districts, we propose several strategies to optimize the layout of the construction of service facilities for older people.

Keywords: older people; service facilities; Guangzhou; POI; machine learning; layout optimization; aging

1. Introduction

Population aging is a prevalent social issue worldwide. According to the United Nations Population Report, the global population of individuals aged 65 and over was expected to reach approximately 771 million in 2022, accounting for 10% of the world's total population. By 2050, this proportion is expected to rise to 16%, or approximately 1.6 billion people [1]. China, as the world's most populous country, is also facing the challenges of an aging population. The Seventh National Population Census conducted by the National Bureau of Statistics of China in 2020 revealed that the population of individuals aged 65 and above in China was 190.64 million, comprising 13.5% of the total population [2]. Furthermore, China's densely populated megacities, such as Shanghai, Beijing, Guangzhou, Shenzhen, Chongqing, Chengdu, and Tianjin (Figure 1), which have urban populations exceeding 10 million, are particularly affected by the issue of aging [3]. In 2020, the average proportion of people aged 60 and over in these cities had reached 17.32%. In response to the growing demand for older people's services, the Chinese government has implemented a series of policies. In February 2022, the National Planning for the Development of the Aging Career and the Elderly Service System [4] clearly incorporated the integration of old-age affairs into its economic and social development planning, as well as sustainable

development strategies. The plan proposes an increase in investment for various types of service facilities for older people and the scientific planning and allocation of new ones. For densely populated megacities like Guangzhou, finding an optimal approach to plan and optimize the distribution of urban facilities for older people is an urgent task. This study is of great practical significance for a timely, scientific, and comprehensive response to population aging.

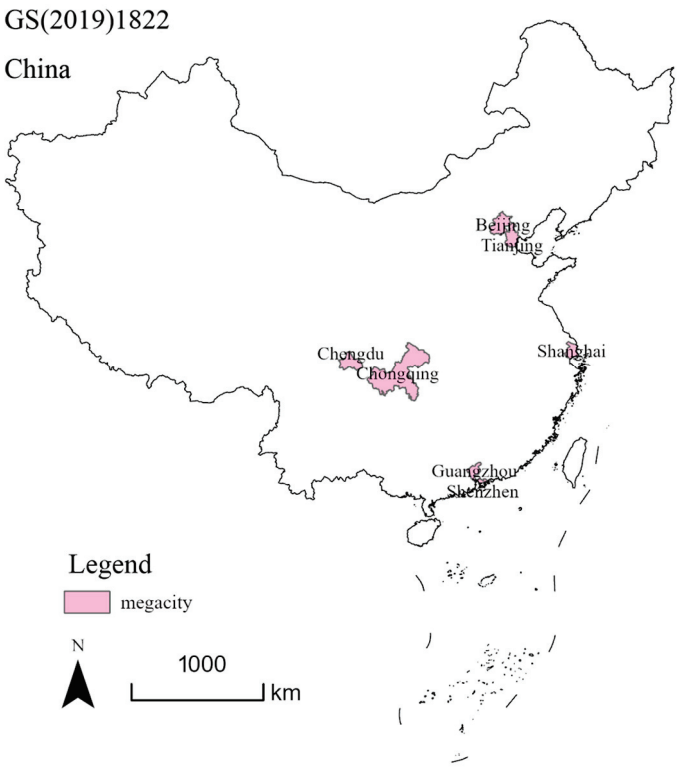


Figure 1. Locations of megacities in China.

Service facilities for older people are a crucial component of urban public services. With the accelerated development of urban aging, the planning and construction of these facilities has become a new issue in urban planning. The layout of service facilities for older people needs to be gradually matched with the development of the city and the needs of its citizens [5]. Much research has been conducted on the layout of service facilities for older people [6–8]. The first type of study is the arrangement of land sites for service facilities for older people in urban planning. The traditional layout planning of such facilities usually adopts the perspective of the land supply in urban master planning [9,10]. The study of the land demand for service facilities for older people mainly considers factors such as the demand for land by older people in plots around the city [11] and the matching of the supply and demand for older adults [12]. The second type of study aims to evaluate and optimize the allocation efficiency of existing service facilities for older people [13,14]. The studies cover various aspects, including the geographical environment and spatial factors affecting the balanced layout of service facilities for older people [15,16], the distribution characteristics of service facilities for older people and the coupling relationship between facilities and people [17,18], the accessibility of facilities, and the spatial coordination and continuity of service facilities [8,19,20]. The third category of studies focuses on modeling and forecasting the sizes and types of future service facilities for older people [21,22], mainly based on the natural growth rate of the local population [23,24]. However, the current forecasts focus mainly on the city and county level and do not sufficiently consider the street level and the correlation with other existing public services in the city. Current research on urban service facilities for older people in Guangzhou focuses on the spatial layout of

existing facilities and assessing their coupling with population growth projections [25–28]. However, simulating and predicting the distribution of future service facilities for older people is an important research direction. In particular, as emerging urban data, POI data have been widely used in studies in areas such as urban function and land use planning, and many studies have used POI data to attempt to analyze the distribution of urban public facilities [29–31]. Faced with a large amount of urban data that need to be analyzed, machine learning has been widely applied to the mining of urban big data [32]. Compared with traditional linear and mathematical modeling methods, machine learning has unique advantages in the analysis of non-linear problems in big data [33]. Machine learning algorithms learn large amounts of urban data, from which they can discover complex patterns close to reality and predict future developments [34]. Machine learning methods are widely used to analyze correlations between urban elements, and machine learning algorithms are applied according to different urban data and problems [35–37]. In addition, studies using POI data and machine learning to assess the current locations of urban public services and to make predictions about future locations are beginning to emerge [38,39]. These studies are an important foundation for this research.

The aim of this study is to provide a more rational, objective, and efficient means of siting service facilities for older people by using POI big data and machine learning algorithms in combination with high-density street-scale demographic data in Guangzhou city [40,41]. The paper is organized as follows. Section 2 introduces the study area and data sources, and Section 3 presents the methodology of the study. Section 4 illustrates the results of the study in the form of graphs. Finally, we discuss and conclude our research. The study provides a reference for the layout optimization and future planning of service facilities for older people in Guangzhou and related megacities.

2. Study Area and Data

2.1. Study Area

Guangzhou is located in the central part of Guangdong Province, with a total area of about 7434 square kilometers. Guangzhou contains 11 administrative divisions, namely the Yuexiu, Liwan, Haizhu, Tianhe, Baiyun, Huangpu, Panyu, Nansha, Zengcheng, Conghua, and Huadu districts. Guangzhou is the capital city of Guangdong Province, and, as an economically developed and densely populated metropolis, the aging problem is more concentrated, and its demographic problems are typical of megacities in China [42]. According to the urban development pattern of the successive versions of the master plan, Guangzhou is divided into three circles: the central urban area (Liwan, Yuexiu, Haizhu, and Tianhe districts), the suburban area (Baiyun, Huangpu, and Panyu districts), and the remote suburban area (Huadu, Nansha, Conghua, and Zengcheng districts) (Figure 2). The ageing population in Guangzhou city shows a trend of rapid and unbalanced growth in all districts, which poses specific requirements for the adjustment and optimization of the spatial layout of the social service system for older people. For the administrative area data, we divided Guangzhou into 29,793 grids of 500 m by 500 m, based on the 15-min walking distance of older people [43], and the service radius of service facilities for older people should not be more than 500 m [44,45]. Each grid has a unique number, which offers convenience for the subsequent exploration of the spatial distribution of service facilities for older people and other types of urban public service facilities.

2.2. Research Data

POI data are data based on the core location-based services, which essentially cover all aspects of urban life, and are suitable for research related to urban public facilities [46]. POI data for this study were obtained via the acquisition of relevant POI information within the study area in November 2020 on Gaode Map, including the type, name, latitude and longitude, category, address and other relevant attribute information about urban public facilities. Due to the large amount of raw POI data acquired, there were duplications or intersections in the data in terms of classification, so it was necessary to pre-process

the POI data. The pre-processing included deleting duplicated points and points with missing attributes. Then, based on the relationships among the service facilities for older people, the various types of facilities in the city, characterized by the POIs, were classified into 14 categories, namely transport, hotels, sports and leisure, business and enterprises, medical services, real estate, government institutions, living services, science, education and culture, shopping, finance, tourist attractions, catering and food, and facilities for older people, with a total of 664,031 data (Table 1). From the above POI data, a total of 1369 data were filtered out as service facilities for older people. Service facilities for older people include nursing homes, elderly care centers, homes for the aged, older people's universities, elderly apartments, elderly service centers, social welfare centers, etc.

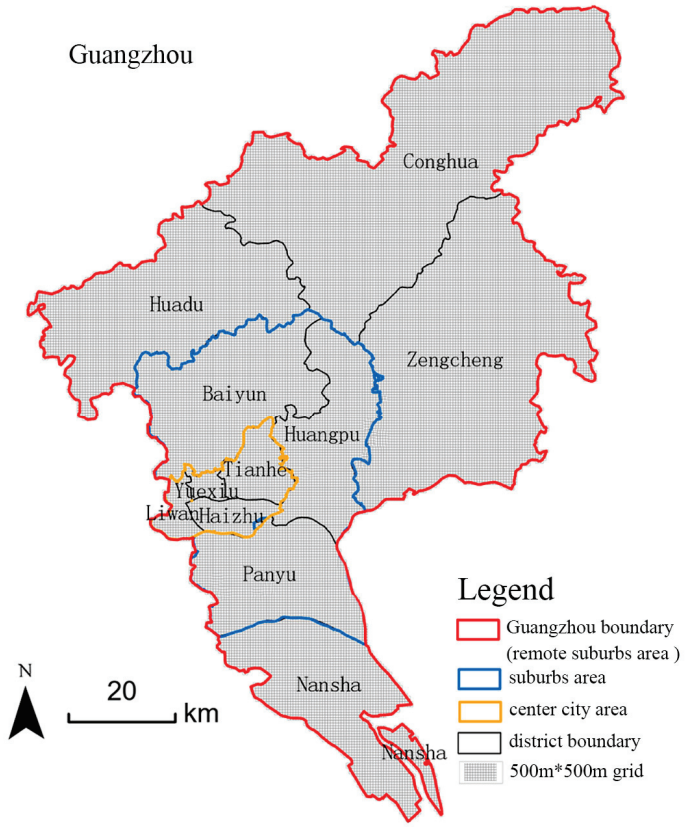


Figure 2. Map of Guangzhou city districts.

Table 1. Categories and quantities of POI data related to service facilities for older people.

Data Source	Category	Quantity
POI data	Accommodation	21,287
	Attractions	6891
	Catering facilities	72,961
	Corporations	126,000
	Governmental facilities	29,750
	Financial facilities	12,572
	Life services	101,446
	Medical services	17,493
	Real estate	11,676
	Scientific, educational, and cultural facilities	31,167
	Sports and leisure facilities	3521
	Shopping facilities	225,541
	Transportation	2357
	Service facilities for older people	1369

Census data contain a wealth of spatial geographic information, combined with information on individuals, households, and dwellings, and are widely used in studies of the spatial distribution of urban facilities [47]. The census is an inevitable requirement for an accurate picture of China's demographic situation, an objective necessity in solving demographic and related social problems, and provides important basic information for the implementation of the national strategy of actively addressing population aging and promoting high-quality development [2]. The latest Seventh Population Census of Guangzhou in 2020 showed that the city's total population had reached 18.67 million, of which 2,130,598 were aged 60 and above, accounting for 11.41% of the city's total population, while 1,460,333 were aged 65 and above, accounting for 7.82% of the city's total population. Compared with the 2010 Sixth Population Census, the proportion of people aged 60 and over and 65 and over has increased by 1.67% and 1.15% respectively [48]. Data on the specific elderly population in 171 streets are shown in Figures 3 and 4. Figure 3 shows the number of people aged 65 and over in each street, while Figure 4 shows the aging rate in each street. In terms of the number of older people, there are 50 streets where the number of people aged 65 and over exceeds 10,000, with the highest number of older people in a street reaching 29,601. Regarding the aging rate, there are 107 streets where the aging rate exceeds 7%, and 40 streets where the aging rate exceeds 14%, indicating severe aging. These detailed population data serve as important bases for the setup of service facilities for older people.

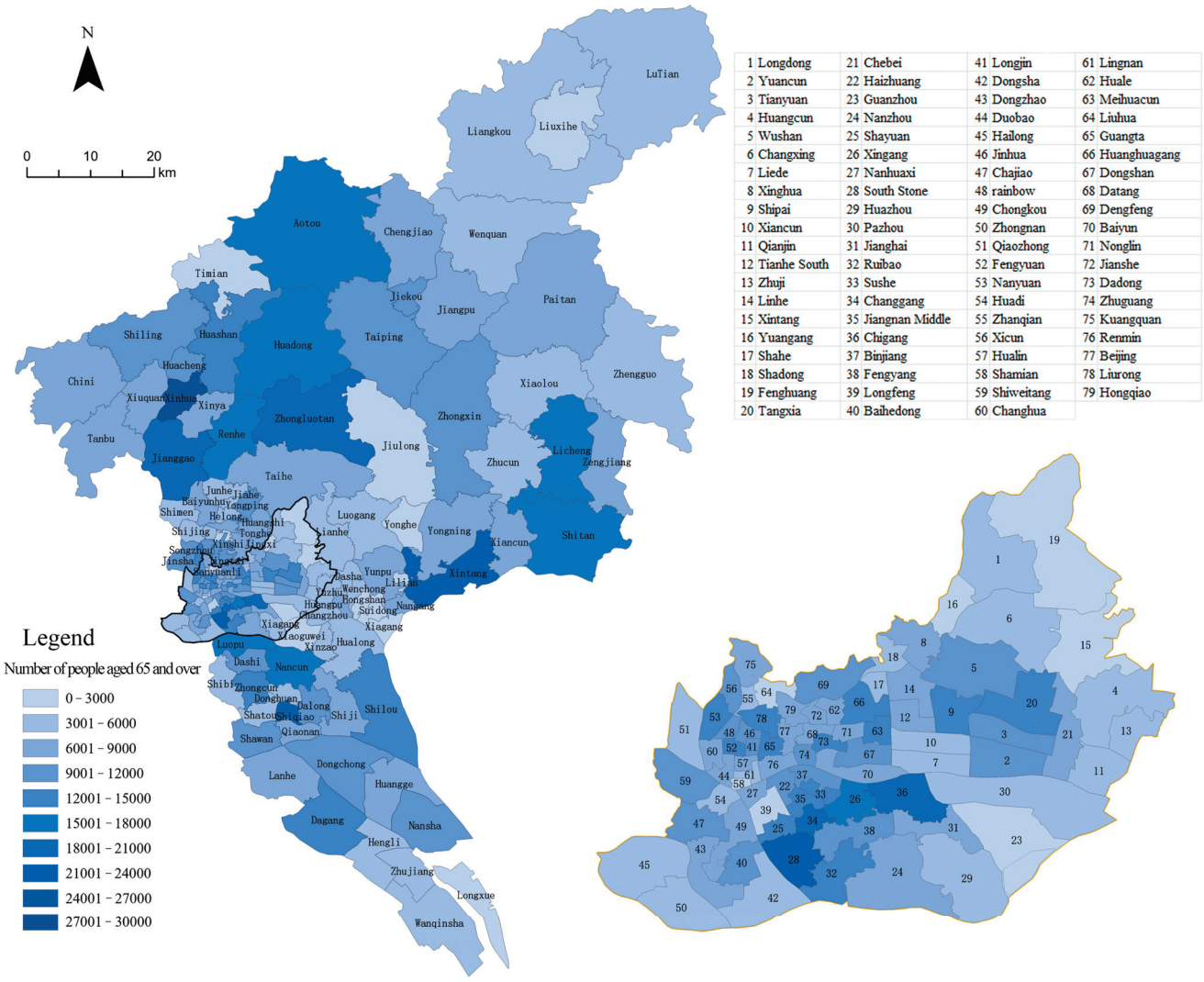


Figure 3. Size of elderly population in each street in Guangzhou.

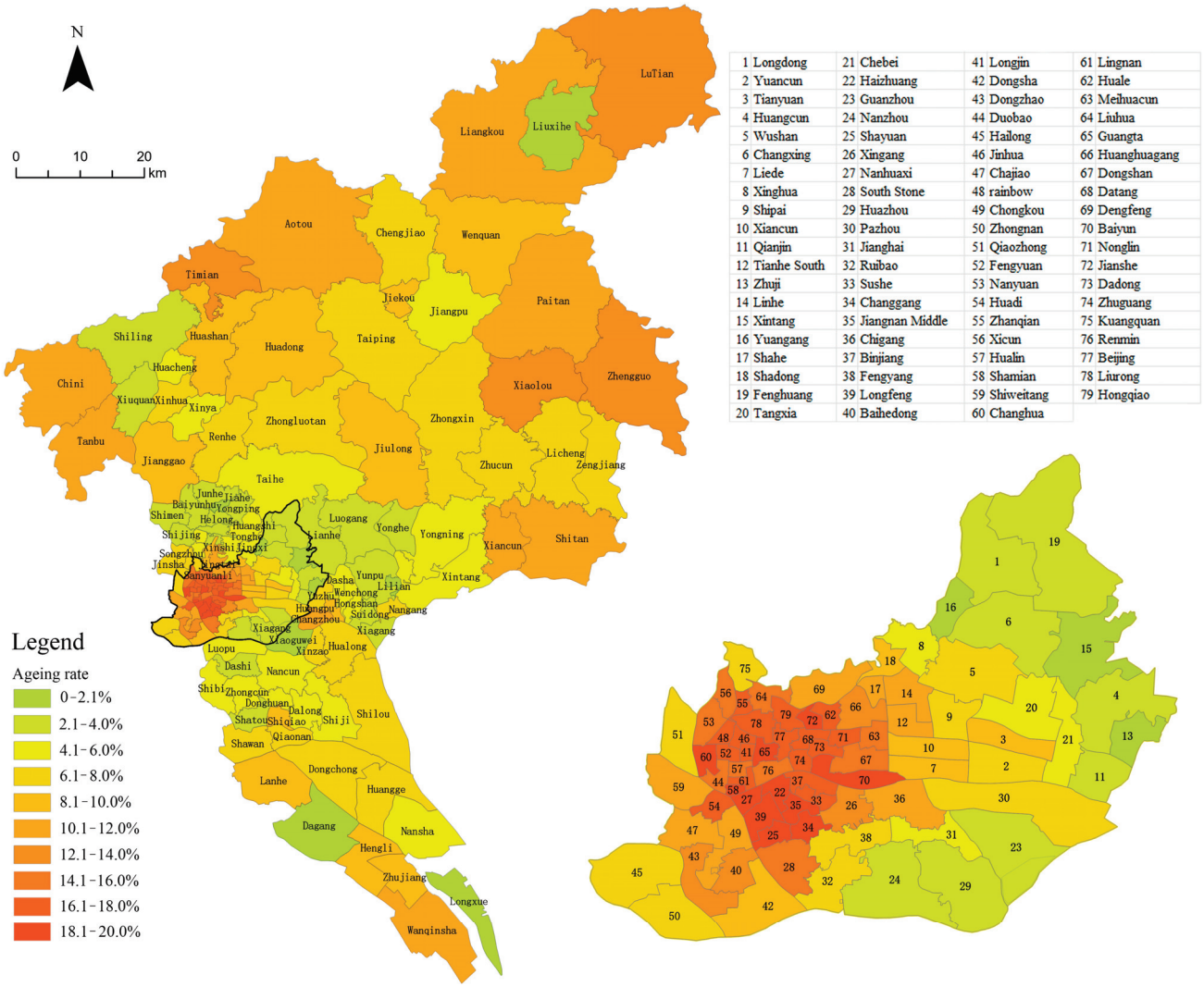


Figure 4. Aging rate of each street in Guangzhou.

3. Methodology

Service facilities for older people, as a type of basic functional facility in the city, are closely related to the distribution of other public facilities. Therefore, it is reasonable and relevant to analyze the current distribution characteristics of service facilities for older people and optimize the future layout of these service facilities in Guangzhou through POI big data. This paper also draws on similar research methods [39]. The methodological framework of this study is shown in Figure 5 and described in detail below.

3.1. Gridding the Distribution of Urban Public Service Facilities

First, using the spatial overlay function of the ArcGIS 10.2 software, the POI location information is overlaid on a 500 m × 500 m urban grid to obtain the distribution status of the urban public service facilities in each grid. Among the 29,793 grids in Guangzhou, there are 15,771 valid grids containing public service facilities, of which 985 grids contain service facilities for older people. These 985 grids containing service facilities for older people are used as positive samples in the dataset, while the same number of grids not containing service facilities for older people are randomly selected as negative samples to construct the dataset for machine learning. Then, 80% of the grids from this dataset are randomly selected as the training set and 20% of the remaining dataset is used as the validation set to verify the accuracy of the model. Excluding the dataset for the training of the model, the rest of the grid data are used as the final test set.

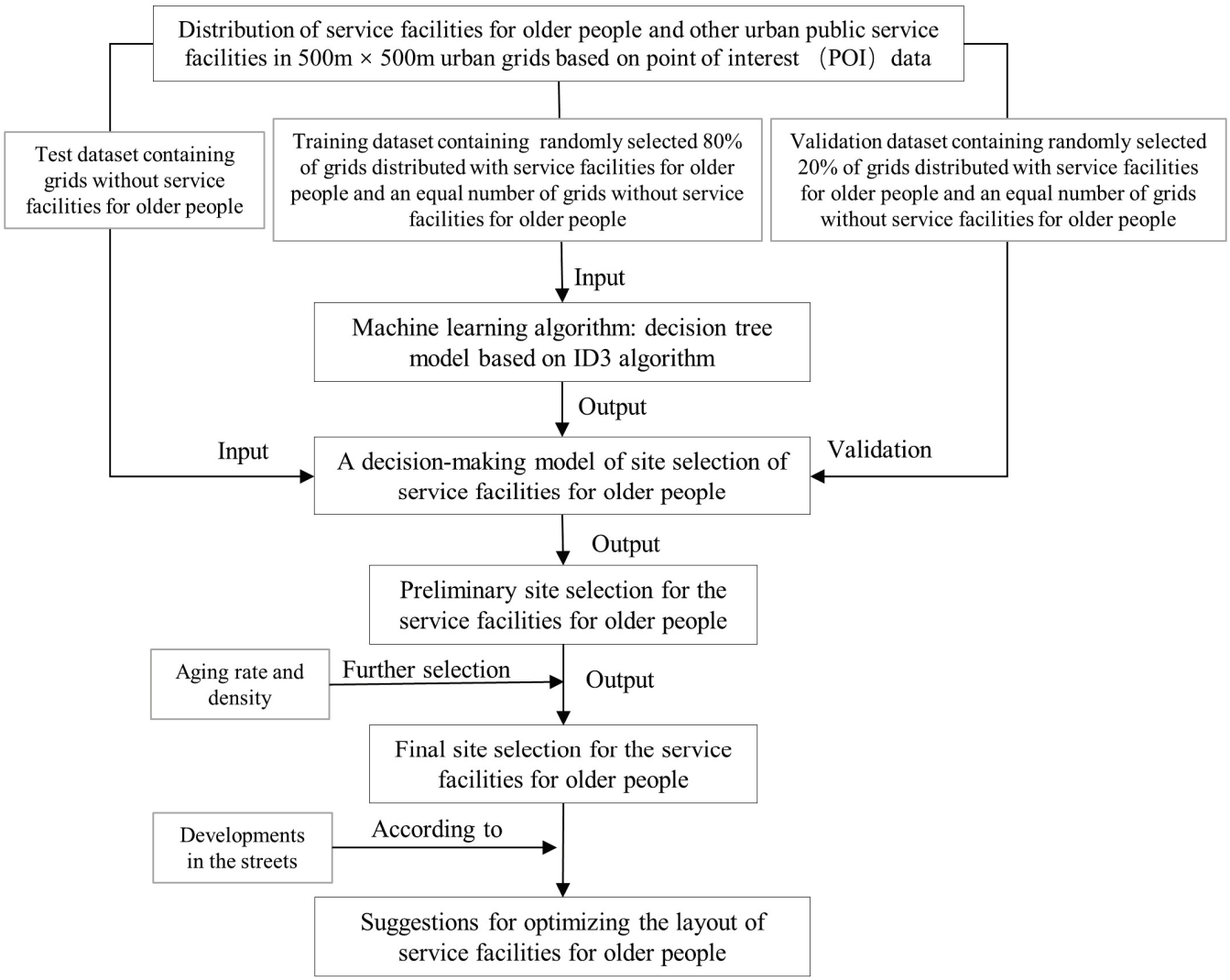


Figure 5. Methodological framework.

3.2. Training of the Prediction Model for the Siting of Service Facilities for Older People

Second, the machine learning ID3 algorithm is used to simulate the distribution pattern of facilities for older people and obtain a preliminary site selection decision model. The ID3 decision tree algorithm is a supervised learning algorithm [49,50] that is widely used in data mining work such as the classification and prediction of POI big data [51]. The ID3 machine learning algorithm is mainly based on the distribution of public service facilities in the urban grid, seeking to determine whether the urban grid is suitable for the implementation of service facilities for older people. According to the POI data, 13 types of existing facilities in the grid are used as the independent variables, and the availability of service facilities for older people is used as the dependent variable, to train the decision tree based on the ID3 algorithm for siting [39]. Using the above-prepared training set data, a decision tree model for the location of urban service facilities for older people in Guangzhou is trained, and then the validation set is used to evaluate its accuracy. The result shows that the accuracy of the model is as high as 87.46%. This result indicates that the configuration of the existing service facilities for older people is highly consistent with the predictions of the model. Therefore, the model is reliable and suitable for the prediction of sites for new service facilities for older people.

3.3. Prediction of the Siting of Service Facilities for Older People and Recommendations for the Optimization of the Layout

Third, the data of the grid that does not contain service facilities for older people are input into the above-trained older people service facility site selection model to predict the overall older people service facility sites in Guangzhou city, so as to obtain the preliminary site selection suitable for service facilities for older people. Then, according to the population data on the existing streets, the site selection is optimized and filtered to determine the final predicted sites for the service facilities. The final site selection is compared with the current facilities and the urban development of each district and street to give recommendations for the optimization of the layout of service facilities for older people.

4. Results

4.1. Preliminary Site Selection for Service Facilities for Older People

The test set data were fed into the trained model, and 4534 grids of suitable service facilities for older people were obtained as the preliminary site selection (Figure 6). The results have the following characteristics. The preliminary site selection is consistent with the distribution of service facilities for older people in the current situation. Overall, there is a clear difference in the number of predicted points in the three circles, which are mainly clustered in the central city area, with a gradual decrease in the number of predicted points as the distance to the central areas increases. For the same reason, other preliminary sites are clustered in the central streets and townships of each district. Specifically, the Liwan and Yuexiu districts, the oldest districts in the central urban areas, have the largest number of preliminary sites and also the largest number of existing service facilities for older people. In contrast, newer urban areas such as Tianhe district, where commerce and education are the main functions, have fewer existing service facilities for older people and more sites for new service facilities for older people. Baiyun district and Panyu district, in the suburban area, are also relatively well developed in terms of urban public service facilities. The distribution of site points is also relatively even, with the prediction points in Huangpu mainly concentrated in the southern part of the district, mainly affected by the natural geographical environment, and in the northern part of the district, mainly in the natural mountainous terrain. The prediction points are scattered in the centers of villages and towns that have a certain level of infrastructure. The preliminary site distribution characteristics of the Huadu and Nansha districts among the far-suburban districts are similar to those of the near-suburban districts, while the more peripheral Conghua and Zengcheng districts are restricted by their hilly natural environments, with the predicted sites mainly concentrated in the center of each district and the other predicted sites mainly scattered. The preliminary site distribution also has a distinctive feature in that it is closely connected with the city's major transportation, mostly built around the highway, subjected to the spillover of the pressure of the center of the city's aging population.

Based on the decision tree model and POI data, it is possible to obtain a preliminary selection of sites for the new service facilities for older people, which is predicted on the basis of the public facility situation in the city. However, in order to obtain a more accurate selection of locations, we also need to consider direct factors such as the elderly population and the aging rate in each region. This process helps to determine the final site selection and to prioritize areas of high construction demand in the government's decision-making process.

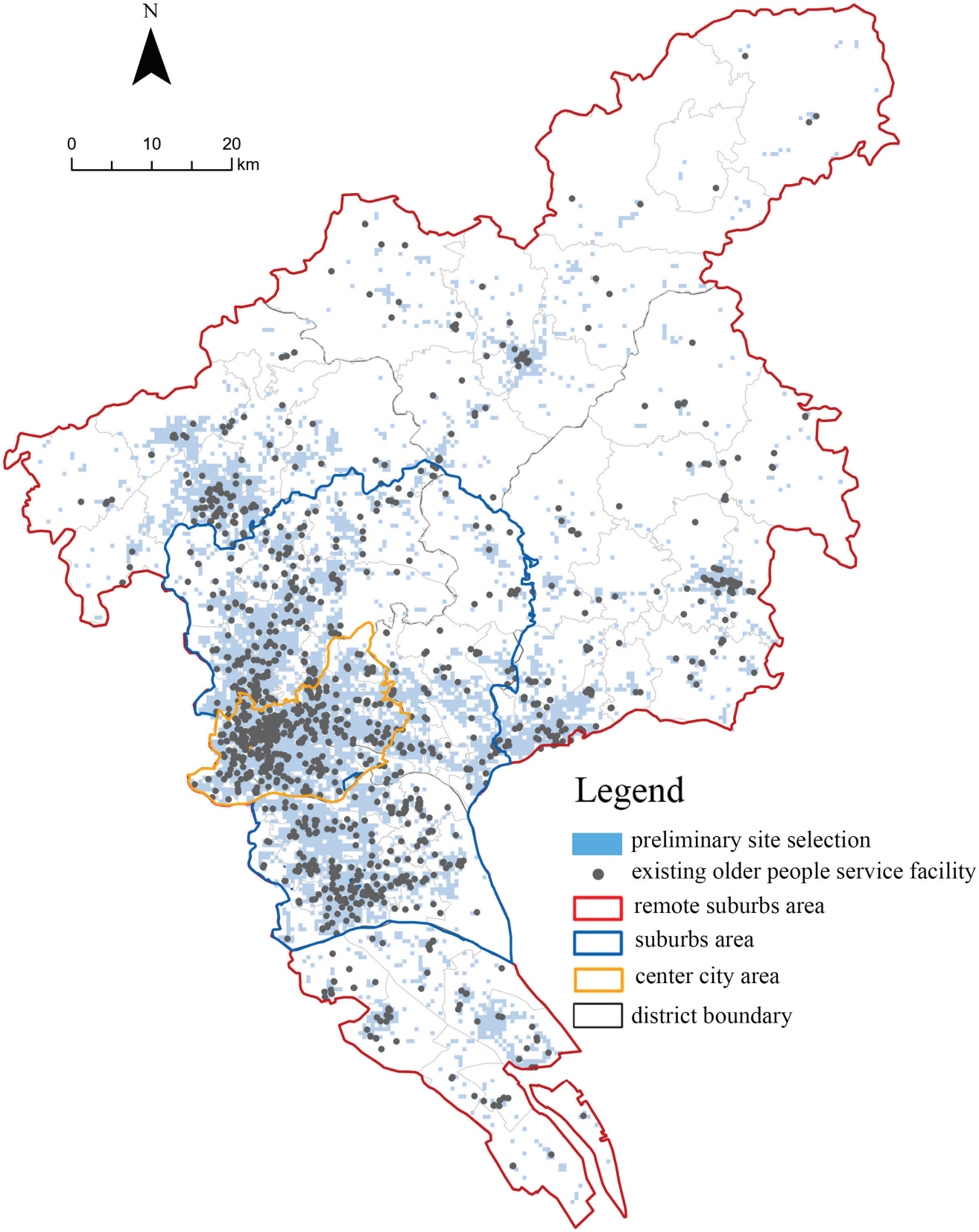


Figure 6. Preliminary site selection for service facilities for older people.

4.2. Final Site Selection for Service Facilities for Older People

One of the main considerations when choosing the location of a new service facility for older people is to meet the demand for older people's services of the population in the area [45]. Once the proportion of people aged 65 and over exceeds 7%, it means that the region has entered the stage of an aging society; therefore, the construction of new service facilities for older people in such a region should be prioritized. In addition, the size of the elderly population is also an important consideration in deciding whether or not to build service facilities for older people. The average number of people aged 65 and above in each street in Guangzhou has exceeded 8000; therefore, those streets with a population of more than 8000 should be the key areas for the construction of service facilities for older people in Guangzhou. The aging rate of each street was calculated based on the total populations of 171 streets and the number of older people aged 65 and above, and the selected neighborhoods with aging rates of more than 7% and streets with populations of 65 and above exceeding 8000 people. The results showed that 62 streets in Guangzhou city met the requirements. Then, using ArcGIS, all grids covered by the 62 streets were searched for suitable sites, and the grids with an existing layout of senior living facilities were removed. Finally, 1066 grids suitable for new service facilities for older people were obtained as the final site selection.

As shown in Figure 7, 62 streets in Guangzhou have an aging population of more than 7%, which need to be considered primarily as new sites for the building of service facilities for older people. Among these streets, 24 streets have an elderly population aged 65 and above exceeding 14%, making them severely aging neighborhoods. Three of these streets even have an elderly population of more than 15,000. These streets are mainly concentrated in the Haizhu and Liwan districts, among which the aging problem on Shayuan Street is the most severe, with the aging rate of the district reaching 20%. Reviewing the above situation, the aging problem in the Liwan and Haizhu districts is more prominent. However, they have complete public facilities; hence, there are many potential locations for new service facilities for older people.

For the suburban area of Guangzhou, the influx of the working-age population attracted by the modern service industry and strategically emerging industries has reduced the degree of aging in the area. In this area, eight streets have reached an aging level, including three in Baiyun district, four in Panyu district, and one in Huangpu district. Although the degree of aging in the suburbs is relatively low, there is still a considerable number of older people. For example, the elderly population on Shiqiao Street, Panyu district is as high as 23,400. As the area is well equipped with infrastructure, abundant medical resources, and convenient transportation, there are many suitable locations in which to introduce elderly service facilities.

In the remote suburban area, the streets with a high degree of aging are mainly located on the border between the near suburbs and the far suburbs. The aging situation of the streets is similar to that of the suburban area, with some streets having very large elderly populations, such as Xinhua Street in Huadu district, where the aging rate is 7.45% but the number of older people reaches 29,601. Many streets in the far suburbs have not yet been listed as priority areas. However, because these streets are far from the cities, have a large elderly population and relatively outdated facilities, and are scattered, the need for new facilities for older people in the suburbs is even more important. It is necessary to build new facilities for older people in these suburban areas based on preliminary site selection.

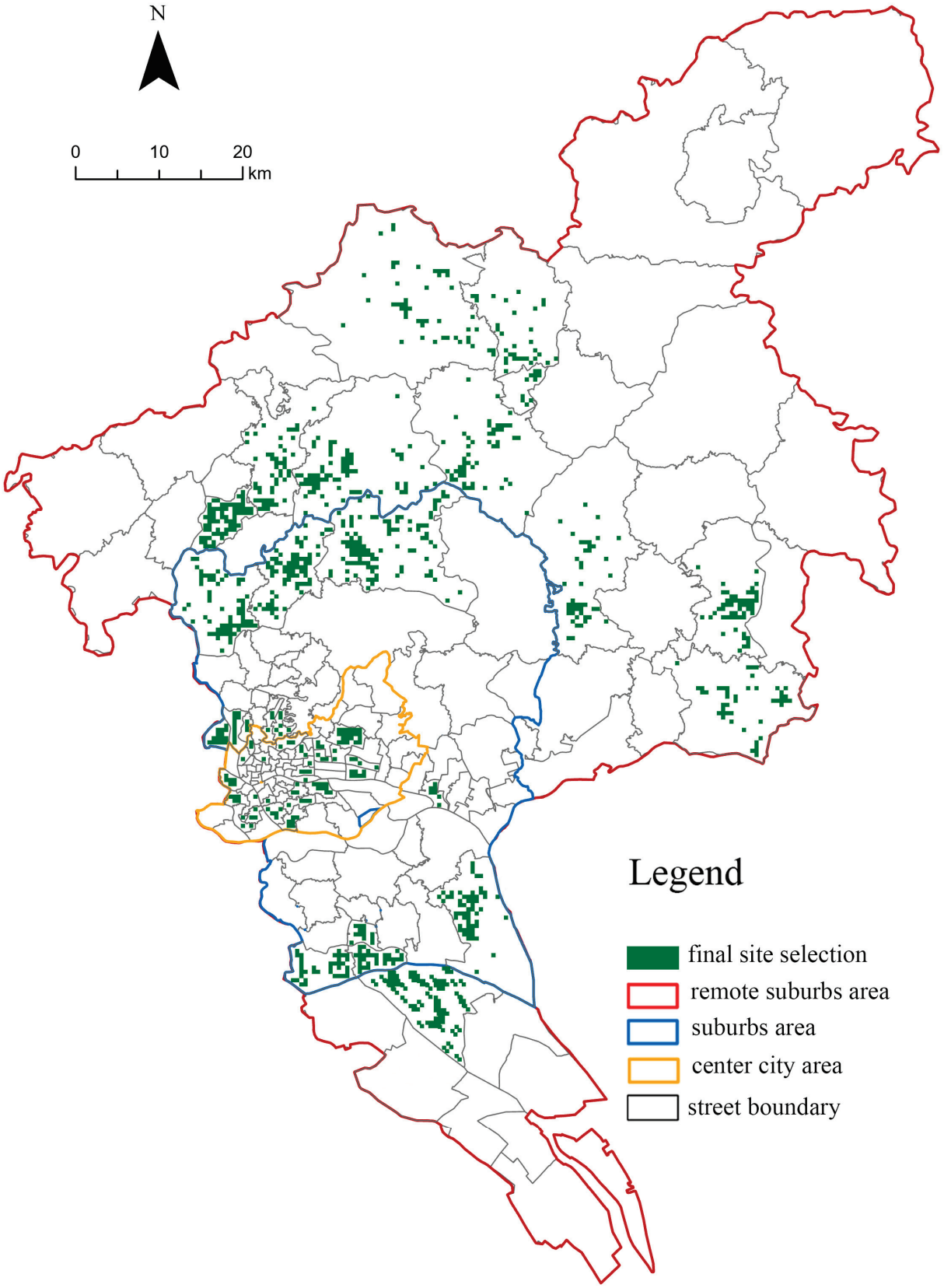


Figure 7. Final site selection for service facilities for older people.

4.3. Suggestions for the Optimization of the Layout of Service Facilities for Older People

The site selection of service facilities for older people mainly considers the number and the aging rate of the population of each street. The implementation of the optimization of the layout of service facilities for older people must also take into account the actual conditions of each street. The central urban areas are seriously aging, with a concentrated demand for service facilities for older people, but there is a shortage of land for new construction. Therefore, the existing institutions in these areas should be renovated and upgraded, and advanced medical equipment should be introduced to improve the service quality and maximize the use of existing resources. In addition, more community services for older people should be established in densely populated areas to complement institutional services for older people. Especially in the resource-poor Yuexiu district, more community elderly care centers should be established to improve the home-based elderly care services. At the same time, it should also be considered to transfer older people to large-scale elderly care centers in other districts to alleviate the pressure on elderly care. As for Tianhe district, which is dominated by commerce, due to the high land prices, it can be considered to use high-rise and large-scale facilities to save land and fully utilize the city's public facilities. According to the characteristics of different regions, various types of service facilities for older people can be built. For example, Wushan Street in Tianhe district is a university cluster, so we can make use of its rich educational resources to build community schools for older people.

The suburban areas are rich in land resources, and new residential areas are plentiful and affordable. As a result, Guangzhou's suburban areas are likely to welcome a large number of residents in the future. In view of this, we propose that suburban areas be the key areas for the construction of future service facilities for older people, while medium and large service facilities for older people should be built in residential areas. Furthermore, the planning and layout of services for older people in the suburbs should be tailored to the local conditions, continuously adjusting and optimizing the spatial layout according to various indices like the structure and density of the resident population, rather than simply establishing large-scale facilities due to issues of land use or funding.

For remote suburban areas, considering their relatively inexpensive land prices and excellent natural environment, large-scale elderly care institutions can be built in conveniently located areas. High-end commercial elderly care institutions can be introduced to these areas to meet the vacation and leisure needs of some older people. In more remote towns, taking into account their large populations and sparsely populated nature, large service facilities for older people can be established around township centers, taking advantage of the well-developed transportation networks and expanding the scope of the services.

5. Discussion and Conclusions

In this study, POI data are combined with machine learning algorithms to more scientifically and comprehensively consider the factors influencing the site selection of service facilities for older people, and, at the same time, the study refines the site selection to the accuracy of 500 m squared at the street level. In contrast, most of the previous planning for urban senior service facilities was based on urban land use planning [52] and natural population growth matching [53], as well as the evaluation of the current situation [27]. The predicted site selection in this study is more objective, more effective and precise for the site selection of urban service facilities for older people in Guangzhou, and more targeted towards the urban construction suggestions.

The methodology and results of this study also have important implications for planning and allocation decisions for public facilities in cities in general. First, by dividing the city grid more precisely, we can provide more accurate results for the location of service facilities for older people, which will help to avoid wasting public resources and land resources [54]. Second, with the help of machine learning methods on large amounts of current urban data, we can now better simulate the patterns of these urban forms. The use of machine learning has been proven to make some urban economic infrastructure

more efficient, resilient, and inclusive, thus providing better quality of life for residents [32]. Furthermore, the creation of smart, digital, and connected cities is the main direction of modern urban development. It is not only service facilities for older people but also other healthcare and public service facilities that face the same digitization needs, which require the collection and simulation of rich urban big data, and the use of machine learning methods is beneficial in addressing the integration of facility planning in digital and smart cities [40].

This study also has some limitations. It is based on urban POI data, which are applicable to the more mature development and data coverage of the city; however, for the city's new districts or departmental infrastructure, where the construction is not complete, the POI data will exhibit incomplete coverage and insufficient data, and the results of the analysis will have a certain degree of bias. This study also does not separate service facilities for older people, and, in future research, urban service facilities for older people can be further subdivided according the level and service scope the facilities. Moreover, the differences in the location and layout of different types of service facilities for older people need to be further explored [39]. In addition to the issue of facility distribution, the impact of individual preferences, gender differences, and other subjective perspectives on service facilities for older people is a direction worth considering for future research [55].

This study focuses on the megacity of Guangzhou in China. Using POI data and machine learning algorithms, we develop a street-level location selection model for new service facilities for older people in Guangzhou. Based on the range of activities of older people, we divide Guangzhou into 29,793 grid units of 500 m $\times$ 500 m. Among these grids, 985 grids contain service facilities for older people and are selected as the model training dataset. Then, we use the ID3 decision tree algorithm to train a site prediction model for service facilities for older people. Through this model, we identify 4534 grids within Guangzhou as the preliminary site selection for new service facilities for older people. Taking into account the aging rate and the number of older people in each street, we further narrow the scope and finally select 1066 grids as priority sites. Finally, based on the selected sites and the actual social conditions of each district and street in Guangzhou, we propose optimal construction strategies for service facilities for older people.

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Article

Importance of STEM and STEAM Education for Improvement of the Land in the RURAL Environment: Examples in Latin America

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Abstract: Interdisciplinary STEM and STEAM education gives us the opportunity for training students to achieve all educational objectives in a sustainable development framework. Land in a rural area is a scenario with a range of educational resources for the development of STEM and STEAM projects to train students to interact with the rural environment. The possibilities of the land in order to prepare students for the needs of today's world are linked and sensitized to the environment. In this article, we will offer contemporary examples of STEM and STEAM projects that have been carried out in Latin America. These projects are being developed in which young people establish links with their environment, territory, and the local environment surrounding them. We must look carefully at projects and works in which students' ties to their land and environment are valued through the STEM and STEAM education necessary today. In this scenario, a comparison has been made between the projects in Latin American countries and Spain.

Keywords: STEM and STEAM education; interdisciplinary education; sustainable development; environment; rural environment; land; Latin American; Spain

1. Introduction

Rural environments worldwide offer endless educational resources that must be valued. While it is true that countries in different parts of the world have their own rural situations and therefore precise comparisons cannot be made, it is necessary to look at what some countries are doing to educate and create a population that sustains the rural environment and the planet. The education one receives throughout one's life and especially from an early age will constitute one's outcome as a human being. According to Luengo [1], the first maternal care, the social relationships that occur within the family or with groups of friends, attendance at school, etc., are educational experiences that shape our way of being.

The importance of the concept of education is complex. What precisely does education mean? School, high school, and university are linked closely for most people. However, it must be agreed that education is a broad concept closely related to the experiences of human beings throughout their lives.

We must ask ourselves what the purpose of education is, why one has to be educated, and what one is looking for when one is looking to be educated. As Touriñán exposes [2], the fundamental objective of education, as a result, is the acquisition in the educational process of a set of behaviors that enable the student to choose, commit, decide, and carry

out their personal life project. These behaviors will constitute a means to create valuable people and are a form of insertion and prosperity in human beings.

There are different types of education; one could speak of formal, informal, and non-formal education, although according to Pastor [3], the concepts of formal and non-formal education have an evident historical and political relativity, since an educational activity can be formal in a country and non-formal in another. At this point, we can reflect again since, in each country or territory, a specific type of education will be binding to the formation of their citizens, and this will be so for different reasons, mainly social reasons.

As Delors affirms [4], one of the four learnings around education throughout life will be "learning to do" to influence one's environment. Training people to impact the environment positively is a current objective in education.

Education must generate a path of improvement, and in our current world of the 21st century, our societies must be able to commit to the improvement of the planet, which means that individuals must be involved in caring for their environment and habitat.

Faced with environmental problems such as those arising from global climate change and what this implies, such as droughts, fires, reduction in ice at the poles and other catastrophes, a possible solution that involves human beings in respecting the environment must be sought through education. According to Hall and Bridgewater [5], the time has come for approaches to mitigate environmental deterioration to be given priority in the context of communication, education, and public awareness. Otherwise, we risk entering a spiral of environmental destruction with dire consequences for humanity.

With the emergence of the concept of environmental education in the 1970s, at the International Environmental Conference in Stockholm, education has contributed to generating changes in people, their attitudes, and their environmental values. Environmental education and the development of projects from school linked to respect for the Earth train children, who will be our future society, to be more sensitized from an early age to their urban or rural environment. Environmental education constitutes the educational process that deals with the relationship of the human being with their environment (natural and artificial) and with themself, as well as the consequences of this relationship [6] in the human being themself, in their land, their environment, and obviously in their life.

To review the origins of when environmental education became important, one has to go back to the preface in the book edited by UNESCO in 1980 [7], which includes the main guidelines of the UNESCO Tbilisi Conference. The Tbilisi Conference [8] constituted the starting point of an international environmental education program, according to the unanimous desire of the Member States. Environmental education began to gain strength precisely at that moment, a decade in which the planet was already experiencing immense noticeable environmental changes due, among other causes, to significant industrial and technological advances. In that same book, it is stated that environmental education, properly understood, should constitute a general continuing education that will react to the changes that occur in a rapidly evolving world [7]. That leads us to think about the importance of a permanent education that can and should be developed to achieve the union of the human being with their environment, with the environment that surrounds them, with the land that surrounds them, always taking care of nature and in short, taking care of the planet. The same document says that by adopting a global approach rooted in a broad interdisciplinary base, environmental education creates a general perspective within which a profound interdependence between natural and artificial environments is recognized. That leads us to think about the importance of interdisciplinary education today since our current world is interdisciplinary, and interdependence between the natural and artificial environment exists today. As humans, we must take advantage of resources that can provide interdisciplinary education, improve human beings, and make people more sensitive to caring for the environment, land, and planet.

As Labrador and Del Valle [9] mention about the Moscow Congress of 1987 [10], environmental education and the perspective that it should be addressed to the public of all ages and educational levels, also in non-formal education and education of adults, for

specific, very diverse, professional and/or social groups. Within this diversity, including people who live in rural areas is necessary and very valuable. Environmental education also harbors the nuance of transdisciplinary. As Schrodinger [11] suggests, transdisciplinary is one of the highest ideals of environmental education, in that environmental objectives can only be achieved by addressing the issues across all areas and forming new associations. Martínez [12] explains that there has been awareness of the interdependence between the environment, development, and education based on a transversal and transdisciplinary response providing an educational paradigm. Working on environmental education is the basis for generating a series of changes in the behavior of human beings that will lead to creating more just, more developed societies that are more careful with their habitat, which is the land on which they live, their environment, and the planet.

Considering everything mentioned, education for sustainable development has been proposed for some years. Currently, the 17 Sustainable Development Goals (SDGs) of Agenda 2030 [13] will lead us to a better and fairer world. Goal 4, which proposes quality education, is essential to educate our children.

A permanent, interdisciplinary, and transdisciplinary education will train citizens to be better prepared for the world they have had to live in; a world of problems and advances. When talking about the problems, it is necessary to recognize the social, economic, and environmental issues, territories with hunger and wars, which humans must be capable of improving in many aspects to affront those. An education that trains citizens with interdisciplinary and transdisciplinary approaches will help people emerge better developed to adapt to these times. Permanent education should also be designed to sensitize these people from an early age to their land, environment, and planet. In that case, people will be better formed to live on this planet through knowledge and thus be more sustainable, resilient, resolute, and committed to their environment.

STEM education was born in the United States in the 1990s, as the integration of sciences, technology, engineering and mathematics. STEM is an acronym that serves to refer to the professional field that includes the different scientific–technological disciplines but also to refer to the set of knowledge, skills and practices that must be promoted and developed throughout schooling [14]. Educational policies in different countries are recognizing the importance of STEM education [15].

The STEM educational model has, as its pedagogical model, the promotion of academic autonomy for students through the development of critical thinking in environments oriented towards the formation of learning communities inside and outside of the classroom. In 2006, the STEM model was redefined, incorporating art into its structure, and called STEAM [16]. This educational model allows artistic skills such as empathy or creativity to address science, technology, engineering, and mathematics from different perspectives. A collaborative learning approach transforms theories into models applied to real life and the world around them. It is a strategy to know and understand reality throughout life from inquiry and interaction.

Interdisciplinary STEM and STEAM education presents an opportunity for creativity and educational innovation in a world scenario that needs training in which students can achieve all educational objectives and are prepared to achieve sustainable development.

The STEM Women's Congress held in 2021 discussed how science unites with the environment through STEM education [17]. According to Pearson group [18], STEM projects with a focus on social responsibility are ideal for raising awareness and instilling values in the environment since they start from real needs (for example, using greener energy or improving the nutrition of a community) and empower students to find solutions on their own. STEAM methodology involve more than the incorporation of the arts; Piaget and Vygotsky have already pointed out the processes of assimilation, accommodation, scaffolding, and a global vision of education is the novelty of this methodology, as it does not work with science, technology or the arts independently [19]. According to the OAS practical guide, to achieve an inclusive society, it is essential to incorporate a gender perspective in STEAM education programs and initiatives, and STEAM professions are rapidly growing

and have greater influence in promoting innovation and the economic development of countries. STEAM education also promotes individual and social–economic success [20]. As Jiménez [21] states, according to data from the Ibero-American Science Observatory, Technology and Society (OIE), 2020, educational management strategies must be reoriented to guarantee the increase in scientists with interests in the formation of identities in science, technology, engineering, arts and mathematics, addressing global and national problems of Latin America and Caribbean countries.

Educating for the environment is necessary; unfortunately, it is often not a current goal. This article highlights the importance of global action to make environmental education a necessary reality for sustaining the planet. The 2030 Agenda for Development Sustainable highlights the importance of the STEM approach to education development. It refers to the relevance of the participation of women in STI through STEM. Furthermore, this entity displays the "education in science, technology, engineering, and mathematics (STEM); and education for sustainable development (SDG) as part of a quality education" [13]. Vallejos and Callao [22] emphasize the need for the educational and environmental process to lead individuals to perceive themselves as members of and as co-responsible for the environment; however, teachers, scientists and public policy makers still have a limited vision. There are countries like Colombia where the concepts and characteristics of environmental education clearly stated in the policy of education, environmental education and the PRAE are the pedagogical strategy for the inclusion of environmental education as a transversal axis in the educational formal system [23].

Currently, in order to improve the current rural situation, STEM and STEAM education is being developed in Latin American countries (such as Colombia, Chile, and Peru) and in European countries (such as Spain), with significant differences, but with a shared background towards improving the rural situation.

The rural women in the Latin American countries studied in this article suffer from a gender gap that translates into the early leaving of school, with all that this fact implies. Carrying out STEM and STEAM education to address the gender gap is important nowadays and even more so in rural areas. Many countries develop programs along these lines.

Local sensitivity is achieved by valuing and using the resources of the rural environment to carry out STEM/STEAM education. Activities, sessions, and projects are developed that link students with their environment, their habitat, their people, their culture, and their traditions; with all this, we manage to enhance sensitivity to the local communities, which will result in a desire to stay in the countryside, caring for it, respecting it and working sustainably with everything that the countryside has to offer, and of course, their land. It is essential to set up governmental educational programs that work on the rural environment and gender.

According to Rubio [24], the depopulation and ageing of rural communities are problems that occur equally in Europe and Latin America; they are caused by the lack of generational replacement in the activities that persist, and the slower economic development of the latter aggravates poverty. Land in rural areas is fundamental: it provides food, income from its cultivation, and economic and social possibilities, thus its care and development are essential to rural areas. Rural dwellers have been tied to their land for generations and their care, knowledge, and maintenance keeps the rural area and its people alive.

2. Objectives and Methods

This study aims to demonstrate that STEM/STEAM education applied in the rural world can be an integrative tool that serves as an impulse for the creation of new citizenships committed to social and environmental justice and, at the same time, are committed to achieving changes that lead to creating links with the territory in which they live and increasing opportunities in this environment. This article is a source to see the rural world and its resources as an educational source to carry out STEM and STEAM education in students, observing STEM and STEAM education as an education capable of training

students who can achieve all educational objectives and are prepared to achieve sustainable development. To this end, and in order to narrow down our research, some experiences of STEM/STEAM education to improve skills in rural areas of Latin American countries are fundamentally examined. We mainly focus on Colombia, Chile, and Peru countries, where interesting STEM and STEAM education is developed.

The specific actions developed in this study analyzed the situation in Latin American countries, especially Colombia, Chile, and Peru, regarding education in rural areas and STEM and STEAM education. Likewise, we proceed with are view of educational programs and laws developed in these countries, collecting successful cases of the implementation of STEM and STEAM education in rural areas.

In addition, various actions of Spain in this area are reflected, not to make a precise comparison with Latin American countries, since this is not possible because they are countries with very different situations, but to highlight the advances in STEM and STEAM education for the improvement of education in the rural world in different Ibero-American countries.

This article reflects comparative educational research using qualitative methodology. The qualitative study is based on a bibliographic review of documentary sources on the evolution of STEM and STEAM, focused on the rural world. Considering the research, the selection of primary and secondary sources was made considering the following keywords: STEM and STEAM; Latin America; rural education; Colombia; Chile; Peru and Spain, since 2000.

The results were systematized and organized to facilitate this study. The primary sources are those based on reports, legislation, and other institutional publications of governments and international organizations such as the United Nations. Regarding secondary sources, a search was carried out for scientific research articles related to the topic of study in bibliographic databases and storage systems for academic publications. All of this information has been categorized into three levels of information, considering the theoretical–conceptual approaches provided by various researchers, institutional approaches and documents, and some contributions from non-scientific publications associated with the object of study.

3. Education for the Improvement of the Land in the Rural Environment

Currently, the rural population represents 70% of the world's population, and inequalities between the countryside and the city constitute a significant obstacle to sustainable development. This is why rural education is traditionally addressed with subsidiary policies, especially in developed countries [25].

In the midst of the COVID-19 pandemic, villages became important safe havens where many people from the cities went to live and work. Before the pandemic, many urbanites from the cities only saw towns as a place of rest, but towns should be a place to live in an excellent way with all the benefits offered by rural areas at the service of citizens. As Hernández [26] points out, it is important to highlight the recovery of cultural heritage for the population and the projection of local culture for society as a whole. The territory must be presented as an opportunity to live. However, these roots are maintained, and with this, there is an improvement in the rural environment and its land and people, which is a direct consequence of our fundamental factors to fix the population in rural areas through education, health, technology, and employment [27]. Gavari, Espinosa and Lucini [27] point out that education is the protagonist, and the other three factors revolve around it. Let us then recall the 17 SDGs of the 2030 Agenda, which revolve around SDG 4; women being employed is of vital importance, hence the importance of gender equality in terms of educational and employment opportunities in rural areas.

It must be noted that a rural environment can show many problems and under recognized values. As Amiguinho [28] explains, emphasis must be placed on participatory insertion in the closest community to be a citizen of an increasingly globalized world: a citizen of the world is true from somewhere, with roots in the "local". These roots are maintained, and with this, there is an improvement in the rural environment and its land

and people, which will be a direct consequence of the four pillars that must be assembled for functioning in the rural environment: education, technology, work, and gender.

The rural environment offers us agricultural and forestry resources that must be exploited, and to do so, we must think about the fundamental physical, biological, historical–cultural, and economic values that are usually minorly recognized in the rural environment such as food production, rural environment reserves like minerals, plants, and animals, the rural environment presenting an oxygen factory at the service of humanity thanks to its forests, the rural environment as a source of culture in the form of traditions, customs, cuisine, and others, and it being a source of architectural resources, archaeological resources, and landscapes that are spaces of incalculable value [29].

In this sense, educational services for the improvement of rural areas stands out. How? By forming human beings that are better linked to their environment, their land, and their habitat. Thus, education can form human beings linked to the land they live on. But let us not only think of the youngest and of our future society, but also of our elders in the rural population.

Undoubtedly, citizens' education achieves economic, social, and environmental development. Economical because the best-educated citizens are able to face the financial problems that arise in their lives and their work; social because education makes human beings grow in all their social landscapes; and environmental responses because it can develop better-trained citizens in this area.

To the permanence of the rural environment, it is crucial that people can live in towns because there are means, work, and economic resources for their population. It is also vital that rural inhabitants have their full social expectations. To this end, it is important to address the problems of depopulation, aging, and gender in many rural areas. In the villages, we need to value our elders and women because if there are no women, the population becomes masculinized, and the village dies. The environmental ties from the rural world to its inhabitants are also crucial for maintaining the rural environment. If its inhabitants are sensitive to their environment and land, they will want to stay in it and live there, lasting with it. In this way, they will try to stay in rural areas, on their land.

In short, the importance of education, particularly STEM and STEAM education, to develop a current, interdisciplinary, transdisciplinary, and lifelong vision of the economy, society, and the environment using the educational resources offered by rural areas should be highlighted. The development of STEM and STEAM education projects in this area will train people who are better prepared in rural areas and are more linked to their land, with all that this implies. The rural environment with its land is a scenario that offers us a range of educational resources, which must be used in schools and institutes, linked to the agricultural and forestry world and also social, to, among other aspects, propose the development of STEM and STEAM projects in which students who are better trained and prepared for the needs developed of today's world, as well as students who are more linked and sensitized to the environment, to the rural environment and its land, thus are important in this time. With these resources, rural students can and should achieve interdisciplinary knowledge in science, technology, engineering, arts, and mathematics and be more prepared for today's world, since one of the objectives of this methodology is to contribute to developing student competencies. The 21st century has developed such that more children can become leaders, innovators, and researchers, and develop the tools necessary to face today's challenges and their communities' future [30].

The rural environment has social resources that should be paid attention to. A rural environment that suffers from depopulation, with a large part of the population aged in many areas of the planet, must take advantage of the knowledge and wisdom of its elders as educational resources. With their experience, culture, and wisdom, older people can become an additional educational resource, transmitting their knowledge to new rural generations [31]. Also, STEM and STEAM education can generate knowledge in reverse, generating new knowledge in older adults, such as the European Commission's "BRAIN" project, which aims to transmit a substantial and sustainable impact; older adults involved

in the local program, after having acquired new knowledge and skills, will act as replicators of their learning that will raise their self-esteem and promote their social inclusion [32]. This project, called "BRinging STEM into Active AgINg", has been financed with the support of the European Commission, and its information is included in the framework of the European program "Erasmus Plus KA2 Strategic Partnerships for Innovation and the Exchange of Good Practices".

4. Rural Situation in Latin America

Although it is true that already at the beginning of the 21st century, as Hendel affirms [33], several Latin American countries, mainly Bolivia, have begun to experience profound political transitions that propose the redefinition of the organizational parameters of their economy, their politics and their state, outlining a questioning of the notion of development that characterized the rural development policies of the world's great powersduring the 20th century.

Talking about the rural situation in Latin America is complex due to the number of countries we are talking about; all of them have differences, but they also have common points, such as the spoken language. The definition of urban and rural space in most countries is complex because the meaning of one does not default with the other. However, similar quantitative and/or qualitative criteria are generally adopted [34].

Poverty is one of the most persistent features of Latin American society and has been resistant to the conventional policies designed to reduce or eliminate it [35]. According to Clausen [36], rural territories are, therefore, still far from meeting the objective of not being "left behind" in eradicating all forms of poverty.

Bolivia, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Mexico, Paraguay, Peru, and the Dominican Republic are countries that have unquestionable natural and cultural wealth. Approximately 20% of the world's oil reserves, 25% of strategic metals, and more than 30% of primary forests are in the Latin American and Caribbean region [37]. The recognition of the use of the natural landscape to achieve a better quality of life is an element that has gained validity from rediscovering the concepts of rural development and new rurality [38]. Exploiting natural resources sparks disputes about the use of water, biodiversity, land, and critical ecosystems, among others, and about the repercussions that exploitation has on them [37].

It is important to know the situation of each rural territory, as well as the problems of the people who live there, especially the most vulnerable people: people of different ages (children and older people) and women in rural areas. The Latin American Center for Rural Development (RIMISP), a network formed in 1986 by different partners and allies, helps to understand rural transformations and formulate better strategies to achieve equitable territorial development in Latin America [39]. In the rural environment, understanding the rural situation, the environment, the people who make up it, and their problems, as well as moving towards the development of the land, is vital. The RIMISP highlights the importance of proposing respectful, relevant, and innovative research strategies that involve the voices and knowledge of territorial actors, considering ethnic, generational, and gender diversity [39].

Rural Situation in Colombia, Peru, and Chile

Colombia is the second most populous country in South America and the fifth largest in territory in both Latin America and the OECD [40]. In Colombia, the economy has recovered significantly from the COVID-19 crisis, and a strong response in monetary and fiscal policies has managed to avoid a further contraction in income. Economic growth has been observed, but to mobilize rural potential, the government must prioritize the structural challenges historically limiting rural development, such as gaps in access to quality health and education services [40]. Actually, Colombian rural communities are experiencing profound transformations in public policy. However, the institutional framework still maintains a rural development bias focused on primary activities, social

assistance, and security as a legacy of a historical vision of development focused on urban [40]. Deforestation has increased in Colombia, and to achieve current greenhouse gas emission reduction targets, further reductions in deforestation will be necessary, with the country committing to reducing net deforestation to zero by 2030 [40]. According to the National Administrative Department of Statistics of Colombia (DANE) [41], in Colombia, the unemployment rate throughout 2021 and half of 2022 has been higher for rural women than for men, with a rate gap between 6.8 and 9.7%. The population in rural regions in 2021 was higher than the average of other Latin American OECD countries (Mexico and Chile) [40]. In 2022, 23.7% of the population, 12.2 million people, were located in rural areas, and among the rural population, 48.2% are women and 51.8% are men. On the national average, women are 51.2% [30]. Contrary to the global aging trend, Colombian rural regions benefit from a high young population (26% in 2021), well above the OECD average (17%), and other Latin American OECD countries, such as Chile (19%) [40]. This fact is perfect for the rural world and its development, since rural areas will remain associated with technology, innovation, and the economy. Colombian rural regions are a potential source of wealth and wellbeing and contain one of the most diverse ethnic presences in South America and a more significant number of young population than the OECD average [41].

Peru is the seventh American country in terms of population. In 2022, its population was 3,396,700, 50.4% women and 49.6% men, settled in 1874 districts [42]. In recent years, inequality of opportunities between rural and urban areas in Peru has been pronounced. Following the recession caused by the COVID-19 pandemic, the economy rebounded quickly but has since slowed sharply to just 1.1%. It is expected to increase gradually by up to 2.7% in 2024 [43]. Looking back and seeing how its population has changed from 2016 to the present, we can observe small changes. In 2016, 20.8% of the population in Peru lived in rural areas, and only 28.2% accessed all drinking water, electricity, and sanitation services vs. 82.6% of urban residents [44]. According to the latest national survey on perceptions of inequalities (ENADES 2022), 61% of the people surveyed perceive a severe disparity between Peruvians living in cities and rural areas [45].

Chile is the ninth Latin American country in terms of population. According to data from the National Institute of Statistics of Chile (INE) from the end of 2021, the population figure is 19,458,000 people [46]. The Chilean economy recovered quickly from the pandemic, and inflation has risen to a 30year high, with peaks close to 14% annually in 2022, driven by an expansionary fiscal policy and exacerbated by global supply constraints and the war in Ukraine [47]. Since the population and housing census carried out in 2017 [48], it can be seen that its population has increased until now, since it was a total of 17,574,003 people, of which 8,601,989 (48.9%) are men and 8,972,014 (51.1%), women [46]. Currently, 25% of the Chilean population live in territories (82% of the total territory) with high rurality. Environmental challenges and risks are important, but they also offer significant opportunities for the future [47]. Rural–urban migrations, the productive reconversion of farms that have reduced their workforce, and earthquakes have produced unemployment in the countryside, which goes hand in hand with the de-agrarianization of local activities [49].

5. State of the Art of Rural Education in Latin America

At this point, the characteristics of the education received in rural schools are noted. According to Caliva [50], the contents are conceived in most cases from situations outside the rural area and without sufficient consultation, thus resulting in universalizing, academic, monotonous, excessively extensive curricula with very little range for adaptation to the local situations. This is something to reflect on since, in an environment so rich in land resources and landscapes, using curricula that are not adapted to the environment of the rural situation from an educational point of view has its consequences. Education must be capable of responding to each territory's needs. Emphasis should be placed on the need to promote innovative educational processes based on the needs and potential of the different rural populations of Latin America [50]. As cited by Arias [51], today's rural schools must

teach school content and recognize local knowledge related to agricultural work, roots in the land, environmental sustainability, and community history.

The educational policy of most of the Latin American and Caribbean region began to experience a reactivation at the end of the 20th century and, especially at the beginning of the 21st century [52]. In 2023, the Regional Educational Policy Forum was framed in the political implications and implementation strategies of SDG 4 of the 2030 Agenda [53]. Working on this SDG is necessary in all areas of the world. Still, in this Forum, the idea was to think about how digital technologies can contribute to transforming the educational systems of Latin America and the Caribbean [53].

Illiteracy among adults and youth continues to be a mainly central to rural populations, and the preschool level practically does not exist in these areas [54]. However, we must highlight that rural education in Latin America is a viable possibility [55]. According to Santa María et al. [56], researchers agree that to confront the problem of educational inequality, a drive for change is required that addresses the factors that mark said inequality.

Latin American countries that achieved coverage of the school system present serious quality problems in the learning results of boys and girls who participate in learning achievement measurements [54]. At international events on education, proposed agreements are made to improve the population's learning levels and prepare students for life [56]. The latter is essential because educating the population about rural life prepares rural inhabitants to live harmoniously in their local environment, consequently improving their quality of life.

The International Congress Epistemologies of the South and Latin American Ruralities held in 2019 focused on rural education, the pedagogy of Mother Earth and the ecology of knowledge and territory, women and Latin American spiritualities, ancestral practices, and knowledge [57]. It is worth highlighting the importance of the Ibero-American Colloquia on Rural Education that the Thematic Network for Research in Rural Education (RIER) [58] has been developing for some years now in rural schools. The VI Ibero-American Colloquium on Rural Education was the most recent, held in July 2023 and developed by the Rural Education Division of the National University of Costa Rica, in collaboration with RIER.

Rural Education in Colombia, Peru, and Chile

In Colombia, school dropouts have increased considerably due to the pandemic, especially among students from disadvantaged socioeconomic backgrounds [59]. According to data collected in DANE [41], in Colombia in 2021, 75.4% of rural women and 75.2% of rural men between 6 and 21 years old were studying, while in urban areas, these percentages are 79.3% and 79.2%, respectively. Women suffered from dropping out of school due to home and family issues. 11.2% of rural women between 6 and 21 years old who do not study do so because they must take care of household chores, and 4.4% do so because of pregnancy [41]. Dropout rates in secondary education, which tend to focus on students from disadvantaged socioeconomic backgrounds, increased in 2020, and only 50% of children aged 3 to 5 years have access to preschool education [59]. In the General Education Law of 1994 [60], article 10 describes formal education, article 36 refers to non-formal education, and article 64 refers to peasant and rural education [61], mentioning that the National Government and the territorial entities will promote a peasant and rural education service, which will mainly include technical training in agricultural, livestock, fishing, forestry, and agro-industrial activities that improve human conditions, work, farmers quality of life, and increase food production in the country (art. 64) [60]. In this country, the PER Rural Education Program is currently being developed. It has Phases I and II, implemented since 2009, to mitigate the problems affecting educational coverage and quality in rural areas, helping to overcome the existing gap, and the Special Rural Education Plan [62,63]. In Colombia, there is a clear intention to rescue the living memory of past adversities, recognize forgotten population sectors such as farmers, Afro-descendants, and displaced people, and defend the territory [57]. According to the data provided by the ICFES and the OECD, it is evident the challenge rural education represents for the country

in its commitment to improving educational quality [64]. It is also worth remembering the V International Congress of Local Development held in 2019, whose motto was Socioeconomic Systems with Territorial Anchors, where it reflected how local areas should be promoted as places to satisfy economic, social, cultural, and environmental needs [65].

In Peru, public spending on education is low (2.7% of GDP in 2018). At least 96% of adults completed primary education in 2020, thus surpassing other Latin American countries [43]. In 2018, 24% of secondary school students were behind in school versus 7.4% in urban areas, and 8.7% of women over 15 years of age and older versus 3% of men are illiterate, according to data from CREER (growing with multigrade rural schools in Peru) [66]. This information about women's education is significant. The school dropout rate in rural areas is a fact, and in rural areas, women represent the population with the highest dropout rate (8.6%) compared to men (6%). In rural areas, only 32% of the population completes secondary education, and 8% ends higher education [43]. In secondary school, the gender gap remains relatively high, with 34% of women over 15 years old, compared to 42% of men, completing secondary education [67]. A higher proportion of 15-year-old girls achieve below-average results in mathematics and science compared to their male peers, while girls achieve better results than boys in reading [43]. The work obligations of adolescent girls outside of school and teenage pregnancies are the main factors that explain female-school dropouts, especially in rural areas [43]. There is a profound difference between urban and rural education, evidenced even more since 2020 from social isolation due to the COVID-19 health emergency [42]. Among the actions implemented in the country, we can highlight the Non-School Initial Education Program (PRONOEI). This public, early childhood education program comprehensively provides care and education to children in rural and remote areas with limited access to formal education [68]. And also, the UNESCO Horizons Program, a rural secondary education program that works in six regions of Peru (Amazonas, Ayacucho, Cusco, Piura, Arequipa, and Puno), ensures that adolescents in public schools located in rural territories finish their secondary school studies [69,70].

In the case of Chile, the school system is structured in two mandatory cycles: 8-year primary education (1st to 8th grade) and 4-year secondary education cycle (1st to 4th grade) [25]. The CASEN 2022 survey showed 62% more rural poverty than urban poverty in Chile, a figure also supported by the 57% corresponding to extreme poverty rates [71]. Several laws and programs must be highlighted in Chile concerning rural education: The Rural Basic Execution Program of 1980, the Quality Improvement and Equity Program (MECE/Basic/Rural) that took place from the 90s to 2002, Decree No. 4 that regulates the Rural Basic Education Program of 2001, and Decree No. 968 of 2012 [25]. In 2020, 52 proposals were proposed to improve rural education in Chile: institutionality and public policies for quality rural education, curriculum and teaching roles with a territorial perspective, educational offer for a lifelong trajectory, and infrastructure. And schools that favor learning objectives were introduced [72]. In Chile (2019), there are 3401 rural schools, and around 1800 correspond to multigrade establishments; that is, they work with students from different grades in the same classroom [73]. Currently, female participation in the labor market is low, and expanding access to quality early childhood education would close critical gaps in cognitive and social progress and enable more women to work [47].

6. Results

6.1. STEM and STEAM Education in Latin America for the Improvement of the Rural Environment

According to Bonilla et al. [74], STEM education is an emerging trend that seeks modular, adaptable, and easy-to-use tools to help students in practical teaching. STEM/STEAM education offers economic, social, and environmental benefits to the rural population, among other things, by working interdisciplinary with science, technology, engineering, arts, and mathematics.

Working on STEM and STEAM education in rural areas of Latin America implies an improvement in the rural environment since participants in this type of education will

be better prepared to face the rural world in which they live their daily lives. Working on gender in rural areas, thanks to STEM/STEAM education, improves the environment in which such education is developed, in this case, the rural environment, since this implies better trained and prepared women. Better-trained people will continue to live in rural areas and take care of their homes, land, environment, and survival over time in that environment.

For the towns, it is vitally important that women remain in them. Of note in STEAM education, is the inclusion of discussion and analysis of gender inequality in the teaching and application of science and technology to encourage the participation of more women in these fields [75]. There are countries where being a woman continues to represent a severe disadvantage in science, both when choosing a career and when looking for a job related to disciplinary skills in STEM. As Arredondo et al. say, according to UNESCO, in terms of enrollment in STEM careers at the higher education level, women represent only 34% in Argentina, 25% in Chile, 30% in Brazil, and 38% in Mexico. In the case of Colombia, the global gender gap is 73% [76]. With the conviction that it is possible to break down gender prejudices and stereotypes, inspire girls in STEM, and increase female participation in this type of career, Ingeniosas: Science and Technology for All was born in Chile in 2016. Its initiatives have since expanded to Argentina and Colombia [77]. Considering the networks that promote the STEM/STEAM approach in Latin America, we can highlight the STEAM Laboratory in the rural classroom or the Educa STEAM Network [78,79]. The STEM Latin America Network, made up of more than 180 partner institutions from 14 countries, promoted by the Siemens Stiftung International Foundation, stands out. This network aims to form active citizenship that forges sustainable communities and territories [80].

STEM territories stand out as initiatives (46 already existing) that collectively promote STEM education in Latin America. Before creating a STEM territory, the actors promoting it are expected to identify territorial needs and/or problems, for which this structure could offer solutions based on educational innovation, community building, and sustainable territories. These initiatives are carried out in a total of eight countries. To begin, two questions need to be answered: Why promote a STEM territory initiative? What does the STEM territory initiative aim to promote (objectives)? [81].

The following table (Table 1) shows answers to these questions and also the union of all of this to promote the four fundamental axes already mentioned, so that the rural area lasts, which are: education, employment, health and technology.

6.2. STEM and STEAM Experiences in Rural Environments in Colombia, Peru, and Chile

In the case of Colombia, Cifuentes and Caplan [30] explain how, after the development of a successful experience of formal STEM/STEAM education in a rural school in Cundinamarca, STEAM education offers possibilities for raising the quality of education in rural contexts when focused towards a globalizing model in which diversity and inclusion are valued and respected. In Medellín, according to Cano et al. [82], implementing an integrated approach of STEM plus humanities translates into the best results and constitutes a fundamental factor in developing the local context. STEAM allows the generation of ideas to solve local problems and can contribute to developing interdisciplinary experiences, motivating students to participate in projects linked to the subjects that comprise it, and promoting cultural diversity [82]. According to Ochoa et al. [75], the STEAM community broadcasting solidarity extension project in Magdalena Medio was developed so that the peasantry can remain in the territory and live in harmony with animal and plant species through the defense of peasant culture and food sovereignty through agroecological practices, as well as peacefully resisting war [75].The STEAM project *Campesino* Laboratory for the Transition to Agroecology (*Lab Campesino*) [83], developed between 2018 and 2019, was a solidarity extension project led by groups of students from the faculties of engineering, sciences, and arts of the National University of Colombia and the rural organization, Tierra Libre, to generate a space for rural youth and children for exploration, experimentation and prototyping around agroecology, co-creation, and community organization, promoting

adaptive habitat, production, and consumption systems. Projects of this nature make rural inhabitants more linked to their environment and more respectful of the surrounding environment. Furthermore, according to Ochoa et al. [75], solidarity economy strategies are necessary to generate stable economic income to allow decent futures in the territory.

Table 1. Challenges of the Latin American STEM territory in conjunction with education, technology, health, and employment. Sources: www.educacion.stem.siemens-stiftung.org [81] and Gavari et al. (2022) [27] and own elaboration.

Tracing Specialized or Government Information Sources	Recognition of Challenges that May Have Links to STEM Education	Some STEM Territory Objectives in Latin America	Relationship with Four Fundamental Factors to Fix the Population in Rural Areas
- Public politics - Development plans - Reports from observatories - Local characterizations	- Sustainable development - STI and citizenship promotion - Learning gaps - 21st century skills and problema solving	- Promote science, technology, research, and creativity, strengthen research processes, improve the quality of life of the community. - Promote scientific vocations that seek social transformationto bridge the gap between men and women in STEM careers, integrating strategiclines in STEM Olympics, climate change, teacher training in STEM, project-based learning and challenge-based learning. - Contribute to educational quality from the STEM approach to promote context ualized curricula, integrating relevant aspects such as climate change and sustainable development, teacher profesional development (training) and educational innovation.	- Education: With STEM education, quality education is developed for today's 21st century world. - Technology: In STEM education, we work on, among other things, technology aimed at today's technological world. - Health: We worked with STEM education to educate for climatechange and sustainable development, creating healthier and healthier environments. Fairersocieties are created by working on the gender gap. - -Employment: Better-educated people are trained, prepared for the professiona ldemand of the 21st century. Work is being conducted to bridge the gender gap in the world of work in sciencecareers.

In Peru, it is already expected that intervention projects will be increasingly based on systematic studies of schooling in rural areas and that public education will be developed with opportunity and relevance [58]. In 2017, a study carried out in the Peruvian Amazon explored the community practices and knowledge that Shipibo children manage, as intercultural actors, linking with extracurricular spaces where their life and activity take place: the house, the river, the forest, and the farm, giving meaning to the school space and taking ownership of the school [84]. The "VI National Educational Research Seminar" that took place in November 2018 in the city of Cusco was held simultaneously with the II Ibero-American Colloquium on Rural Education, addressing the topic of "Perspectives and challenges of rural education: dialogues between research and educational policy" [85]. To strengthen the STEM competencies of Peruvian teachers, the Pontifical Catholic University of Peru (PUCP) developed a free course to, among other things, analyze the role of education in forming citizens with local and global socio-environmental rights and duties [80].

In Chile, the Center for Didactic Research in Sciences and STEM Education (CIDSTEM) of the Pontifical Catholic University of Valparaíso developed a STEM education program in a "blended learning" format, creating 83 STEM educational resources with an inclusion and gender perspective [80]. Bascopé and Reiss [86] analyzed STEM education in Chile through the socio-ecological component, concluding that this approach, when applied to local challenges, opens up new sources of knowledge that are difficult to achieve with forms of learning, based on the transmission of knowledge. Faced with the global problem of climate change, the Research Center for Advanced Studies in Education, CIAE, the Climate and Resilience Center CR2 and Inquiry-Based Science Education, ECBI, of the University of Chile worked for the development and adaptation of educational resources in various formats on climate change, to design a certifiable course for teachers on the subject by surveying 125 teacher members of institutions linked to the STEM Latam Network were survey about their priorities [80].

6.3. Situation in Spain: Education for the Improvement of the Land in the Rural Environment and STEM and STEAM Education (Experiences in Rural Environments)

As indicated in Gavari, Espinosa, and Lucini [27], the problem of rural depopulation continues in Spain, affecting education and other sectors. This is because the small population in rural areas has aged and there are only a few young people trained in rural areas; the majority must migrate to urban areas to complete their training. This displacement is due, in part, to the gradual reduction in Spanish rural schools, which inevitably forces students to have to move to centers with a larger population.

Although there is a reduction in the population that corresponds to "emptied Spain" [87], we must highlight the recent concept of "new rurality" discussed by Trigueros et al. [88], where new functions are provided to the rural environment, such as recreational, residential, conservation, and protector of cultural and landscape heritage. In this search for the potential of rural areas and to improve them, the GEOVACUI project [89], developed by the Complutense University of Madrid, provides promising conclusions to change the view of the rural environment and promote it as a "living and active territory" [90]. It is possible that, if we combine the proposals obtained in said project, together with the possibility of accessing funds from the Recovery, Transformation, and Resilience Plan, we could speak of an excellent opportunity to promote the rural environment as an attractive environment in the 21st century [91]. In general, most of the actions undertaken related to the rural aspect, to date, are focused on women in rural areas, and it would be interesting to expand the focus to reach the entire educational community.

However, despite the key role that rural education plays in improving depopulated, rural Spain, it is only sometimes feasible to promote its improvement. The rural education sector involves several agents, and it needs open schools with teachers and students in person and available, with updated resources. It can be an engine of change towards the living and active rural territory. Compared to the urban school, the rural school presents some economic, geographical, and social peculiarities, such as multigrade classrooms, instability of the teaching staff, or geographical disaggregation. One of the most notable differences between rural and urban schools is the greater involvement of the student in the environment and its sustainability; therefore, promoting rural education under the scenario of the 2030 Agenda is a fact that will be more affordable in rural areas.

Regarding the quality of education, it is worth recalling the analysis of the PISA 2015 report by Domínguez and Sánchez [92], where the lack of public resources is already evident, which has implied the closure of rural schools. In the recent PISA 2022 report [93], the worst data has been shown in the education of Spanish adolescent students. However, we have found that the best results have occurred in communities with depopulation problems in rural areas, such as Asturias, Cantabria, and Castilla y León. This fact leads us to consider whether, despite the gradual reduction in the rural population, in those centers where rural schools are maintained, rural education is presented as a potential alongside urban education to promote the future of young people, stimulating their learning

capacity and interest in their education. It would be interesting to analyze the dropout rates in these same communities, even in rural areas, to be able to verify if, in these communities, captivating strategies and methodologies are developed from the point of view of educational success to extrapolate their models to other Spanish regions, where worse education data are recorded in the PISA report.

In 2022, the Ministry of Education, Vocational Training and Sports awarded aid worth one million euros to 30 projects developed to promote educational inclusion and innovation, including the project "The rural school as an inclusive model and element stimulator of culture and the development of the environment", developed at Grouped Rural School (CRA) Río Tajo (Alcolea de Tajo, Toledo), CRA La Coroña (Ceceda, Asturias), CRA De Lozoya (Lozoya, Madrid) and the project "Sustainability, health and sport in the rural environment", developed at CRA Bajo Gállego (Leciñena, Zaragoza) and Early Childhood and Primary Education center (CEIP) O Salvador (Pastoriza, Lugo) [94]. Seeing the rural environment as an opportunity to educate people more linked to their land and environment is noteworthy.

In Spain, the competency learning model on the current Organic Law of Education (LOMLOE) is based on the acquisition of eight competencies. One of them is Mathematics and Science and Technology (STEM) competence. In this way, the STEM educational approach is integrated into the competency-based curriculum by integrating mathematical and scientific, technology and engineering competence that entails understanding the world using scientific methods, mathematical thinking and representation, technology, and methods of engineering to transform the environment in a committed, responsible, and sustainable way [95]. The LOMLOE offers an opportunity to create an educational model based on the didactic capacity to train students in the competencies that enhance sustainability and resilient capacity [96].

Currently, the Rural Campus Program [97] is committed to the potential of the territory, the promotion of young employment, and the promotion of local talent, promoting the connection of the population from different areas with rural spaces, generating new forms of roots and ties, promoting and creating employment opportunities in the territory.

In Spain, some STEM/STEAM projects of great interest are being carried out in rural areas, such as the "Rural, Remote and Real, R3 Project" of the University of Deusto [98], to promote STEM vocations in rural schools through remote experimentation. The "STEAM Laboratory in the Rural Classroom" Project [99] aims to, among other things, promote the reduction in the gap between science and technology that affects this environment. The STEAM Alliance for female talent, Girls on the Foot of Science, is an initiative of the Ministry of Education and Vocational Training to promote STEAM vocations in girls and young people and reduce the gender gap [100]. It is developed in rural and urban environments. Still, it is obvious that in the rural environment, it takes on great significance, generated by the fact that there are women in the depopulated towns of this country, contributing in such away that constitutes the break of rural depopulation existing in Spain. Let us not forget that if towns become masculinized from a lack in female population due to unemployment, towns end up dying.

As Alba comments in an interview with Lacalle [101], it is important to facilitate access for boys and girls for STEAM training adapted to their socio-demographic reality and address the three factors that continue to hold back girls from becoming interested in technology: the messages they receive from society, gender stereotypes, and the lack of female role models in the technology sector. This responsibility, this sustainability, and this commitment are also the same in the rural environment when this competence is improved in the formal education of rural schools in Spain.

7. Discussion and Conclusions

This article shows the real and evident role in the time of STEM and STEAM education for rural environments; it promotes the birth of a rural society with social (with emphasis on gender, at this point) and environmental justice. STEM and STEAM education enhances

the creation of early sensitivities in students, developing emotional, sentimental, and sensitizing connections towards the rural environment and its territory. All of this shows us that STEM and STEAM education, carried out with these objectives in rural areas, favor the improvement of opportunities for its people.

The research carried out in this article aims to highlight the strengths of STEM and STEAM education for the improvement of rural environments, thus improving the lives of the people present there. This article is aimed at rural educators so that they see this type of education as an opportunity to improve the rural environment, its land, and its people. This extremely important work performed by teachers should not be forgotten; they have the duty to strengthen their didactic and pedagogical preparation, with the aim of facing new challenges in the cognitive development of students and applying learning strategies to allow a better understanding of the contents presented in the different subjects [22]. Rural areas need well-trained, up-to-date people and professionals prepared for an interdisciplinary world of work, and STEM and STEAM education develops people who are professionally prepared for the demands of today's work environment.

The rural situations of Latin American countries are different, and the rural situations between Latin America and Spain are also different. Although a precise comparison cannot be made because other countries have different educational models, it is possible to emphasize the advances in the countries studied to improve rural areas, their environment, their land, and, of course, the people who live there.

STEM education was born in the United States in the 1990s, and later, Yakman [102] restructured the term into STEAM, making citizens better prepared for the world we live in, which is an interdisciplinary world. With STEM/STEAM education, our children can be educated and prepared in the current knowledge of science, technology, arts, mathematics, and engineering in a united way and without barriers between disciplines; it is a holistic education for a holistic world.

This paper shows that STEM/STEAM education projects are carried out in all of the countries studied to improve the rural situation. Each country has different educational situations, so improvement is sought through different STEM and STEAM education strategies.

Women in rural areas in Latin American countries suffer from a gender gap, especially in the countries studied in this article. This leads to a gap and delays in the knowledge of the rural environment's inhabitants at different levels. For rural advancement to be as it deserves, it must be able to uplift women just as it does men, in full equality. Information has been collected on the educational situation of girls and women of rural areas in Latin America and Spain, and a series of STEM and STEAM projects of interest are being developed to fight against the gender gap.

Generating links with the environment and its land is allowed with STEM/STEAM education if the rural and forest resources of each rural area across the world are used, training people who are more prepared to know the land surrounding them. The rural environment and its people should be included in the world, as it is a source of wisdom, culture, and has resources of priceless value. Valuing the rural environment is vital in our time, to observe the territorial models of countries from other perspectives. The resources of rural areas are undeniable: landscapes, food, land, clothes, dances, wisdom of the elders, environment, etc. The rural environment offers a place to reside and must be cared for and maintained for future generations. Using the resources that rural areas provide makes citizens more linked and aware of the rural environment and land. In this way, children sensitized to rural areas will want to return to their land, live there, and work there, taking care of said land and keeping it alive without depopulation.

We observe that STEM and STEAM education in rural areas is necessary and possible, and even more enriching if the resources that rural areas offer are used as educational resources to their land and their environment, thus forming better-prepared citizens who are more linked to the land and its surroundings. Working on gender through STEM and STEAM education in different countries is necessary and even more so in rural areas, where it is observed that if villages become masculinized, they end up dying.

Latin America offers invaluable educational resources in rural areas to train citizens who are better prepared and more aware of their environment from an early age, forming citizens who are more respectful of their land. Colombia, Peru, and Chile are countries where very interesting STEM/STEAM education is being carried out, highlighting rural areas. At this point, we highlight Colombia as a country of great importance in Latin America in developing STEAM education. Colombia is clearly committed to STEM/STEAM education in rural areas.

We can observe that formal education advocates STEM education in Spain, since the LOMLOE Education Law contemplates it; this fact is of utmost importance. The main problem in Spain in rural areas is depopulation; although, the tendency to move to cities also affects other countries. Other factors must be taken into account here, not only educational factors but also the desired territorial model in each country. In Spain, there are no gender differences in education in rural areas as marked as they exist in the Latin American countries studied. In countries like Spain, the rural population is elderly, and this aging population in the villages can carry out engaging, informal education as they are a constant source of wisdom. It is also essential for older people to be informed and trained to stay up to date in today's world.

We conclude that education must be used to improve the rural environment and is vital for rural development. Students are trained in rural areas by valuing and knowing their resources, and their environment will have citizens who are more linked to it, thus awakening sensitivities from an early age, which will translate into a person–rural environment bond in different areas, such as cultural and social, environmental, emotional, professional, etc. STEM and STEAM education is necessary in our world, rural and urban, for students to develop and be better prepared for the needs of today's world. STEM and STEAM education presents interdisciplinary needs, in addition to training students to be more linked to the environment, the rural environment, and their land.

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Tax Planning on New Tobacco Risk-Reduced Products in Europe: Assessment and Implications for Public Policies

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Abstract: Taxes on the consumption of certain products have played a key role in public revenue analysis in European countries. This work assesses the differences in tax planning for new non-combustion products across some European territories. Through theoretical analysis, the paper has three distinct aspects. Firstly, we show the taxpayer profile in different countries. Secondly, the study analyzes the risks for the health system and the individual. Thirdly, the design of the national tobacco tax is based on previous experience and planning in Europe. This paper concludes with a case study for different countries: (1) Spain "vapers" and "smokers", where the analysis is based on micro-data from the European Health Interview Survey 2020. (2) Sweden, with the analysis of snus, shows it as a practice on how to reach economic savings while decreasing economic costs thanks to the nudging of consumers towards better products. The results show taxation and, especially, land taxation should consider differences in planning in the case of new products, such as non-combustion products, given the user per capita income and the potential lower health risks involved.

Keywords: taxes; EU; risk-reduced products; taxation; external effects

1. Introduction

Consumption taxes have taken on a major role in terms of their contribution to public sector revenue. In the case of territories in Europe, this phenomenon has been accompanied by the emergence of new products that are supposed to replace those whose tax design is already developed. This is why policymakers are faced with the dilemma of whether to tax these new alternatives and, if so, how to proceed. This also affects land taxation for European tobacco crops. The consumption of certain products has been a crucial source of public revenue in recent years, with taxes on these products playing a significant role. However, the existence of new non-combustion alternatives (RRPs—Risk Reduced Products such as e-cigarettes, heated tobacco products, snus, and nicotine pouches) has prompted the need for an optimal land tax design protocol. This paper aims to establish such a protocol by conducting a theoretical analysis that considers three distinct aspects: the taxpayer profile, health risks, and previous experiences in other countries.

The main objective of this article is to establish a land tax protocol for the optimal design of taxation on products that generate negative externalities. The relative amount of harm produced by the consumption of each product is a fundamental variable to take into consideration. The negative impacts of these products on society, such as health risks or environmental harm, create a need for policy interventions, such as taxation (including land taxation), to nudge consumers toward better consumption patterns. In this context, the article aims to provide a framework for designing taxes that will be able to accomplish this objective while minimizing unintended consequences. Through this protocol, policymakers and researchers can create evidence-based tax policies that balance economic, social, and environmental considerations.

The global market for alternative risk-reduced tobacco products, such as e-cigarettes, heated tobacco products (HTPs), nicotine pouches, and snus, has been rapidly growing [1,2].

As these products are relatively new, there is a lack of consensus among policymakers on how to regulate them, particularly in terms of taxation. In some countries, e-cigarettes and HTPs are taxed at the same rate as traditional cigarettes, despite evidence suggesting that they are less harmful to health [3,4]. This lack of differentiation in taxation could discourage smokers from switching to these less harmful alternatives, ultimately hindering public health efforts to reduce the prevalence of smoking.

The main motivation for this article is to explore the benefits of differentiating taxation rates between traditional tobacco products and alternative products. By reviewing existing literature on the health effects of different tobacco products and their associated externalities, we aim to provide evidence-based recommendations for policymakers on how to design optimal taxation policies that promote the use of less harmful alternatives. Additionally, we will examine case studies from countries that have successfully implemented differentiated taxation policies to understand their impact on public health outcomes and revenue generation. Through this article, we hope to contribute to the ongoing policy debate on the regulation of alternative tobacco products and promote evidence-based policymaking in the public health domain.

With this work, we aim to suggest that before implementing price regulations or interventions to reduce traditional tobacco prevalence, policymakers should consider the taxpayer's socio-economic profile and the risks produced by the specific products to their health. Additionally, the article highlights the potential benefits of harm reduction strategies that prioritize less harmful alternatives to smoking, such as vaping, HTPs, nicotine pouches, and so on. The authors suggest that taxation policies able to recognize the reduced harm of these alternatives can encourage smokers to switch to them, reducing the burden of smoking-related health problems. This is a challenge in Europe for fiscal policies.

In addition to addressing externalities, we recognize that tobacco taxation serves multiple objectives, each with its own unique significance. Beyond mitigating negative health externalities, governments utilize tobacco taxes to generate revenue, fund healthcare initiatives, and promote public health campaigns. Moreover, these taxes can act as a deterrent, aiming to reduce tobacco consumption and thereby improve overall public health. These distinct goals should impact the selection of tax mechanisms and the determination of tax rates. In this sense, we include a section that delves into these diverse objectives of tobacco taxation, shedding light on their interplay and influence on policy decisions.

This article will be structured in three distinct parts. The first focuses on a brief review of the literature and proposes an approach to the problem posed above. The second focuses on an overview of the negative externalities of consumption theory. Thirdly, an empirical approach to the optimal design of taxes is proposed. Finally, conclusions and suggestions for the future development of public policies are presented.

2. Brief Literature Review and General Background

Electronic cigarettes and other risk-reduced alternatives to tobacco have been on the rise in recent years. These products are often marketed as a safer alternative to traditional tobacco products, and as a result, they have become popular among both current tobacco users and some non-users. The latest Eurobarometer Report [5], however, shows that e-cigarette initiation rates hover around 2.5%, while HTPs' initiation is virtually non-existent. There is still much debate regarding the safety and efficacy of these products, and as such, it is important to consider the potential impact of taxes on their use.

As analyzed by the German Federal Institute for Risk Assessment (BfR), non-combustible products have been found to substantially reduce levels of major carcinogens in the emissions of analyzed heat-not-burn products with conventional tobacco cigarettes, thereby reducing the harmfulness of non-combustible products as compared to combustible products [6]. Furthermore, the UK House of Commons Science and Technology Committee [7] estimated e-cigarettes to be approx. 95% less harmful than conventional cigarettes, suggesting that both e-cigarettes and additional heat-not-burn products should be used as alternatives to conventional tobacco products.

As the consumption of tobacco has been linked to various health issues, many countries have implemented taxes as a tool for curbing its use. However, the use of alternatives to tobacco—such as electronic cigarettes or heated tobacco products—has become increasingly popular. This is an important (and factual) development to consider when creating the optimal tax design for these products. A tax design that must certainly focus on delivering positive health outcomes. This literature review aims to provide an overview of the research conducted on the optimal design of taxes for alternatives to tobacco.

Several studies have examined the optimal design of taxes for alternatives to combusted tobacco. One such study by ref. [8] found that taxing RRPs at a lower rate than traditional tobacco products could be an effective way to reduce the use of the latter. This approach is based on the premise that RRPs are a safer alternative to traditional tobacco products and, as such, should be taxed at a lower rate to encourage their use. This idea is also stated in ref. [9], promoting differential taxation between products based on product harmfulness. Therefore, the use of harm-reduced products in exchange for harmful combustible products is encouraged.

The optimal design of taxes for alternatives to tobacco is a challenge for fiscal policies across countries, and it requires the consideration of a variety of factors in the territory, including the potential harm of the product, the potential impact on public health, and the impact on consumers' behavior. Research has shown that taxing e-cigarettes and other alternatives to combusted tobacco at a rate that is proportional to their harm could be an effective tool to reduce the use of more toxic products, incentivizing the substitution of harmful products with less damaging alternatives. Ultimately, the optimal design of taxes for alternatives to tobacco will depend on a variety of factors depending on the territory, among others, and further research is needed to fully understand the potential impact of different tax structures.

3. Tobacco Economy and Methodology

This section is divided into the following parts: tobacco cultivation and land taxes, tobacco competitive markets and negative externalities, and tax policies' measures.

3.1. Tobacco and National Taxes

The cultivation and consumption of tobacco have long been intertwined with European societies, economies, and health systems. As European countries have sought to address tobacco's economic and health-related challenges, taxation has emerged as a crucial policy instrument. This section aims to explore the relationship between tobacco cultivation taxation and the distribution of consumers in Europe, focusing on how variations in taxation policies influence consumer behaviors, market dynamics, and public health outcomes.

Tobacco cultivation taxation serves as a vital revenue source for many European countries while also acting to regulate tobacco consumption. By levying taxes on the cultivation of tobacco, governments can control the supply chain, influence the pricing of tobacco products, and potentially discourage consumption. However, the effectiveness of taxation policies depends on various factors, including the level of taxation, the presence of alternative tobacco and nicotine products, and the prevalence of illicit trade.

Consumer behavior plays a pivotal role in shaping the demand for tobacco and nicotine products. High tobacco cultivation taxes often lead to increased retail prices, which may deter some consumers from purchasing tobacco products. Consequently, this section examines how varying levels of taxation can influence smoking prevalence rates and patterns of tobacco use across different demographic groups. Analyzing consumer behavior in response to taxation is essential for understanding the potential impact of taxation policies on public health outcomes.

The distribution of tobacco consumers across Europe is not uniform, and taxation policies can contribute to regional disparities in tobacco consumption. Some countries may adopt more aggressive tobacco taxation strategies, resulting in reduced consumption rates,

while neighboring countries with lower taxation levels might experience higher tobacco use. Taxation policies can inadvertently create opportunities for the illicit trade of tobacco products (Table 1). When taxes lead to substantial price differences between neighboring countries, consumers may turn to illegal channels to acquire cheaper tobacco products.

Table 1. Tobacco and cigarette taxation in the EU countries.

	Ad Valorem Excise in %	VAT in %	Ad Valorem Excise + VAT	Total Tax (Incl VAT)
Country	**(as % of TIRSP)**	**(as % of TIRSP)**	**(as % of TIRSP)**	**(as % of WAP)**
AT	34.5	16.67	51.17	77.6
BE	40.04	17.36	57.4	82.87
BG	25	16.67	41.67	81.94
CY	34	15.97	49.97	75.2
CZ	30	17.36	47.36	82.32
DE	21.69	15.97	37.66	69.44
DK	1	20	21	88.46
EE	30	16.67	46.67	87.18
EL	26	19.35	45.35	84.69
ES	51	17.36	68.36	79.26
FI	52	19.35	71.35	89.85
FR	55	16.67	71.67	84.76
HR	34	20	54	82.51
HU	23	21.26	44.26	80.99
IE	10.06	17.36	27.42	83.06
IT	51.24	18.03	69.27	77.83
LT	25	17.36	42.36	79.27
LU	46.65	14.53	61.18	69.27
LV	15	17.36	32.36	82.78
MT	23.4	15.25	38.65	78.33
NL	5	17.36	22.36	84.89
PL	32.05	18.7	50.75	81.3
PT	14	18.7	32.7	76.23
RO	14	15.97	29.97	74.29
SE	1	20	21	73.27
SI	22.9	18.03	40.93	81.33
SK	23	16.67	39.67	82.79

Notes: VAT: Value Added Tax. Ad valorem: The term 'ad valorem' refers to a type of tax calculated as a percentage of the assessed value of the goods or services. In this context, it signifies that the tax rate is based on the value of tobacco and cigarettes. TIRSP: tax-included retail selling price. WAP: weighted average price. Source: Authors' analysis from the Directorate General of Taxation and Customs Union of the European Commission.

One significant factor contributing to differences in traditional combustible tobacco consumption across Europe lies in its rich history and diverse cultural influences. European countries have distinct tobacco-related traditions dating back centuries. For instance, Mediterranean countries such as Italy and Greece have a long-standing tradition of tobacco cultivation and consumption, often in the form of hand-rolled cigarettes and cigars. In contrast, Northern European nations may have adopted tobacco consumption at different points in history, with varying cultural norms and habits. These historical and cultural differences play a pivotal role in shaping tobacco consumption patterns, with preferences for specific tobacco products deeply embedded in regional identities. Another compelling reason behind the disparities in traditional tobacco consumption in Europe is the socioeconomic diversity among its member states. Countries within the European Union exhibit significant variations in income levels, education, and access to healthcare. Socioeconomic disparities can translate into varying rates of smoking prevalence. In some wealthier European nations, higher incomes and greater access to smoking cessation programs have contributed to lower smoking rates. Conversely, in less economically developed regions, where tobacco may be more affordable and fewer resources are allocated to anti-smoking initiatives, smoking rates tend to be higher. However, the situation is not so clear-cut.

Some higher-income countries still show high prevalence rates (and high intensity of use) in adults, such as France and Germany. The simple differentiation between high- and low-income countries does not seem enough to explain the final results. Within-country income level disparities play an important role, too. These disparities highlight some of the complex interplays between economic factors and tobacco consumption behaviors Figure 1.

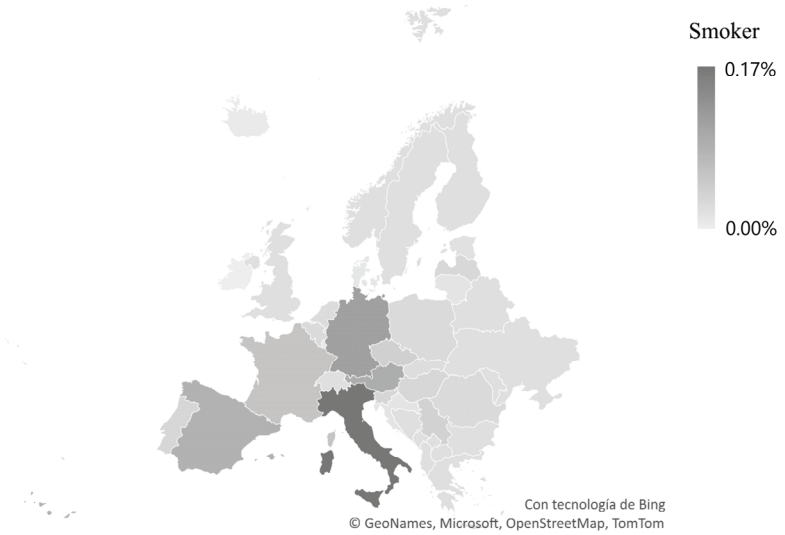


Figure 1. Distribution of traditional combustion tobacco consumers in Europe. Source: Authors' analysis from [10] (Wave 3—2020).

Another different approach is the analysis of the percentage of daily smokers in Europe (Figure 2). The analysis of the percentage of daily smokers in Europe is justified by its specific focus on individuals who maintain a higher and more regular level of tobacco consumption. This is relevant because daily smokers are at greater risk of experiencing the long-term adverse effects of tobacco compared to occasional smokers. Concentrating on this demographic group gives a more detailed understanding of the true burden of smoking in terms of public health. This information is crucial for designing effective public health policies and planning targeted interventions aimed at reducing tobacco consumption and, ultimately, mitigating the severe health consequences associated with smoking for the population.

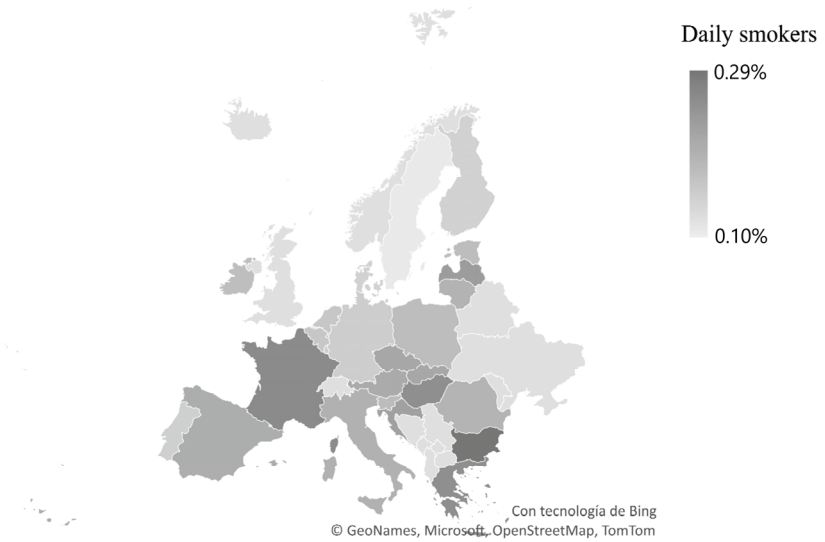


Figure 2. Daily smokers in Europe. Source: Authors' analysis from OECD database.

3.2. Tobacco Competitive Markets and Their Failures

According to classical economic theory, the conditions for considering a market to be competitive are mainly four. First, the existence of many suppliers and demanders must be considered. Second, there must be perfect information, i.e., all market participants must have information about the risks and opportunities that arise. Thirdly, the product must be homogeneous and practically non-differentiable. Finally, there should be no barriers to market entry and exit.

However, despite the guidelines provided by theory, experts know that in practice, markets function in a much more complex way. This is what, in the end, has come to be classified as a market failure. These failures are classified into three types: externalities, imperfect or asymmetric information, public goods, and market power.

In this paper, we will focus on the study of externalities. Externalities are consumption, production, or investment decisions made by individuals, households, or firms that affect third parties that do not necessarily participate in the market. This market failure has indirect effects on the consumption and production opportunities of third parties who do not directly participate in these transactions. However, the price of the product taken into consideration does not reflect this impact. As will be discussed below, such effects may be positive (as in the case of education) or negative (as in the case of sugar, alcohol, and tobacco consumption).

3.3. Negative Externalities Tax Policies' Measures

The specific case studied here, that of RRPs as a new alternative to traditional combusted tobacco consumption, can be understood as a change in the status of the externality of consumption. The direct health effects will not only affect those who use it but will also have a significant impact on third parties. The question, therefore, arises here: How to optimally correct the costs caused by a negative consumption externality?

The state generally deals with the reduction of the social cost associated with a negative externality of consumption through regulation, taxation, and the education of society. The first two measures are generally the most effective in the short term. However, the design of regulation and taxation is not a simple task. This is why policymakers make use of expert opinions and expertise in carrying out such a task.

Combusted tobacco consumption is widely regarded as a negative externality due to its harmful effects on smokers and non-smokers. According to ref. [11], the negative health consequences associated with combusted tobacco use extend far beyond the individual smoker and can have significant impacts on broader society. This is because the smoke produced by the combustion of tobacco contains numerous harmful substances that can cause a wide range of health problems, including cancer, heart disease, and respiratory illnesses. Non-smokers who are exposed to second-hand smoke are also at risk of developing these health problems, creating a negative externality for individuals who have not chosen to smoke.

Furthermore, combusted tobacco consumption has a significant economic impact on society. According to a report by the World Health Organization [12], the costs associated with combusted tobacco use are substantial and include both direct healthcare costs as well as indirect costs related to decreased productivity and increased absenteeism. These costs are borne by society rather than just by individual smokers, making combusted tobacco consumption a negative externality. The World Health Organization (WHO) report notes that the economic burden of combusted tobacco use is particularly high in low- and middle-income countries, where healthcare systems may be less equipped to handle the health consequences of smoking.

Among some of the main steps identified to achieve a good design of the taxes associated with the correction of an externality, we must highlight three: The determination of the risk in comparison with other consumption alternatives already subject to taxation; the knowledge of the taxpayer's profile; and finally, the tax design.

4. The Empirical Approach

This part of the paper is divided into two sections. The first section presents the basic protocol for establishing and designing optimal consumption taxes for alternatives to traditional combustion tobacco in Spain. Secondly, we present a case where the introduction of new alternatives to traditional cigarettes—such as snus in Sweden—results in a decrease in the prevalence of traditional tobacco products and allows for savings in both health and cost terms. This best practice will therefore allow for obtaining the main guidelines for the design of public policies, both from the point of view of tax design and the needed deregulation of the less-damaging consumption alternatives.

4.1. The Design of Taxes in Spain

As we have observed in the previous section, in the European Union, the tax criteria for regulating new alternatives to traditional tobacco do not always follow a common pattern. However, a vast majority of countries in the EU similarly regulate new products, showing signals of pre-harmonization. Seventeen countries in the EU have opted for tax differentials of various magnitudes in favor of new alternatives. Some countries, such as Spain, have opted for non-regulation. In this section of the work, we will try to carry out a brief simulation of two of the steps that decision-makers ought to take in terms of taxation. To do this, we will take the case of Spain as an example.

If we had to follow the experience of other European countries in terms of regulation, Spain should be able to decide whether to regulate the market for alternative tobacco devices in the same way as the traditional ones or not. To do this, we must consider two fundamental steps. First, the characterization and differentiation of the taxpayer. We can do so by observing their differences in personal and socioeconomic characteristics. Secondly, once the profile of the consumption-related taxpayer is known, we must analyze the risks for the health system. We do so both in terms of health-related spending and in terms of the health of individuals.

In this microsimulation, we will use a simple econometric methodology rather than offering a solid empirical strategy. This seems to the authors to be the best method to face the research question of this study. Furthermore, we will present a study protocol before moving forward with the material design of the tax.

Brief Methodological Note

As a starting point, it should be considered that the database used in this study is the European Health Interview Survey [10]. Thanks to its 22,000 observations, it allows us to identify which Spanish citizens among these are traditional (combusted) tobacco consumers and which, instead, have opted for new non-combustion alternatives. In other words, specifically, RRP consumers.

To approach the design of a possible tax, we must first understand the taxpayer's profile and then consider the risks related to the consumption of the good taken into consideration. To know the taxpayer's profile, we will carry out the elaboration of two probit models, which will indicate the probability of a. being in the group of consumers of RRPs or b. being in the group of traditional (combusted) tobacco products. This elaboration is based on a set of explanatory variables (personal and socioeconomic). The mathematical form applied to the model is the following:

$$p(vaper_i) = \propto + \beta \cdot X_i + \varepsilon_i$$

$$p(smoker_i) = \propto + \beta \cdot X_i + \varepsilon_i$$

Here, the variable $vaper_i$ takes the value 1 if the individual is consuming RRPs and takes the value 0 if not. β represents the probability in marginal terms that, given a defined explanatory variable X_i, the individual does or does not belong to the group of RRP users. Firstly, as we have pointed out, X_i represents the set of variables of which we want to discover the incidence in terms of the probability that the individual is part of one or the

other group. Secondly, ε_i is the error term of the estimated model. In the case of $smoker_i$, the only difference is that this variable takes the value of 1 if the individual claims to be a smoker of traditional combusted tobacco or not.

On the other hand, to know the risks, we use two different types of econometric approximations. First, to estimate the effect on the use of health services by vapers or traditional tobacco smokers, we carry out a negative binomial regression model (recommended in health economics for these cases).

This model is used because, on many occasions—as is the case with our data, too—there is a problem of over-dispersion, determined by the possible existence of negative values in the prediction of the dependent variable, in which case the use of the OLS model is not recommended. This negative binomial regression model, or Poisson model, is frequently used in cases such as the one in this paper [13].

Finally, beyond the social cost and to define the risks to the individual's health, we elaborate a second round of probit probabilistic regression models that allow us to discover through their marginal effects the probability of suffering from some of the diseases commonly associated with the consumption of this type of substance. These will use the mathematical expression:

$$p(sickness_i) = \propto + \beta \cdot (type\ of comsuption_i) + \varepsilon_i$$

where *sickness* represents the variable that dichotomously indicates (taking values 1 or 0) whether or not you suffer from the condition; and $type\ of\ comsuption$ represents the type of product you use, i.e., vapers (which is our proxy for all non-combustion alternatives) or smokers of traditional combusted tobacco (also using values 0 or 1 depending on whether or not you use the product).

The objective is to find out β, i.e., the effect of the type of consumption on the probability of suffering from the disease.

4.2. Empirical Approach

Once the data and the methodology to be applied are known, first we are going to know the differences, if any, between the groups of "vapers" and "smokers" through the analysis of the results of the probits. As we can see in Table 1, in the case of vaper consumers, it is observed that their consumption significantly decreases with age. Most of the "vapers" will be comparatively (relatively) younger. Once again, it is important to underline that we use "vapers" as a proxy for all new alternative products. Observing the market penetration of the different products in Spain, this result seems consistent with reality.

Empirically, according to ref. [14], Spanish combustible smoking prevalence was reported to be highest in the age group 25–34 years, amounting to 30.9%. In general, combustible smoking prevalence rates were reported to be highest among younger consumer groups and higher among men as opposed to women [15]. Furthermore, combustible smoking prevalence was reported to be highest among less-educated consumer groups and lower-income consumer groups. These reported figures are consistent with the figures in Table 1, showing that the likeliness to consume combustible tobacco increases for younger consumer groups while decreasing for older consumer groups.

Furthermore, the Spanish government reports switching from combustible products towards RRPs being observable among older consumer groups, not younger consumer groups. The share of older consumers having switched from combustible products towards RRPs was reported at 62.4%, whereas the share of younger consumer groups was reported at only 33.8% [15]. These findings match the results in Table 2, as RRPs consumption seems mainly appealing to older consumer groups.

Table 2. Probit models to determine belonging to the group of vapers or traditional tobacco smokers.

	Vapers			Combustion Tobacco		
	dy/dx	**SE**	**Sign.**	**dy/dx**	**SE**	**Sign.**
Sex	−0.001	0.001		−0.042	0.007	***
Age group (<25)						
25–34	−0.001	0.004		0.050	0.021	***
35–44	−0.002	0.004		0.023	0.019	
45–54	−0.001	0.004		0.055	0.019	***
55–64	−0.006	0.004		−0.056	0.018	***
65–74	−0.010	0.003	***	−0.158	0.017	***
75-More				−0.201	0.016	***
Migrant	−0.006	0.003		−0.096	0.014	***
Education (elementary)						
Basic	0.004	0.002	***	0.041	0.011	***
Medium	0.009	0.002	***	0.037	0.012	***
High	0.006	0.002	***	−0.033	0.013	***
Quintile (Q1)						
Q2	−0.006	0.003		−0.039	0.013	***
Q3	−0.004	0.003		−0.054	0.013	***
Q4	−0.009	0.003	***	−0.067	0.013	***
Q5	−0.009	0.003	***	−0.068	0.013	***
Working	0.001	0.002		−0.001	0.010	
Sport	0.000	0.000		−0.010	0.002	***
Social support	0.000	0.007		−0.053	0.028	*
Observations	9.093			10.357		

*** significant at 1% level; * significant at 10% level. Source: Authors' analysis from [10] (Wave 3—2020).

On the one hand, it is easy to notice a higher penetration of e-cigarettes in the Spanish market, which seems to have a larger appeal among the younger cohorts. On the other hand, anecdotal data seems to suggest that HTPs are usually consumed by older groups and have a very small market share in the country. Finally, nicotine pouches are virtually non-existent, and snus is banned.

Given this market reality, we can draw a natural relationship with income. As this is higher, the probability of being part of the group "vaping" decreases significantly. Conversely, you are more likely to be part of the group "vaper" as your educational level increases.

If we compare it with smokers of traditional combusted tobacco, we also observe a decrease with age. Likewise, it seems that the fact of being an immigrant decreases the probability of being part of the group "vaper". An increase in income has the same effect. However, a significant difference from "vapers" is related to the educational level. In the case of traditional tobacco smokers, as the educational level increases, the probability of belonging to this group decreases. The opposite is true in the case of "vapers". In other words, the higher the education level, the higher the probability of being in the group of "vapers".

Therefore, given the market reality of Spain, we can conclude that the profile of the taxpayer is that of a relatively younger consumer with low income and a relatively higher education level (above the elementary level). This data is meaningful enough so that, when combined with the risk analysis that we will carry out below, it clearly indicates the direction that tax regulation should take.

Once the approximation of the profile of the vaper has been carried out—and considering the taxpayer characteristics—we must now focus on the differences between the traditional smoker of combusted tobacco and the consumer of new alternatives. For this, we have estimated the results obtained in Table 3. It shows the effects of being part of the group "vaper" on the use of health services. Thus, we can estimate the risk in terms of health spending. As a result, those who decide to consume RRPs do not have significant results in terms of increased use of general practitioner or specialist health services. However, they do

seem to visit the hospital less frequently than the consumers of combusted tobacco products (this variable is measured as the number of nights that the subject remains hospitalized).

Table 3. Negative binomial regression on the probability of being a tobacco user and vaper making use of health services.

	General Practitioner			Hospital			Specialist		
	Coef.	**SE**	**Sign.**	**Coef.**	**SE**	**Sign.**	**Coef.**	**SE**	**Sign.**
Traditional Tobacco	−0.020	0.024		−0.124	0.135		−0.029	0.020	
Vapers	−0.038	0.081		−0.417	0.197	***	−0.012	0.066	
Sex	0.053	0.020	***	−0.596	0.143	***	0.015	0.016	
Age	0.024	0.009	***	0.062	0.047		0.005	0.007	
Age^2	−0.002	0.002		0.010	0.014		−0.002	0.002	
Migrant	0.028	0.031		0.323	0.280		0.010	0.029	
Sport	−0.016	0.004	***	−0.116	0.022	***	−0.006	0.003	***
Marital	0.016	0.017		−0.149	0.083	*	0.014	0.012	
Working	−0.066	0.025	***	−0.332	0.132	***	−0.020	0.019	
Constant	0.231	0.041		1.200	0.246	***	0.230	0.040	***

Note: Age^2: quadratic relationship. *** significant at 1% level; * significant at 10% level. Source: Authors' analysis from [10] (Wave 3—2020).

Regarding patterns of consumption of health services, we are unable to obtain significant conclusions. The same issue occurs in the case of consumers of traditional combustion tobacco.

Let us now look at the individual health risks, which, indirectly, also play an important role in increasing health spending. Table 2 shows clear and significant differences between those who consume vaping and those who consume traditional combustion tobacco.

For this part of the work, we are going to use three of the most important diseases related to tobacco consumption as dependent variables. In the first place, bronchitis. Evidence shows that the consumption of traditional combusted tobacco increases the marginal probability of suffering from it. However, this is not the case for the group "vapers", where the effect is not significant. In the case of suffering from coronary and oral diseases, the same pattern seen for bronchitis is repeated.

That is why these latest models yield a much more significant result on the risks and, therefore, will be more useful to obtain our conclusions (Table 4).

Table 4. Probit models estimate the probability of suffering from a disease based on whether you vape or smoke traditional tobacco.

	Bronchitis			Coronary			Oral		
	dy/dx	**SE**	**Sign**	**dy/dx**	**SE**	**Sign**	**dy/dx**	**SE**	**Sign**
Sex	−0.003	0.004	-	−0.005	0.002	***	−0.005	0.007	-
Age	0.005	0.003	-	0.005	0.002	***	0.019	0.003	***
Age^2	0.000	0.001	-	−0.001	0.000	***	−0.001	0.001	**
Traditional Tobacco	0.023	0.006	***	0.002	0.004	**	0.058	0.008	***
Vapers	0.005	0.029	-	0.012	0.011	-	0.018	0.037	-
Migrant	−0.009	0.011	-	0.001	0.004	-	0.023	0.012	**
Sport	−0.003	0.001	***	0.000	0.000	-	−0.010	0.002	***
Marital	0.001	0.004	-	0.002	0.001	-	0.001	0.004	-
Working	−0.020	0.006	***	−0.011	0.004	***	−0.039	0.008	***

Note: Age^2: quadratic relationship. *** significant at 1% level; ** significant at 5% level. Source: Authors' analysis from [10] (Wave 3—2020).

4.3. Health Risk and Cost in Sweden

Snus, a form of smokeless tobacco, has been widely used in Sweden for several decades. Despite being a form of tobacco, snus has been associated with lower health risks

compared to smoking, leading to it being perceived as a safer alternative to smoking. The use of snus has been credited with the declining tobacco prevalence rates in Sweden.

4.3.1. A Brief Review of Previous Literature about Snus

The use of snus as a harm reduction alternative to smoking has been a topic of interest in the scientific literature for several decades. [16] conducted a study to assess the impact of snus use on smoking prevalence in Sweden, where snus has been widely used as an alternative to smoking since the 1970s. The study found that the use of snus was associated with a significant reduction in smoking prevalence, particularly among men. The authors suggested that the availability of a less harmful alternative to smoking, like snus, may have contributed to the decline in smoking prevalence in Sweden.

In 2016, ref. [17] conducted a similar study in Sweden to assess the impact of snus use on smoking prevalence over time. The study found that snus use had contributed significantly to the decline in smoking prevalence in Sweden since the 1970s. The authors suggested that the widespread availability and acceptance of snus as a less harmful alternative to smoking had played a crucial role in reducing the prevalence of smoking in Sweden.

The findings of these studies suggest that the availability of harm reduction alternatives like snus can contribute to a reduction in smoking prevalence. Careful regulation and education are necessary to ensure that the benefits of snus as a harm reduction tool are maximized while its potential risks are minimized.

Overall, these studies highlight the potential benefits of harm reduction strategies that prioritize less harmful alternatives to smoking, like snus. Further research is needed to better understand its potential role in reducing smoking prevalence in other countries.

4.3.2. The Impact of Snus on Smoking Prevalence in Sweden

As discussed above, tobacco prevalence drops substantially when legislation is introduced in favor of alternatives, in this case, snus. For the analysis of the impact of snus use, we will follow two steps.

First, we will take into consideration the calculation of actual and hypothetical cases of disease and death. For this, we will consider data provided by [18,19]. This data provides us with information on smoking and snus in terms of prevalence and their relation to some reference diseases such as lung cancer, ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD), and stroke. Secondly, for this analysis, we will consider the impact in terms of health costs, differentiating between the following direct costs: those related to all services associated with illnesses, treatment costs, hospitalization and medicalization costs, and indirect costs related to productivity losses: costs for morbidity, early retirement, and premature mortality.

4.3.3. Actual and Hypothetical Health Risks

For the calculation, we will essentially start with two different assumptions. The first assumption will answer the following question: How many people would be smoking in Sweden in 2019 if they had not switched to snus and remained cigarette smokers—assuming an EU average prevalence in Sweden? The second assumption will try to explain the differences between snus users and smokers in terms of the risk of suffering from any of the four smoking-related diseases.

To answer the first question, we must assume two scenarios: scenario A and scenario B. To graphically observe the results, let us look at the following Table 5.

Table 5. Calculation of actual and hypothetical disease and death cases.

Scenario A [1]	Scenario B [2]
Smoking prevalence: 10% Snus prevalence: 14% 850,000 people could be smoking in Sweden in 2019	Smoking prevalence: 23% Snus prevalence: 0% 1,850,000 people could be smoking in Sweden in 2019

Source: Authors' analysis from [18,19]. Note: [1] Prevalence including those who smoke both snus and cigarettes. [2] Assumes that all snus users were cigarette smokers in scenario B and that there is no initiation of snus in scenario A.

Regarding the second assumption, the one related to the probability of suffering from the four reference diseases, we can say that, according to [20], the risk for snus is lower for lung cancer and IHD. In the case of COPD and stroke, the risk of snus is also lower than that of traditional combusted tobacco (cigarettes, rolls of your own), as indicated by ref. [21]. Once the above two premises have been established, the scheme for the analysis of the risk calculation of suffering from a disease (or dying from it) follows Table 6:

Table 6. Several disease cases regarding the health risk levels.

Scenario A			Scenario B	
Non-smokers and non-snus users	Snus users	Smokers	Non-smokers and non-snus users	Smokers (smokers and snus users from scenario A)
No additional risk	Higher health risk compared to non-smokers and non-snus users; lower health risk compared to smokers.	Higher health risk compared to snus users	No additional risk	Higher health risk compared to snus users
140,000 disease cases from COPD, IHD, lung cancer, and stroke in the total population in 2019.			186,000 disease cases from COPD, IHD, lung cancer, and stroke in the total population in 2019.	

Source: Authors' analysis from [18–20].

Therefore, we can conclude that if snus had not been introduced and snus users were cigarette smokers, the risk of having one of the four diseases would have been much higher for them, increasing the number of disease cases.

4.3.4. Actual and Hypothetical Health Costs

The second step, as described at the beginning of this section, concerns a rough calculation of the associated costs. Thus, according to the methodology used by ref. [21], we will estimate the direct and indirect costs following the same scenario scheme as in the previous section (Table 7).

Table 7. Direct health costs calculations.

Scenario A	Scenario B
Annual treatment costs per case per disease (€) X Number of disease cases (result from step 1) Direct costs = 1.5 bn Euro	Annual treatment costs per case per disease (€) X Number of disease cases (result from step 1) Direct costs if snus had not been introduced = 1.9 bn Euro

Source: In both scenarios, the annual treatment costs per case per disease have been obtained from the following literature: [21–23].

For the analysis of the indirect costs associated with lost productivity, three different variables will be used:

- The number of years a patient suffers from a disease is referred to in health economics as years lived with disability (YLDs).
- The number of individuals inactive at work because of suffering from a disease multiplied by the smoking-related shares of YLDs from COPD, IHD, lung cancer, and stroke.
- Labor costs are measured by the average labor cost per year combined with smoking-related incapacity to measure productivity loss due to retirement and permanent incapacity.

Although there are several approaches to the calculation, such as the willingness-to-pay approach introduced by ref. [24], for our study, we will use the human capital approach, considered by ref. [25], which considers the number of smoking-related deaths per age group multiplied by the present value of lifetime earnings and yields the following results (Table 8):

Table 8. Total health costs for smokers and total population following the human capital approach.

Total Costs among Smokers		**Total Cost among the Total Population**	
Cost due to smoking in Scenario A	Increased costs due to smoking in scenario B	Cost due to smoking in scenario A	Increased costs due to smoking in scenario B
2.10 bn Euro	4.61 bn Euro	5.91 bn Euro	7.61 bn Euro

Source: Authors' analysis from data by [18,19].

As we can see, the differences in the first case, i.e., among cigarette smokers, are about 2.51 bn Euro, while, on the other hand, among the total population, the costs would increase by 1.70 bn Euro. Based on this approximation of the calculation, if snus had not been introduced, the costs for the total population would have increased by 28.76%. The same would occur if we were to analyze the indirect costs with this same approximation. The results show that the loss of productivity associated with morbidity would be 48% higher if snus had not been introduced. The loss associated with premature mortality would be around 45% higher.

These calculations seem to suggest that the introduction of snus has been crucial for the reduction of tobacco consumption in Sweden, generating significant savings in terms of direct and indirect costs and, most importantly, a reduction in the risk of contracting diseases such as lung cancer, COPD, IHD, and stroke.

The case of Sweden should also have a relevant impact when analyzing the prevalence and trends of traditional tobacco consumption. The learnings from the North give some important signals to policymakers when redesigning fiscal policies related to the taxation of these types of products.

In conclusion, the use of snus has significantly contributed to the declining combusted tobacco prevalence rates in Sweden. The perception of snus as a safer alternative to smoking, its social acceptability, availability, affordability, and the reduction in smoking initiation rates among young people are factors that have contributed to this trend. Further research is needed to better understand the potential impact on tobacco prevalence rates in other countries, but the Swedish case seems too strong of an example to overlook.

5. Conclusions

This paper aims to establish a basic protocol for the optimal design of taxes in the European territories on products whose consumption represents a negative externality. However, to do so, we believe it is appropriate to highlight three elementary design stages. The first of these is related to the taxpayer's socio-economic profile. The second is the knowledge of the risk involved in terms of expenditure for the system and, finally, the determination of the health risk of the individual who consumes it.

From the case study presented for Spain, we can derive some of the necessary signals for the design of this kind of taxation. This should be extrapolated to many other countries. On the one hand, it can be observed that the profile of consumers of non-combustion

alternatives to traditional tobacco, such as the ones being part of the over-comprehensive group of "vapers" in our case, are young individuals with medium and low income levels. Observing the market penetration of the different products in Spain, this result seems consistent with reality. On the one hand, it is easy to notice a higher penetration of e-cigarettes in the Spanish market, which seems to have a larger appeal among the younger cohorts. On the other hand, anecdotal data seems to suggest that HTPs are usually consumed by older groups and have a very small market share in the country. Finally, nicotine pouches are virtually non-existent, and snus is banned. We can also conclude that "vapers" have lower individual health risks than those who opt for combusted tobacco, although no significant differences have been found in terms of contribution to overall public expenditure yet.

Based on previous literature, RRPs are a less harmful alternative to traditional tobacco smoking. Non-combustible products do not contain tar, which is a major contributor to the health risks associated with smoking. They produce significantly fewer harmful chemicals than traditional cigarettes. Additionally, research suggests that non-combustible products are an effective tool for smokers who wish to quit tobacco smoking.

Given these facts, governments must implement taxation policies that reflect the reduced harm of RRPs compared to combusted tobacco. Imposing lower taxes on RRPs than on combusted tobacco will incentivize smokers to switch to less-damaging products, which would ultimately lead to a positive health outcome for both individuals and society. In countries such as the UK, the House of Commons, or in Germany, the government institution (BfR), has acknowledged the potential entailed in harm-reduced products to reduce health care costs.

Moving in the opposite direction could also lead to an increase in the black market for RRPs, creating additional health and safety risks for consumers.

Additionally, analyzing the experiences of Sweden, we discover that the use of snus has significantly contributed to the reduction in the prevalence of traditional tobacco smoking in the country. Snus is a smokeless tobacco product that is less harmful than traditional cigarettes, and its use has been widely accepted in Swedish society for decades. By promoting snus as a less harmful alternative to smoking, the Swedish government has been able to nudge consumers away from combusted tobacco products, reducing the prevalence of smoking and the associated health risks. The success of snus in Sweden highlights the potential benefits of harm reduction strategies that prioritize less harmful alternatives to smoking. However, it is important to note that the use of snus is not risk-free and can lead to various health issues. Therefore, careful regulation and education are necessary to ensure that the benefits of snus as a harm reduction tool are maximized while its potential risks are minimized. The production of Snus, which requires less tobacco than traditional tobacco products, can have a positive impact on reducing the demand for tobacco cultivation and, consequently, freeing up land for other purposes. This could lead to greater crop diversification, which in turn would help alleviate pressure on water resources since other crops may require less water compared to vast tobacco fields. Furthermore, by encouraging the adoption of other flavoring substances that require less water and resources for production, we can strengthen the agricultural economy by diversifying options for farmers and promoting more sustainable agriculture practices. It is essential to highlight that the focus on the development and promotion of Snus and other flavoring substances should go hand in hand with education and awareness campaigns, informing the public about their benefits and risks while ensuring strict compliance with regulations to safeguard consumers' health and well-being. Promoting responsible production of snus and other flavoring alternatives is a valuable and promising proposal to reduce tobacco cultivation, preserve natural resources, and enhance agricultural sustainability. Together, we can progress towards a more balanced and healthier future for our planet and future generations.

As main suggestions for policymakers, this article suggests that, before making hasty decisions to reduce the prevalence of traditional combusted tobacco through price regu-

lation or intervention, other academic criteria related to the optimal design of taxation of tobacco and its alternatives should be considered. To this end, the profile of the taxpayer and the risks to his or her health should be considered, avoiding a shift in consumption towards illicit or low-quality products that may be purchased in unregulated secondary markets.

Then, the available evidence supports the implementation of taxation policies that favor harm reduction alternatives like RRPs and snus while discouraging the use of traditional (combusted) tobacco products. RRPs are less harmful alternatives to smoking, and taxation policies that recognize their reduced harm can encourage smokers to switch to these products and reduce the burden of smoking-related health problems.

Higher taxes on traditional tobacco products can discourage their use and reduce the prevalence of smoking, which is the leading cause of preventable death and disease worldwide. Moreover, high taxes on traditional, combusted tobacco products can generate substantial revenue for governments that can be used to fund healthcare programs and tobacco control initiatives. All kinds of combusted tobacco products (cigarettes, roll-your-own, cigars) should be subjected to a relevant increase in their taxation levels to improve both public health and public accounts.

Spain should follow the example of many European countries, which have moved toward a fully specific tax, offering a relevant differential in favor of less-damaging products. In doing so, policymakers will be implementing tax policies that prioritize harm reduction alternatives like RRPs while strongly discouraging the use of traditional tobacco products. Such policies can help reduce the prevalence of smoking and improve public health outcomes while generating increased revenue for public health programs.

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Evaluation of Territorial Capacity for Development: Population and Employment

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Abstract: Rural depopulation and its consequences is a critical social, economic, labour and environmental issue. Based on diagnoses carried out five years ago in two rural territories of the Valencian Community (Spain) in a situation of demographic desertification, this paper aims to analyse if the evolution of employment and population has become a driving force for local development in both territories. To this end, triangulated analysis has been conducted using statistical sources, a survey of the respective Local Development and Employment Officers (AEDLs) and application of the new READI© methodology—based on a matrix with indicators evaluating the level of convergence of the resources, actors and dynamics available to the territory. The survey and READI© methodology have allowed us to complete sociodemographic analysis of population and employment to identify the causes that explain the similarities and differences between both territories in their capacity to generate local development processes. As a result of this study, some positive trends can be observed in the period encompassing 2017–2022, changing the preceding negative tendency and allowing us to generate a hopeful approach for such territories if local development policies correct the detected imbalances.

Keywords: community-led local development; depopulation; local development; rural development; resources; actors; dynamics

1. Introduction and Objectives

It is clear that rural territories have greater difficulties in generating opportunities for job creation and local development. Many factors are working against them: physical distance from urban centres; deficient infrastructure and insufficient means of transport; intermittent supplies and, in many cases, without guarantees; limited access to new technologies; inhibited training processes; lack of financial resources for entrepreneurship; and an ageing, poorly trained population with a lack of innovation and initiative. We would suggest that all of the above factors revolve around a single central element: the depopulation process to which these inland territories are subjected and which, in turn, undoubtedly affects the other factors mentioned above.

The Spanish [1–6] and international [7–10] academic literature has widely studied rural depopulation and its social and economic consequences. This issue has also been investigated from different disciplines and perspectives, such as demography [9,11–15]; geography and rural–urban spatial analysis [10,16,17]; employment and territorial development [8,18–23]; urbanisation and land transfer for developing the regional economy [24]; as a political [14] and social challenge [25]; and public policies and services [23,26]. But the problem can also be explored from the urban–rural digital divide [27] and social media use as a way to help improve organisation performance [28].

The depopulation of a large part of inland Spain is the result of structural changes that have their roots in the development of the Spanish economy during the third quarter of the

twentieth century [6]. But above all, they show that they are not only a critical demographic problem but also a social, economic, labour and environmental issue. This context justifies the interest of this empirical study to evaluate the recent evolution of population settlement and job creation as drivers of territorial capacity for development in two rural areas that have experienced one of the most significant demographic declines in Spain during the last decades, in the context of a marked socioeconomic crisis linked to their rural and peripheral situation.

This paper builds on a thorough diagnosis carried out in 2017 in the 25 different *comarcas*[1] of the Valencian Community (Spain) to analyse the territories in an integrated way and identify the qualities of each geographic space and its development possibilities [18]. It was intended to serve as a guide for policies to combat depopulation in rural areas, receiving the direct involvement of the regional public administrations with competencies in this area through the LABORA organisation—the Valencian Service for Employment and Training.

On this basis, this study aims to analyse if the evolution of employment and population has become a driving force for local development in two distinct rural areas (*comarcas*) in a situation of demographic desertification and located in the interior of the Valencian Community: El Rincón de Ademuz and Los Serranos. To this end, triangulated analysis has been conducted using statistical sources, a survey of the respective Local Development and Employment Officers (AEDLs)[2], and the application of the new READI©[3] methodology [31]—based on a matrix with indicators evaluating the level of territorial capacity for local development processes. The ultimate goal is to lay the foundations of local development policies to address possible imbalances and generate opportunities to retain inhabitants.

Our working hypothesis links the capacities[4] to establish a settled population and to generate employment as driving forces of local development. To verify this, we will analyse how population and employment have evolved and whether they have indeed become driving forces for these territories. Moreover, to provide a gender perspective not considered in previous diagnoses, we will include sociodemographic information differentiated by gender.

This paper is organised as follows. Section 2 reviews the previous diagnosis of the two *comarcas*. Section 3 describes the research method used for triangulated analysis. Section 4 shows the results of the study in three subsections: firstly, in Section 4.1, we describe the recent evolution of the relevant sociodemographic statistical data; then, in Section 4.2, we show the socioeconomic evolution of employment and population outcomes as perceived by the AEDL; and thirdly, in Section 4.3, we provide more detailed diagnosis of the development capacity of each *comarca* in the three dimensions of the READI© matrix: resources, actors and dynamics. Finally, Section 5 summarises the results, showing the usefulness of the READI© matrix in identifying the causes that explain the similarities and differences between both territories in their capacity to generate local development processes.

2. Background: Previous Diagnosis of Two Rural *Comarcas* of the Valencian Community

Taking into account all of the above regarding the difficulties in generating opportunities for job creation and local development in rural territories, what shows itself to be the principal problem of depopulation is the quantitative loss of human resources. And so we see that as the average age goes up in these *comarcas*, the age pyramid becomes regressive, relative mortality increases and the birth rate decreases. Consequently, if the migratory balances are negative, the result can only be an ageing population. Bielza [32] points out that an ageing society cannot be an entrepreneurial society since it is dominated by a gerontocracy, and this, in the long term, leads to economic imbalance:

"It might be described as a perfect storm of rural depopulation initiated by the lack of profitable jobs, which causes an exodus leading to the consequent demographic regression to levels of underpopulation, which in turn reduce the provision of services and equipment and the consequent deterioration of the quality of life. All of which lessens the attraction of

an underpopulated rural environment, aggravating the problem of low employment, and the process is reinforced until total depopulation is reached" [32] (p. 618).

The scientific literature on the subject and recent studies corroborate the above, pointing out that depopulation is a not only a demographic and territorial phenomenon but also a social challenge for the territory [4,14,16,25].

In Figure 1, we can see the geographical location of these *comarcas* and the reality of the situation of depopulation in which they find themselves.

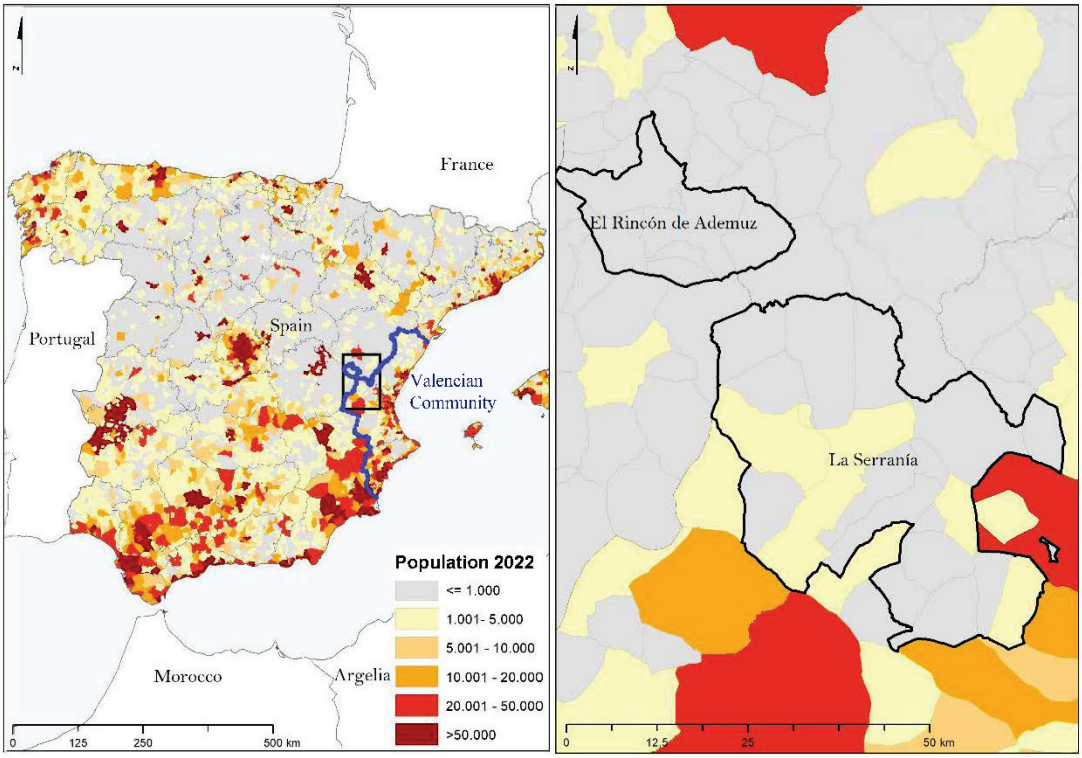


Figure 1. Geographical location and population of the municipalities in the territories analysed. Source: Prepared by the authors from INE-National Statistics Institute.

Territorial diagnoses of these two *comarcas* were carried out in 2017, within the framework of the Valencian Strategy for Employment administered by the Valencian Government [18][5]. These diagnoses identified the existing resources in both territories to favour development potential and seek out local networks to form the backbone of the development process. All of this was with the ultimate aim of laying the foundations of a local strategy whose main courses of action were:

1. To make the most of the available resources and the need to strategically dimension the potential of the territory.
2. To promote endogenous initiatives from, by and for the territory.
3. To generate population attraction poles, especially for women and young people.
4. To improve infrastructures to circumvent the technological gap (roads and basic amenities such as electricity and Internet).
5. To encourage private initiative through public–private partnerships.
6. Who leads the territory? A joint, comprehensive, integrated and integrating vision.
7. To attend to the singularities of these territories.
8. The need to retain and attract capital and talent through training.
9. To activate the population. Do not wait for someone from outside to come and do this or to propose the solution.
10. To address the lack of investment: a strategic plan of action (long term).

All these proposals come together to form the main conclusion that a clear link exists between the capacities that the territory has at its disposal to settle the population, on the one hand, and to generate employment opportunities, on the other hand. Any local development project must take into account and coordinate these two variables in order to achieve success. The combination of these two capacities (simplified through a dichotomy of whether they are capable/not capable) determines four scenarios a rural territory may face, shown in Figure 2.

		Capacity to settle its population	
		Incapable	**Capable**
Capacity to generate employment	**Incapable**	***Scenario 1. UNINHABITED TERRITORIES (NO FUTURE)*** - Territories unable to be an attractive proposition for population settlement and unable to generate employment opportunities (after population exodus). - Structural resistances: lack of material and human resources	***Scenario 3: UNSTABLE TERRITORIES*** - Capable of attracting population and settling it in a stable manner, but without guarantees of offering lasting employment. - Unable to settle the population with the necessary skills to make the most of the resources. - Generate resistance that, in the long term, degrades the development of the territory.
	Capable	***Scenario 2. ENDANGERED TERRITORIES*** - High labour potential, but no population available to develop it (attractive area, retaining human capital) - It has resources but no actors to activate them and enhance their value. - Needs public measures to encourage population return and population stability	***Scenario 4. DEVELOPING TERRITORIES*** - Great potential for the use of resources - Attract population, high employment potential - Strategies based on the needs of the territory, led and participated in by the population itself.

Figure 2. Possible scenarios in the diagnosis of a territory's capacities for development: settling its population and generating employment. Source: Adapted from [20].

3. Method: Analysis of the Period Encompassing 2017–2022

As previously indicated, five years after the initial diagnosis, this paper analyses in detail the recent evolution of employment and population in the rural territories of the Valencian Community. Our working hypothesis will seek to link the two variables in order to verify whether they have become driving forces for development.

The fieldwork was carried out in the *comarcas* of Los Serranos and El Rincón de Ademuz. Los Serranos (also known as La Serranía) is made up of a total of 19 municipalities and has a population of 16,604 inhabitants. El Rincón de Ademuz comprises seven villages with a population of 2189 inhabitants in 2022 [33]. Both *comarcas* are located in the northwest of Valencia (Spain), with an area of almost 1800 km² and an average density of just 10 inhabitants per km² (see the map in Figure 1).

The data collection and analysis techniques used in the development of this research were as follows:

1. Analysis of statistical and documentary sources, such as:
   - INE-National Institute of Statistics [33];
   - IVE-Valencian Institute of Statistics [34];
   - LABORA-Valencian Employment and Training Service [35].

We also considered statistical sources and secondary data provided by the local administration of both *comarcas*. In addition, to provide a gender perspective not considered in the initial diagnoses, we included sociodemographic information differentiated bygender.

2. The sending of an ad hoc questionnaire to the 23 AEDL technicians of the territory, in which they were asked questions about population, employment and opportunities for territorial development. Of the 23 AEDL technicians (6 from El Rincón de Ademuz and 17 from Los Serranos), 15 responded (5 from El Rincón and 10 from Los Serranos). All the respondents were women (except a man from Los Serranos) since AEDL is an eminently feminine profession. Therefore, results broken down by respondent gender are unnecessary since this sample ensures no gender bias against women.
3. Application of the READI© methodology to know and measure the capacities of the territories for future local development processes. This methodology based on the READI© matrix consists of a set of 165 indicators organised around three large blocks: resources, actors and dynamics. This matrix allows for assessing the situation of the territories by offering a resulting score, as a general whole or itemised, for each element or grouping of indicators. A more detailed explanation of this methodology can be found in [31,36].

The final distribution of **dimensions**, **variables** and **subsections** of this matrix is shown in Table 1 [31]. This complex index shares out a total of 500 points among the three main dimensions as follows: resources (200 points), actors (150 points) and dynamics (150 points). The READI© matrix has been validated as described in [37].

Table 1. READI© matrix final proposal: dimensions, variables and subsections.

MATRIX Summary—Resources, Actors and Dynamics	Scores
RESOURCES[6]	**200**
ECONOMIC[7]	
Own funding sources[8]	15
External funding sources (public)	10
External funding sources (public–private)	10
External funding sources (private)	10
Interest in and seeking participation in European projects	5
PRODUCTIVE	
Quantity of employment generated	15
Quality of employment generated	20
Productive fabric	10
Productive sectors (quantity)	5
Size of companies	5
HUMAN	
Average education level of the population	10
Labour migration balance (local employment system)	10
SPATIAL	
Natural resources	10
Tourism resources	10
Cultural resources	10
Production resources	15
Geographical location	10
Infrastructure	10

Table 1. *Cont.*

MATRIX Summary—Resources, Actors and Dynamics	Scores
ACTORS	**150**
Specific resources for development	25
Presence of socioeconomic actors	25
Presence of a variety of socioeconomic actors	25
Detection, study and analysis process	20
Contact process and collaboration proposals	30
Results obtained	25
DYNAMICS	**150**
Forums and meeting points	30
Types of forum and meeting points	20
Territorial leadership	25
Socio-institutional networks at local level	25
Methodologies and strategic plans	25
Joint vision of territorial development	25
TOTAL MAXIMUM SCORE	**500**

Source: [31].

4. Results of the Study: Evolution over the Period 2017–2022

The results of the analysis carried out in these two territories are shown below. Firstly, the evolution of sociodemographic statistical data is described, then the socioeconomic evolution is described as perceived by AEDLs and, finally, a more detailed diagnosis of their capacity for development is described for each of the three dimensions of the READI© methodology: resources, actors and dynamics.

4.1. Sociodemographic Evolution

Table 2 shows the evolution of the main sociodemographic indicators of the two *comarcas* over the last five years. It also shows the data corresponding to the year in which the historical series began. The year of the beginning of the series is different for each indicator and appears in parentheses in the first column. The last year available is also different for each index (either 2021 or 2022).

We are presented with a difficult contextual starting point, with low activity rates, which distinguish a territory where the priority is to guarantee opportunities for its inhabitants to stay to live there. The danger is that this area could become a land of ghost towns. However, there are certain positive indicators that we feel it is important to highlight.

These areas have experienced some of the greatest demographic decline in the Valencian region, in the context of a marked socioeconomic crisis linked to their rural and peripheral situations. Demographic indicators show the population decline of both *comarcas* with annual growth rates that are clearly negative. The *comarca* of Los Serranos continued to lose population from 17,169 residents in 1996 to 16,604 in 2022, although between 2017 and 2022 there was a small growth in population that has allowed it to stabilise at 0.33 per cent of the regional total since 2017. As regards the *comarca* of El Rincón de Ademuz, the population went from 10,000 inhabitants at the beginning of the twentieth century to 3013 inhabitants in 1996 and 2189 in 2022, falling throughout the period, both in absolute terms and as a percentage of the regional total.

Disaggregated by gender, between 1996 and 2022, the percentage of women dropped from 48.8 to 46.2 per cent for the inhabitants in El Rincón de Ademuz, and from 49.1 to 47.4 per cent in Los Serranos. Therefore, women's population has fallen slightly more than men's in both *comarcas*. However, this negative trend seems to have just changed in Los Serranos during the last five years, with a stabilisation of the percentage of women and the aforementioned small population growth for this comarca.

Table 2. Recent evolution of sociodemographic indicators for both *comarcas*.

Indicators (in Parentheses the Year of the Beginning of the Series for Each Indicator)	El Rincón de Ademuz			La Serranía			Valencian Community
Demographics	**Start of Series**	**2017**	**2021/2022**	**Start of Series**	**2017**	**2021/2022**	**2021/2022**
Population (1996)	3013	2289	2189	17,169	16,237	16,604	5,097,967
Population percentage over the Valencian Community population (%) (1996)	0.08	0.05	0.04	0.43	0.33	0.33	
Density (inhabitants/km^2) (1996)	8.1	6.2	5.9	12.2	11.6	11.8	219.2
Children under 16 (%) (2001)	9.3	12.2	11.1	10.5	11.1	10.8	15.0
Older than 64 (%) (2001)	35.5	30.8	29.7	27.5	27.7	27.7	20.0
Women (%) (1996)	48.8	47.0	46.2	49.1	47.5	47.4	50.8
Dependency ratio[9] (2001)	81.0	75.3	68.8	61.4	63.4	62.7	54.6
Ageing index[10] (2002)	380.30	252.30	263.30	264.70	248.80	251.00	128.9
Longevity index[11] (2002)	52.00	61.90	64.50	49.00	53.80	53.90	48.1
Trend index[12] (2002)	102.7	59.6	80.0	67.7	81.2	77.9	81.4
Labour Force Renewal Index[13] (2002)	86.7	59.3	54.1	114.3	68.7	60.6	74.9
Crude birth rate (‰) (2010)	7.2	5.0	4.9	7.0	6.3	5.5	7.1
Total fertility rate (‰) (2010)	37.43	30.26	31.85	34.88	35.68	31.36	32.52
Crude mortality rate (‰) (2010)	17.6	20.1	19.3	12.6	14.7	14.3	9.9
Life expectancy at birth (men) (2010)	78.4	77.9	78.4	79.3	79.9	80.2	79.5
Life expectancy at birth (women) (2010)	84.2	83.6	83.8	84.5	84.9	85.0	85.0
Companies	**Start of series**	**2017**	**2021/2022**	**Start of series**	**2017**	**2021/2022**	**2021/2022**
No. of companies (DIRCE[14]) (2012)	180	174	162	1.084	1.005	1.029	370.645
No. of companies registered with Social Security (2012)	64	58	75	408	435	459	150.491
Employment	**Start of Series**	**2017**	**2021/2022**	**Start of Series**	**2017**	**2021/2022**	**2021/2022**
Registered unemployment (No. of people) (1996)	134	131	123	701	1.092	883	338.243
Unemployment rate (%) (2006)	5.9	9.6	9.3	6.2	10.8	8.7	10.3
Registered new contracts (2007)	118	87	70	278	275	240	104.916
SS affiliation rate[15] (%) (2012)	29.8	32.4	34.6	32.5	38.1	43.9	61.0
Women's SS affiliation rate (%) (2012)	39.2	40.7	43.4	39.9	39.6	42.7	46.3

Source: Own elaboration from [33–35,38–40].

The qualified young population generally seeks to invest their future elsewhere, where they can find better opportunities. The ageing rate in both *comarcas* is double the average value for the Valencian Community.

The average age is respectively seven years older (Los Serranos) and fourteen years older (El Rincón de Ademuz) than the regional average (48 years). With such a demographic panorama, it is not surprising that the dependency ratio is significantly high compared to the Valencian region as a whole. Thus, a marked deficit in the young and adult population is a characteristic feature of the population structure of these areas.

The combination of all the factors described above has generated an extensive demographic desert with very low population densities. In Los Serranos, the population density has been around 12 inhabitants per km^2 since 1996, while in El Rincón de Ademuz it is 6 inhabitants per km^2, less than 10 inhabitants/km^2, which is considered the threshold of "demographic desertification" [11] (p. 207).

With the current dependency rates, exacerbated ageing rates and low Labour Force Renewal Index, the result is inevitable, especially if we focus on the high ageing index rates, 263.3 in El Rincón de Ademuz and 251 in Los Serranos, as well as longevity rates of 53.9 and 64.5, respectively. The crude birth rate also dropped significantly, from around seven per 1000 in 2010 to less than five in the first *comarca* and five and a half in the second, in 2022. The percentage of children under 16 years of age, which had improved slightly between 2001 and 2017, decreased somewhat between 2017 and 2022, remaining at around 11 per cent in both *comarcas* in 2022, below the regional average of 15 per cent. All this translates to a Labour Force Renewal Index that is much lower than in 2002 and continues to decline well below the regional average of 75.

In contrast to this pessimistic outlook, a few indicators have evolved favourably in recent years. For example, the dependency ratio reduced in El Rincón de Ademuz from a high 81 per cent in 2001 to 69 per cent in 2022, while in Los Serranos it remained around 63 per cent over the same period. These values exceed the regional average of 54 per cent but have improved in the *comarca* with the worst data at the beginning of the century. This improvement is mainly due to the reduction in the percentage of people over 64 in El Rincón de Ademuz between 2001 and 2022. Likewise, between 2017 and 2022, the crude mortality rate changed its trend and reduced slightly in both *comarcas*, although it was still higher than the regional average rate. Finally, life expectancy at birth remains the same as the regional average in the *comarca* of Los Serranos, and a little below in El Rincón de Ademuz, with no sign of a negative trend.

Concerning the economic situation, the supply of employment in these *comarcas* is mainly based on agriculture, commerce and manufacturing industries. However, there is little entrepreneurial strength, with 162 companies in El Rincón de Ademuz and 1029 in Los Serranos. According to the DIRCE[16], the current number of companies in both *comarcas* is lower than in 2012, when the series began. On the other hand, the number of companies registered with the Social Security rose from 2012 to 2022 in both territories (also from 2017 to 2022). These companies are mostly SMEs.

Agriculture continues to be an important activity, although construction and rural tourism have positioned themselves as the economic engine in recent decades. With regard to affiliation to the social security system, it is worth highlighting the significant weight of affiliation by workers with self-employed status in these rural areas, which is double the figures registered in the Valencian Community. The submerged economy—especially for women—and other economic alternatives, such as neighbourhood and family networks, are widely analysed facts of Spanish rural areas [41], with no exception apparent here.

Nevertheless, from 2012 to 2022, Social Security affiliation rates increased in both *comarcas*, up to 35 per cent of the working-age population in El Rincón de Ademuz and up to 44 per cent in Los Serranos. However, they still do not reach the 61 per cent regional average. Likewise, women's Social Security affiliation rate also increased in both *comarcas* between 2012 and 2022, rising to 43 per cent in both *comarcas* and quite close to the 46 per cent regional average.

The educational level of unemployed job seekers registered in 2022 in LABORA shows that almost half of the job seekers in these *comarcas* do not have a school diploma. However, although the absolute number of contracts has declined in the last five years, the number of unemployed people registered in the public employment service and the unemployment rate decreased in both *comarcas*, which can be considered a positive indicator for the labour market. The gender unemployment gap[17] in both *comarcas* is practically the same as the regional average (4%).

In addition, mobility associated with employment opportunities is linked to the possibilities offered by the transport system. There is no public transport service in these rural areas, which constrains employment opportunities in the local labour markets since any kind of mobility implies travel by car. Thus, the traditional deficit of services and infrastructures hinders accessibility and integration between these municipalities and with the wider economy. This brings into evidence the lack of territorial cohesion and the isolation of these rural areas [12,18,26].

Regional policy has largely neglected addressing the specific problems of the territory. Regional and state policy initiatives have been directed mainly towards improving road communications and basic infrastructure to ensure that these rural areas are acceptably attended to. However, these are insufficient, as Pinilla and Saez [4] (p. 14) point out when referring to the unsystematic and disjointed public investment provided to Spain's most depopulated rural areas.

The data in Table 2 above illustrate the "rural–urban" dichotomy, which authors such as Del Molino [2] consider a new centre of inequality in Spanish society, pointing out that this has been accentuated by Spain's entry into the European Union. This dichotomy causes a gap fostered by economic interests, which have focused on large cities and urban areas, and has eroded some of the traditional rural cultural elements to a certain extent. Along the same lines, Del Rey et al. [42] point out that there is a decrease in the importance of the rural environment. And the stigmatisation of all that is rural still pervades [1,5,7].

To address this trend, a European strategy for the rural development policy of its member states is necessary. As Margaras [3] points out, several EU countries are home to sparsely populated areas, so the problem could be addressed from a European perspective and a conception of development understood in a broad sense. Territorial cohesion is one of the fundamental objectives of the European Union, included in the Lisbon Treaty of 2007, to call for a balanced and harmonious development of all European territories according to their strengths and singularities [19].

In this sense, rural areas represent one of the main challenges for development policies throughout the member states, as these areas are more exposed to poverty and social exclusion. Moreover, this situation is aggravated by other deficits that cause the material and immaterial isolation of these areas. These deficits range from the absence or difficulty of access to basic services (such as healthcare) to the lack of education and training infrastructure, especially for young people [13] (p. 223). According to Pinilla and Sáez [26] (p. 331), depopulation policies should have the objective of enabling citizens to reside where they wish and obtain the best possible quality of life. And this could be based on a new governance framework, together with the support of the European Union [21,43], to carry out these policies more effectively and constitute a benchmark of successful territorial cohesion for the member states.

These areas exemplify imbalances in development because of their low expectations and because they are ostensibly unattractive to live in. However, as noted above, if the singularities of these territories are taken into account and rural society is to be preserved, they could also become areas of opportunity. As underpinned by the scientific literature [8–11,27], it is a matter of urgency to attract population and investment in order to fight against depopulation and unemployment.

4.2. Socioeconomic Evolution: Employment and Population Outcomes

The recent evolution of the population and the economy of these two *comarcas* have been surveyed by means of the ad hoc questionnaire answered by 15 AEDLs from both territories. Figure 3 shows that the responses provide a very close pass score (greater than or equal to five out of ten) for all the items, with better values for Los Serranos.

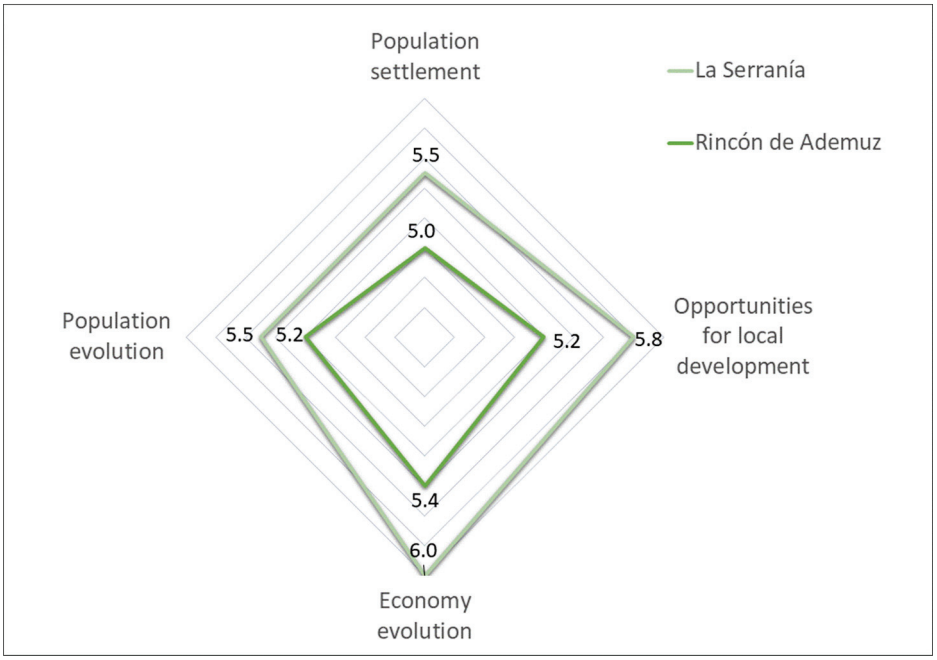


Figure 3. The vision of the AEDLs on the evolution of the population and economy of each *comarca* with respect to its development capacity. Source: Prepared by the authors, based on ad hoc questionnaires (scale from 0 to 10, where 10 = 100% of the territory's capacity).

In both *comarcas*, the evolution of the economy and opportunities for local development are perceived as being somewhat better than the evolution and settlement of population.

According to the AEDLs, the pandemic has slowed the exodus and ageing in both *comarcas* but has not stopped them. Although there has been a settlement of young people in the last two years due to COVID-19, this increase cannot be considered significant. Young people continue to leave for the main urban centres seeking study opportunities, and the population continues to be predominantly older.

And concerning the evolution of the economy, some cooperative and private employment-generating projects have been created in the last years. New services have also been provided, and existing services have been maintained to facilitate the reconciliation of work and family (nursery school, respite for carers and home help services for the elderly), encouraging the incorporation of many women into the labour market. Nevertheless, most of the business fabric is still made up of micro-enterprises with ageing personnel.

4.3. READI© Methodology Results (Resources, Actors and Dynamics)

This socioeconomic vision is also endorsed by the indicators shown below, the result of the application of the READI© matrix [36], which evaluates a territory's capacity for development. This matrix is based on the convergence of three key dimensions: resources, actors and dynamics.

The resources in an area are of no use if there are not actors who know how to make the most of them. Equally, actors are of little use if they do not cooperate and do not establish interaction dynamics among themselves, beyond those motivated by their own interests. Therefore, territories are only competent to the extent that they make the most of their available resources through the actors present and generate dynamics among them.

However, not all factors influence territorial development to the same degree, so they are assigned different weights in this matrix [36].

In Figure 4, we see the summary of the scores for each *comarca* in the main dimensions and variables of the READI© scheme, with four graphs.

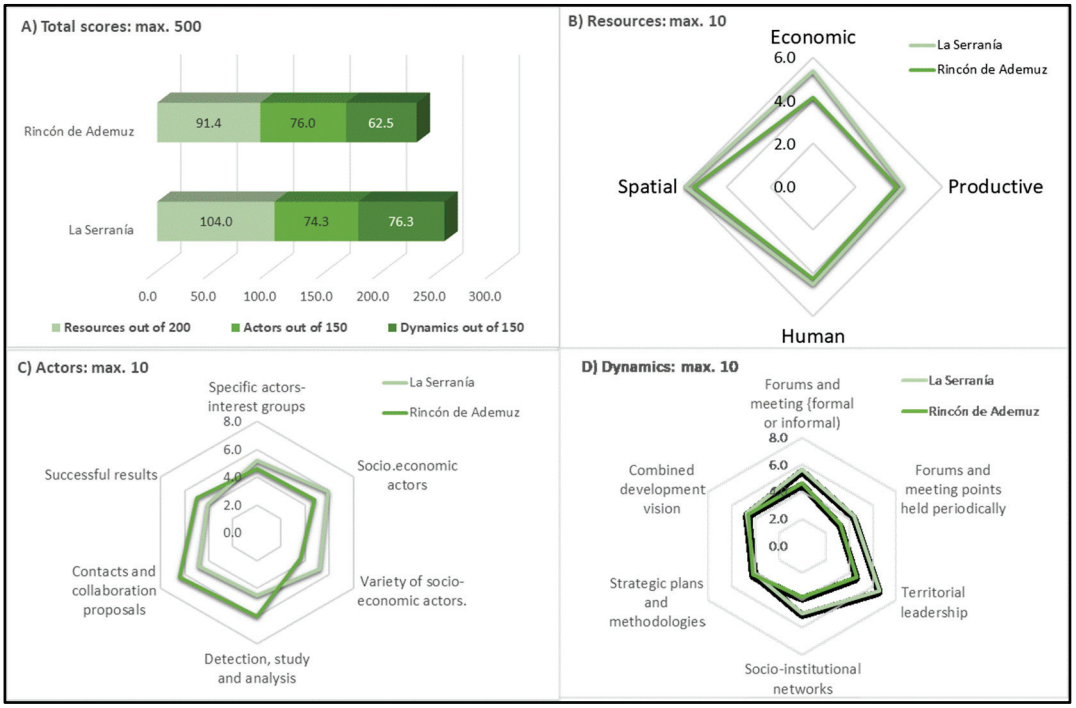


Figure 4. (**A**) Summary with the scores of each *comarca* in the main dimensions of the READI© matrix. (**B**–**D**) Detail with the scores in the variables of each dimension. Source: Prepared by the authors, based on ad hoc questionnaires (scale from 0 to 10, where 10 = 100% of the territory's capacity).

In Figure 4A, we can discern that the total scores of both *comarcas* are located within an intermediate value band in relation to the maximum 500 points of the matrix. El Rincón de Ademuz rests at 46 per cent (229.9/500) of its potential for development, compared to 51 per cent (254.6/500) for Los Serranos.

If we compare the scores for each of the three main dimensions analysed (Figure 4A), El Rincón de Ademuz does not gain a pass mark in the valuation of **dynamics** (62.5/150 = 42 per cent of its capacity), nor in that of **resources** (91.4/200 = 45 per cent of its potential), while La Serranía has an intermediate score in both dimensions, a little above 50 per cent. Finally, the valuation for **actors** just scrapes a pass mark in both *comarcas*.

In this sense, it becomes necessary to consider the relevance of the issue of "social capital" and cooperation links between actors—human, technical and organisational resources, among others—as sources of relationships where the dynamics that generate development strategies take place. According to Barreiro Cavestany [44] (p. 10), as cited in [45] (p. 1012), social capital is relational, and a person or an organisation must relate to another in order to possess this type of capital. Social capital only exists when it is shared. That is to say, although there are actors, if there are no exchanges and interactions among them, no dynamics are produced. In short, this social capital is not used in favour of possible territorial development strategies by both *comarcas*.

The following is a more detailed analysis of each of the three elements of the READI© matrix through their main variables shown in Figure 4B–D:

- As shown in Figure 4B, the **resources** that score best are spatial resources (natural, tourist, cultural heritage, productive and infrastructures), which are located between 55% and 60% of their potential in both *comarcas*. They are followed in capacity by economic resources (self-financing, public or private external financing, and European

Union funding), although with important differences between Los Serranos (54% for potentiality) and El Rincón de Ademuz (41%). Human resources (labour migration balance and training of the population) are at between 43% and 45% of their capacity, with productive resources (quantity and quality of job creation, productive fabric, number of productive sectors and size of companies) being the lowest rated (between 39% and 42% of their capacity). To discover with more detail the capacity of these *comarcas* to generate employment, we will now look at an assessment of three subsections of the "resources" dimension of the READI© matrix, which do not appear in Figure 4. The first subsection is the variable "quantity of employment generated" (valued within the productive resources section), which is between 40% and 45% of its capacity in both territories. The second subsection is the "quality of employment generated", valued at between 46% and 50% of its potential. And finally, the third one is the "labour migratory balance" (valued within the human resources section), which shows that more labour is imported from other places (between 49% and 52% of its potential) than can be exported (between 41% and 44% of its potential). In all cases, Los Serranos has a slightly higher assessment than El Rincón. We will discuss these specific scores later in this paper.

- The **actors** dimension refers to the existence of people and organisations (economic, political, social and technical), both public and private, with a direct or indirect interest in the development of the territory. When we analyse the six variables of this dimension, both territories receive scores of around 50% for the presence of specific stakeholders and interest groups (specific resources for development), with scores of between 46% and 52%. However, they differ considerably in the score received for the variety of socioeconomic actors, which is low in the Rincón de Ademuz (36%), while it achieves a pass mark in Los Serranos (52%). And the contrary occurs with the results obtained from the contacts between the different actors or interest groups in the territory, which achieve minimal success in the Rincón de Ademuz (50%) and a low score in Los Serranos (41%). What is noteworthy in this dimension is that an inverse process is detected for both *comarcas*. In Los Serranos, there are more actors and they are more varied than in Rincón de Ademuz, but in the latter *comarca* there is a remarkable process of detection, study, analysis, contact and proposals for collaboration among the actors. Does this presence of actors and their identification processes indeed translate into dynamics for activating and mobilising the territories' resources? This question will be answered in the next section.
- Finally, the issue of **dynamics** is closely related to that of actors. For dynamics to exist in the territory, not only must the actors be detected and defined, but there must also be spaces for meeting and exchange. In both *comarcas*, there is a wide margin for improvement and progress as regards these issues, with worse scores in El Rincón de Ademuz. It is true that there are forums and meeting points for development at a local level, with an average degree of consolidation and institutionalisation (creation of participatory bodies) that varies between 46% and 56%. However, when it comes to the functioning of these forums and their timing throughout the year, the scores drop to between 32% and 44% of their capacity. As a consequence, the existence of socio-institutional networks for interaction between the different local social actors or interest groups is also low, resting at between 38% and 50%. This also implies that the existence of methodologies and strategic plans is only slightly above 40% in both territories. Only the assessment of the joint vision of development (between 46% and 48%) and the existence of territorial leadership (especially in Los Serranos) are saved from these negative scores.

5. Conclusions

In accordance with our working hypothesis, linking the capacities to settle population and generate employment as driving forces of local development, the main findings of this

research highlight some positive cues facing the issue of depopulation and loss of economic activity and jobs in the rural areas studied.

Firstly, various statistical indicators point in this direction: from demography (low population growth in the last five years, reduction in the dependency ratio and crude mortality rate, and maintenance of life expectancy at birth, among other factors) to employment (increase in Social Security affiliation rates and reduction of the unemployment rate) and economy (increase in the number of companies registered with Social Security). Secondly, the AEDL survey shows that the evolution of the economy and opportunities for local development is perceived as being somewhat better than the evolution and settlement of population. And thirdly, the READI© matrix shows well-valued spatial resources, together with a certain vision and capacity for territorial leadership in these areas, although lacking the forums where their vision turns into plans.

These findings are consistent with other studies [6] examining the recent demographic and economic trends in the so-called "depopulated Spain", finding that some rural areas next to these two *comarcas* also seem to be overcoming the declining course of the past.

Some positive population and employment trends observed in both territories between 2017 and 2022 are detailed below, allowing us to generate a hopeful approach if local development policies succeed in correcting the detected imbalances:

- On the one side, the statistical data on **population** show that Los Serranos maintains its percentage score as regards the average regional population, slightly increasing its population density. Moreover, the dependency ratio fell in El Rincón de Ademuz and Los Serranos in the same period. Likewise, the percentage of people over 64 decreased in the first *comarca* and remained practically the same in the second. Finally, the crude mortality rate reversed its trend and dropped between 2017 and 2022 in both territories. Similarly, the AEDLs interviewed have awarded a marginal pass to the recent evolution of the population and the settlement of people in the municipalities, with values around 50–55% of their capacity (Figure 3), which is also positive. The explanation provided is that the pandemic has slowed the rate of exodus and ageing but has not stopped it. Young people continue to leave, and the population continues to be predominantly older. Focusing on the AEDLs' vision in Figure 3, what stands out is that the recent evolution of the population is valued slightly lower than that of the economy. The evaluation of Los Serranos is slightly better than that of El Rincón de Ademuz for every indicator. According to the working hypothesis, the previous statistical analysis combined with the diagnosis of the AEDLs shows two *comarcas* whose ability to settle the population is less than their capacity for economic development.
- On the other side, analysis of statistical data for **employment** generation also reveals some encouraging data. Between 2017 and 2022, the number of companies and the Social Security affiliation rate have risen in both *comarcas*. In addition, the number of unemployed people registered with the public employment service and the unemployment rate have decreased in both territories, indicating an improvement in the labour market. The insights into employment generation gained from certain specific subsections of the READI© matrix reveal that the "quality of job created" and "labour importation" are valued slightly better than "quantity of job created" and "labour exportation". Therefore, a greater problem is perceived in the quantity of employment than in its quality and, likewise, a greater problem in the ability to export labour than in the ability to import.

The dimensions of the READI© methodology (Figure 4) have allowed us to complete a sociodemographic analysis of population and employment to identify the causes that explain the similarities and differences between both territories in their capacity to generate local development processes: the endowment of resources, presence of actors and generation of dynamics.

The vision offered by the READI© matrix presents a panorama of territories with scarce productive resources (more than human or economic resources), their spatial resources being the best valued. The territory with fewer economic resources and a lower quantity

and variety of socioeconomic actors has developed a greater capacity for detecting actors, contacts and proposals for collaboration between agents.

However, both territories end up receiving a low valuation for the dynamics that generate methodologies and strategic plans. This is surely due to the low score given to the activity carried out by existing forums and available meeting points. It is curious to note that, in the section on dynamics, the most highly valued aspect is the capacity for territorial leadership (an average of 60%). This last result may be interpreted as the high level of willingness of the actors, faced with a challenging starting point, since this leadership does not seem to have materialised yet.

In view of the positive signs, if the trends observed continue in the future, this could be the beginning of a scenario which provides sustainable development, attracts population, generates employment and takes advantage of existing resources. This would undoubtedly be the case if the leading bodies of the process opt for strategies that respond to the needs of the territory, with the participation of the population itself, which would allow these *comarcas* to move towards a more beneficial situation, very close even to scenario 4 in our initial proposal (Figure 2).

The present study has some limitations, and the recognition of these should help refine future research. First, this is a complex issue that requires study over a more extended observation period. Second, although it is an exhaustive study using triangulated analysis, it is based on only two *comarcas* of the Valencian Community. For this reason, we are working to extend the study to other depopulated territories with similar characteristics. This research line is complementary to studying whether these trends will continue in the future in the same *comarcas*. Finally, the initial diagnosis lacked information from statistical sources differentiated by gender. Future research and a revised READI© matrix must incorporate the gender perspective in their indicators.

From this perspective, these *comarcas* are masculinised, with percentages of women around 46-47% of the population, below the regional average of 51% in the Valencian Community. In addition, this percentage of women has decreased over the period analysed (1996-2022). Likewise, the unemployment rate of women is higher than men's (4% of gender unemployment gap). Nevertheless, women's Social Security affiliation rates have increased in both *comarcas* over the last decade, standing similar to men's in Los Serranos and higher than men's in El Rincón de Ademuz. These examples show the importance of applying the gender perspective to the analyses of territorial indicators.

Despite the above limitations, our research provides policymakers with practical tools to understand better the causes and factors influencing the capacity for development in a territory, from local to regional level. The results of this study are intended to serve as a guide for policies to combat depopulation in rural areas. To achieve this, it is essential, on the one hand, to frame these policies within the European strategy for the rural development policy of the member states. On the other hand, it is necessary to consider the singularities of these territories that could also become areas of opportunity. As the scientific literature points out [8–11,27], it is urgent to attract population and investment to fight against depopulation and unemployment.

Finally, next steps for further investigations must be highlighted in addition to those indicated in the limitations paragraph above. The READI© matrix model forms the basis for future research by transforming the concepts into a set of measurable indicators to determine the current capacity for development of regions and territories. The empirical research here has shown the applied results of a previously validated assessment methodology so that other rural territories can implement it and benchmark themselves against peers, aiming to focus priorities for action and face development challenges successfully. Moreover, this contribution can also be of help to conceptual research on the measurement of territorial capacity and competence for development, a topic of interest among researchers and practitioners with very recent new conceptual frameworks [46], analysing the links between the territorial capacities to settle the population, on one side, and to generate employment opportunities, on the other.

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Notes

1 Comarca is a territorial unit in Spain and Latin American countries comparable to a county. It provides an accepted spatial framework and constitutes the highest administrative level for which there are complete and official statistical data (adapted from [29]).

2 The AEDLs are the technicians in charge of employment and local development policies in the territory for which they work (municipalities or groups of municipalities). The AEDL acronym is also known as ADL in Spain and is sometimes translated as Local Employment and Development Agents (instead of Officers) by some Spanish authors. This figure is described in more detail in [30].

3 Matrix registered as a product resulting from the research project code UV-MET- 202060R, developed by GRIDET—Territorial Development Research Group of the University of Valencia).

4 In this paper, capacity will be considered as "the amount that something can produce".

5 A triangulated methodology was used in these diagnoses, combining analysis of secondary statistical sources from public administrations, in-depth interviews with socioeconomic actors in the territory and social forums for development. Twenty-eight interviews and one social forum per *comarca* were conducted, where 30 stakeholders participated.

6 First **dimension** of the matrix.

7 First **variable** of the dimension Resources.

8 First **subsection** of the variable Economic Resources.

9 Dependency ratio = [(Population aged under 16 + Population aged over 64)/(Population aged from 16 to 64)] $\times 100$

10 Ageing index = [Population aged over 64/Population aged under 16] $\times 100$

11 Longevity index = [Population aged over 74/Population aged over 64] $\times 100$

12 Trend index = [Population aged under 5/Population aged from 5 to 9] $\times 100$

13 Labour Force Renewal Index = [Population aged from 20 to 29/Population aged from 55 to 64] $\times 100$

14 DIRCE: Central Directory of Companies of the National Institute of Statistics (INE)

15 SS affiliation rate = [Number of affiliates contributing to Social Security/Working age population (16–64)] $\times 100$

16 See note 14 above

17 Gender unemployment gap = [Female unemployment rate—Male unemployment rate]

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Can Land Circulation Improve the Health of Middle-Aged and Older Farmers in China?

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Abstract: Compared with the urban aging population, the rural aging population in China is larger, and is subject to a lower per capita income, lower social security coverage, and insufficient security capacity. Therefore, ensuring the health of middle-aged and older farmers is an inevitable requirement for maintaining the stability of rural areas and society. This study uses data from the China Health and Retirement Longitudinal Survey (CHARLS) 2018, an ordered probit model and instrumental variable approach to empirically analyze the effect of land circulation out on the physical health of middle-aged and older farmers over 45. The results indicate that land circulation out positively and significantly affects farmers' health. Again, farmer's non-agricultural work and household income play a significant role in this positive relationship between land circulation out and farmers' health. Thus, the promotion of non-agricultural work for farmers and household income enhancement could alleviate household budget constraints while increasing health investment. The findings provide policies advocating for rural health development from land circulation perspectives.

Keywords: farmland circulation; health; budget constraints; IV ordered probit model

1. Introduction

According to the National Bureau of Statistics of China, in 2019, China's population of people aged 60 and above is about 253.88 million, accounting for 18.1% of the total population, including 176.03 million people aged 65 and above, accounting for 12.6% of the total population. Both exceed the age standard of the United Nations for an aging society [1], indicating that population aging will be a major problem facing China in the coming decades. Unlike the population aging of developed countries, "aging before wealth accumulation" is an important feature of population aging in China, which will pose huge challenges to China's medical and older care services. Meanwhile, because of its dual urban–rural system, China has extremely uneven development in urban versus rural areas, which, when coupled with the large-scale urban–rural mobility of labor, results in more severe population aging in rural areas than in urban areas. Compared with the urban aging population, the rural aging population in China is larger, subject to a lower per capita income, lower social security coverage, and insufficient security capacity. Therefore, ensuring the health of middle-aged and older farmers is an inevitable requirement for maintaining the stability of rural areas and society. It is also an obligation to build a harmonious society, enhance people's happiness, and allow the general public to share the benefits of reform.

Because of the late start of medical care, older care, and other social security services in rural areas and the low level of social security, land has become an important form of informal security for farmers [1]. Consequently, the security function of land is far greater than the value of agricultural production itself. "Planting for food, working for expenditure" has become common. Although it is difficult to accumulate wealth by planting crops, especially through the decentralized management of food crops, agricultural production

can still provide necessary food for farmers to survive. For farmers who do not have employment skills, land is the last protective barrier for earning a living. Once land is lost, the foundation for survival is lost. Farmers' dependence on land is an important cause of China's slow-level dilemma of land circulation. Relevant studies have revealed that land circulation [2] is an effective way to realize large-scale agricultural operations and promote agricultural modernization in rural China [2,3]. Farmers transferring land also effectively increase their total household income [4], thus allowing them to invest more in household welfare, including health.

China's current agricultural production is still labor-intensive. Thus, agricultural production is intense and demanding, which imposes a high burden on farmers' physical health. Although proper labor within a certain period may have similar effects on physical health to those of exercise, the physical actions involved in agricultural production are often repetitive. Furthermore, long-term agricultural production increases the physical burden of farmers and causes hidden health risks. Long-term agricultural production involving contact with pesticides, chemical fertilizers, and other chemicals harms farmers' physical health seriously and is likely to cause chronic diseases that have irreversible effects [5]. Existing research has found that land circulation and agricultural mechanization supplement each other [6,7]. Improving the degree of agricultural mechanization through land circulation can help reduce the usage of pesticides [8], thereby reducing the harm of pesticides to farmers' health. Given the above scenario, a potentially positive relationship may exist between land circulation and farmers' health levels to a certain extent. However, there are some obstacles to land circulation in China. As the phenomenon of young people leaving rural areas to work in urban areas gradually increases in China [9], middle-aged and older farmers are becoming the main actors in agriculture production, in which the willingness for land circulation is relatively low [10]. If a positive correlation between land circulation and farmers' health levels does exist, it contradicts the conduct and the original intention of middle-aged and older farmers retaining their own land. Although there may exist a positive relationship between land circulation and mechanization, let us also note that mechanization, which normal involves fuel usage, can could lead to a climate change problem if not applied properly [11,12]. Thus, as nations seek remedies for healthy living among older farmers, it is essential for these nations to use agricultural machinery based on climate conditions and guide mechanization following a requirement to control carbon emissions while ensuring healthy living [13].

Land is not just retained simply because of economic value but more so because of the informal security that land provides for farmers. In other words, despite land circulation improving farmers' health, concern about future security makes farmers less willing to transfer their land. This dilemma has many causes. First, property rights or land use rights are not clear. Incomplete and unstable property rights increase the transaction costs and risks associated with land circulation, making it unpredictable and reducing land circulation scale and efficiency. Second, the effects of land circulation on farmers have not been extensively studied. Currently, the relevant research on land use is focused on the macro level. For instance, some researchers find that industrial structure optimization exhibits a positive linear correlation with urban land use efficiency [14]. Additionally, a study found that land misallocation significantly aggravated environmental pollution [15], which may have indirect adverse factors on people's health. What needs to be noted is that little attention has been paid to other effects of land circulation on farmers, such as those on health, education willingness, and trust in government. This results in incomplete knowledge of the positive effects of land circulation, preventing the further upscaling of land circulation.

To further enrich the research on the effect of land circulation and promote the rational transfer of land, this study uses the China Health and Retirement Longitudinal Survey (CHARLS) 2018 data to empirically analyze the effect of land circulation on the health of middle-aged and older farmers. Again, the mechanism existing in the relationship between the two components is examined. The contribution of the study is threefold. First, we

extend the literature on rural healthcare development by examining the determinants of the health of middle-aged and older farmers from the perspective of land circulation in China, a country striving to promote rural health development while ensuring sustainable agriculture. Second, an appropriate model that can alleviate selection bias in the study's findings is applied. In most cases, the endogeneity issue is ignored by scholars, but this study considers this issue and deals with it. Finally, using income and time allocation as potential pathways, the study explores the action mechanism through which land circulation out affects the health of middle-aged and older farmers further.

2. Literature Review

By combing the relevant literature, it is found that the existing research mainly focuses on the influencing factors of farmers' health and the income of land circulation.

There is a plethora of studies on the factors that influence farmers' physical and mental health. Beard et al. emphasize the importance of socioeconomic and cultural factors, including, e.g., individual socioeconomic status, sex, and race in individual-level dimensions, population composition, social environment, and physical environment in neighborhood-level dimensions [16]. Mitchell et al. conclude that individual and area characteristics influence health [17]. Marmot emphasizes the importance of income, which directly affects the material conditions necessary for biological survival, social participation, and the opportunity to control life circumstances. In addition to analyses of the objective factors that influence farmers' physical health, scholars have begun to pay more attention to the effects of subjective factors such as social relations, health behaviors, and psychological factors on farmer's physical health [18]. Cohen and Sheldon find that three variables that assess different aspects of social relationships, including social support, social integration, and negative interaction, influence health through different mechanisms [19]. Additionally, researchers assert that psychological factors such as shame, respect, and self-esteem impact individual health status [20]. Hartley (2004) finds that medical care contributes less to health compared to social and societal factors, environmental factors, health behaviors, and genetics [21].

The benefits brought about by land circulation are first reflected in income increase. In the context of a large surplus of rural labor flowing to cities and agricultural production gradually undergoing mechanization, agricultural production in the form of intense and demanding farming activities is no longer suitable for the development of productivity. Under the premise that the land contract period is long, land circulation can help to break the fragmented production pattern and lay the foundation for moderate-scale operations, thereby improving agricultural production efficiency and increasing farmer income. Li et al. and Wang et al. find that the transfer of agricultural land significantly alleviates rural poverty by improving saving behaviors and increasing income [22,23]. Specifically, Jin et al. find that Kenya's land rental markets significantly raise farm households' incomes by promoting farm productivity [3]. Some researchers have also found that in addition to the productive income effect, land transfer also has a relatively large impact on non-productive income, which can further reduce poverty [24]. Peng et al. find that land circulations increase the total income of both land circulation in and transfer out households, and further analyses reveal that land flow-out farmers and land flow-in farmers have different main sources of income growth [4]. However, Chen et al. show that though the total income of all rural households transferring in farmland increased significantly, the income of households transferring out of farmland decreased [25]. Yang et al. find that transfer of farmland can affect the key natural capital changes and livelihood strategy adjustments of rural households, which has a positive and significant promoting effect on the consumption level of rural households. Compared to farmers who do not participate in farmland transfer, farmers who participate in farmland transfer have higher consumption enthusiasm [26]. Yao et al. find that China's land conversion program accelerates the transfer of farming labor and improves the income growth from off-farm opportunities [27].

Land circulation is not only conducive to increasing farmer income, but also has a promotional effect on land use efficiency, agricultural production efficiency and modernization. Koirala et al. think that land ownership significantly impacts technical efficiency [28]. The results of Liu et al. indicate that many households in China are using land inefficiently, and it is renting in lands that increase land use efficiency [29]. Fei et al. find that while land circulation improves agricultural land use efficiency, the efficiency is higher in provinces that transfer land in than in provinces that transfer land out [30]. Luo et al. identify that moderate-scale operation through land transfer is beneficial for achieving economies of scale, thereby reducing average production costs and improving technological efficiency [31]. The research of Wang et al. finds that the transfer of land use rights, especially in the form of renting land from other households, is beneficial to both total labor productivity (TLP) and agricultural labor productivity (ALP) [32]. Zhang et al. find that there is a significant nonlinear relationship between land transfer and new-type urbanization [33].

Despite the extensive in-depth studies on farmers' physical health and land circulation, the two issues are seldom addressed simultaneously in the same study. In fact, among the factors that influence farmers' physical health, farmer income is an extremely important factor. An increase in income can alleviate household budget constraints, which can not only affect the health investment farmers are willing to make in daily life but also affect farmers' medical behaviors and medical expenses during sickness. An important role of land circulation is to increase farmer income. Some scholars identify that the transfer out of farmland has brought a richer income structure and higher subjective income level to rural households, gradually reducing basic food consumption and increasing non-food consumption of goods and services to meet personal enjoyment and development needs [34], which means land circulation can at least affect farmer health expenditure levels by affecting farmer income. In addition, it is worth studying other pathways through which land circulation affects health. Qin et al. conducted a study similar to this one, but they mainly analyzed the effect of urbanization-driven land requisition on farmer health in China, pointing out that the low level of compensation for land requisition is not favorable enough for farmers to invest effectively in health, which harms farmer health [35]. Land circulation is quite different from land requisition. Land circulation refers to leasing land use rights and sustainably obtaining benefits rather than receiving a one-time compensation payment, as is the case in land requisition. Therefore, this study is innovative and may add to the existing body of relevant literature.

3. Theoretical Analysis and Model Setting

3.1. Grossman Model

Research on health needs dates back to when Grossman (1972) proposed a model to analyze health needs [36]. The model assumes that the lifetime utility function of individuals is as follows:

$$U = U(\varphi_0 H_0, \ldots, \varphi_n H_n, Z_0, \ldots Z_n) \tag{1}$$

where H_i is the health stock in period i, φ_i is the service flow brought by a unit of health stock, $h_i = \varphi_i H_i$ is the total health service enjoyed in period i, and Z_i is the consumption of other goods.

The change in the health stock is, by definition, equal to the total investment minus depreciation.

$$H_{i+1} - H_i = I_i - \delta_i H_i \tag{2}$$

where I_i is the total investment in health, and δ_i is the health depreciation rate. The production of individual health investments and the production of other goods are determined by the following formulas:

$$I_i = I(M_i, TH_i, E_i) \tag{3}$$

$$Z_i = Z(X_i, T_i, E_i) \tag{4}$$

where M_i and X_i are the input for medical services and production goods (Z_i), respectively; TH_i and T_i are the respective time inputs; and E_i represents the level of other human capital, i (e.g., education capital).

In the meantime, individuals face two budget constraints:

$$TW_i + TL_i + TH_i + T_i = \Omega \tag{5}$$

$$\sum \frac{P_i M_i + V_i X_i + W_i(TL_i + TH_i + T_i)}{(1+r)^i} = \sum \frac{W_i \Omega}{(1+r)^i} + A_0 \tag{6}$$

where Formula (5) presents a time constraint in which TW_i denotes working hours, TL_i denotes the lost time due to health damage, and Ω is the total time (Ω = 365 days if calculated on an annual basis). Formula (6) represents a budget constraint in which the left term of the formula is the present value of total lifetime income, P_i is the price of medical services, V_i is the price of input X_i, W_i is the wage rate, and A_0 is the initial wealth.

Formulas (1)–(6) constitute the basic Grossman model. Under budget constraints (5) and (6), individual utility is to be maximized. The model is extended by adding the variable of land circulation, LO_i, which is not directly involved in the utility function but affects the individual optimization decision in two ways. First, land circulation affects the health depreciation rate. In general, land circulation out can reduce farmers' time on agricultural production, reduce the harm to health from chemicals such as pesticides, and decrease the depreciation rate. Therefore, the health depreciation rate is expressed as in Cropper [37]:

$$\delta_i = \delta_0 e^{\hat{\delta} i} LO_i G_i \tag{7}$$

In Formula (7), δ_0 is the initial health depreciation rate; i is the age, which affects the health through a constant depreciation rate, $\hat{\delta}$; and G_i is a lifestyle variable.

Second, land circulation affects time allocation and, in turn, budget constraints. land circulation out reduces agricultural production time, which directly reduces the time, TL_i, that would otherwise be lost because of health damage. However, the effect on work time, TW_i, is uncertain. If agricultural production time decreases but non-agricultural work time increases, the overall change in TW_i is uncertain. In addition, reduction in agricultural production time may lead to increased physical exercise and social time, which is beneficial to health. The reduction in income caused by the reduction in agricultural production time and the increase in income caused by land leasing cause changes in budget constraints, which affect individual health investment decisions.

3.2. Basic Econometric Model (Ordered Probit)

The explained variables of interest in this study are mainly related to the physical health status of middle-aged and older farmers. The assessment indicators of physical health status are mainly divided into two categories. First, certain objective, comprehensive indicators such as the body mass index (BMI) [38], the quality of well-being (QWB) [39], the instrumental activities of daily living (IADL) and the mini-mental state examination (MMSE) are used to assess physical health status [40]. Such indicators are relatively objective and can reflect the overall health status of an individual. The second type of health assessment indicators are relatively subjective, namely self-assessed health indicators. Self-assessed health indicators are susceptible to the individual's surrounding environment and thus may be different in different populations; however, they have prominent advantages. First, health self-assessment is an individual's overall evaluation of his or her health and may reveal many issues in physical and psychological status. Self-assessed health indicators cover a wider scope and are more refined than objective indicators, with objective indicators likely reflecting a narrower scope of health status. Second, although physical health self-assessment is relatively simple to perform, existing studies have shown that it can be used to predict individual life expectancies effectively, and the prediction is very close to professional measurement results. Therefore, it has been widely used [41].

In view of data availability, this study adopts self-assessed health indicators. Self-assessed physical health status is presented as sorted data, with values ranging from 1 to 5 corresponding to "very poor", "poor", "fair", "good", and "very good" physical health status, respectively. Given that the variable is discrete and its values are ordinal, the traditional ordinal least squares (OLS) method is not applicable. Instead, an ordered probit model may be a natural choice, which is an extension of the ordinary probit model and dedicated to dealing with explained variables whose values are ordinal. Therefore, the following basic model is introduced:

$$y_i = \alpha + \beta \times landout_i + X_i \times \gamma + \varepsilon_i \tag{8}$$

where y_i is a self-assessed physical health status; $landout_i$ is a dummy variable describing whether or not the land is leased—with the value of 1 representing leased land and 0 representing unleased land; X_i is a series of control variables, including demographic characteristics, family characteristics, and provincial dummy variables; and ε_i is a random error term.

3.3. Endogeneity and the Instrumental Variable Ordered Probit Model (IV-Ordered Probit Model)

It is evident that physical health status and land circulation decisions may have endogeneity issues due to missing variables or mutual causality. Because agricultural production requires a large workforce, it has a high requirement for labor health. Farmers in poor health and who are unable to carry out agricultural production may be prompted to lease their land. If this is the case, land leasing is the "effect" rather than the "cause" of health. Therefore, instrumental variables are introduced into the ordered probit model to solve the endogeneity issue caused by mutual causality.

This study selects two instrumental variables [3], one being the village land circulation rate—namely the proportion of land subcontracted or leased out in the village the subject is affiliated with, and the other being the number of households moving out of the village permanently. The two instrumental variables affect the endogenous explanatory variable, namely land lease out, through different pathways. First, the higher the proportion of land subcontracted or leased in a village, the more active the land circulation market. The active market influences the individual decision of land leasing in two aspects. On the one hand, the more active the land circulation market, the more likely farmers will be affected by neighbors who conduct land circulation; that is, there is a peer effect, which increases the willingness for land circulation [1]. On the other hand, land circulation includes leasing out land and leasing in land, and the mere willingness to lease land out does not necessarily result in actual land lease out, as land lease out also requires a corresponding demand. The more active the land circulation, the bigger the supply and demand of land, thereby reducing the cost of land circulation and increasing the possibility of it Second, the more households migrate from the village, the larger the village's land stock, and the larger the average amount of farmland per household, thereby increasing the possibility of land circulation. Finally, both instrumental variables are village-level variables. Although they can influence individual land circulation decisions through the above pathways, they do not affect individual physical health; therefore, the instrumental variables meet the exogeneity requirement. To sum up, the above two instrumental variables fulfill the requirements. A more detailed instrumental variable test is given below.

An endogeneity-corrected IV-ordered probit model is introduced as follows:

$$y_i = \alpha + \beta \times \widehat{landout}_i + X_i \times \gamma + \varepsilon_i \tag{9}$$

where $\widehat{landout}_i$ is the fitted value of $landout_i$ regressed on the instrumental variables and the other control variable, X_i, and the estimate of the coefficient, β are valid and unbiased.

4. Data and Descriptive Statistics

4.1. Data

The data used in this study are from the China Health and Retirement Longitudinal Survey (CHARLS) 2018. The survey uses four-stage probability proportional to the size sampling to ensure that the samples are unbiased and representative. The survey data were collected from 19,000 people over 45 years of age from approximately 12,400 households in 450 village-level units of 150 county-level units. The survey content includes not only variables relating to demographic characteristics, work, and family characteristics, but also the health status-related variables necessary for this study, making the survey results a high-quality data source.

4.2. Descriptive Statistics

The core explanatory variable of interest in this study is land lease, which is a dummy variable. The land lease variable is set to 1 for farmers who own land and 0 for farmers who do not. Considering the Grossman health demand model and previous research, other control variables are selected to include demographic characteristic variables, individual social security and behavior characteristic variables, family characteristic variables, and provincial dummy variables. Their definitions and descriptive statistics are shown in Table 1.

As shown in Table 1, only 23.4% of farmers conduct transfer out; that is, land is leased out. In contrast, the calculation shows that the proportion of farmers leasing in land is also low, at only 11.4%. Both the supply and demand of land are relatively low, indicating that China's land circulation is still in the initial stage and is facing a "low-level dilemma". The low level of land circulation causes fragmentation of land operation, which prevents the land from being operated on a moderate scale and in turn results in low agricultural production efficiency, creating obstacles to the modernization of agricultural production and the increase in farmer income. Therefore, further study of the advantages of land circulation and its effect on farmer income is of great practical significance.

As shown by the descriptive statistics in Table 1, the health status of farming households without land circulation out is better than that of farming households with land circulation out, namely with an average value of 3.051 versus that of 2.960, respectively. The descriptive statistics alone imply that land circulation out would be conducive to farmer health. This is because the impact of land circulation out on health level is mainly realized by increasing family income and alleviating family mobility constraints; that is, the reduction in land increases farmers' non-agricultural employment, which has a positive impact on health by increasing family income.

Other control variables also have certain characteristics. The average household age of farmers with land circulation out is high, which is consistent with this group of farmers' aforementioned poor physical health. Generally, the older the farmers, the poorer their physical health, and the greater their willingness to lease the land. In addition, compared to the farming households without land circulation out, those with land circulation out have a higher rate of participation in old age care insurance. This indicates that land does provide informal security in rural areas. If security is improved in other aspects (i.e., number of children, medical care, and old age care insurance), the informal security function of land would be weakened. In turn, the farmer's willingness to lease land out would be enhanced. Of course, the relationship between the above-mentioned variables and land circulation needs to be quantitively analyzed in detail. Finally, the two instrumental variables have significantly higher means for the farmer households with land circulation out than for those without. For example, the proportion of land circulation in the villages of farmer households transferring land is as high as 16.46%, and the average number of households permanently moving out of the villages is 13.06, in contrast to that of 9.63% and 7.078, respectively, in the villages of farmer households without transferring land. Therefore, the village land circulation rate and the number of households permanently moving out of the village have a positive correlation with land circulation out.

Table 1. Major variables and descriptive statistics.

Variable	Description	Total	Leased Out	Not Leased Out
Health	The self-assessed physical health status; "very poor" = 1, "poor" = 2, "fair" = 3, "good" = 4 and "very good" = 5	2.981	3.051	2.960
		(1.015)	(1.038)	(1.006)
Landout	Whether or not the land is leased; leased = 1, not leased = 0	0.234		
		(0.423)		
Age1	Age of the respondents	60.78	61.42	60.59
		(9.340)	(9.435)	(9.302)
Sex	man = 1, woman = 0	0.482	0.475	0.484
		(0.500)	(0.499)	(0.500)
Elementary	Dummy variable; primary education = 1, others = 0	0.239	0.241	0.238
		(0.426)	(0.428)	(0.426)
Middle	Dummy variable; junior high school education = 1, others = 0	0.204	0.212	0.201
		(0.403)	(0.409)	(0.401)
High	Dummy variable; high school education = 1, others = 0	0.0673	0.0838	0.0623
		(0.251)	(0.277)	(0.242)
College	Dummy variable; college degree or above = 1, others = 0	0.00289	0.00340	0.00273
		(0.0537)	(0.0582)	(0.0522)
Marriage	Marital status; married = 1, others = 0	0.808	0.779	0.816
		(0.394)	(0.415)	(0.387)
Pension	Dummy variable; having old age care insurance = 1, others = 0	0.0608	0.0812	0.0546
		(0.239)	(0.273)	(0.227)
Cigar	Dummy variable; smoking = 1, others = 0	0.0307	0.0349	0.0294
		(0.172)	(0.183)	(0.169)
Drink	Dummy variable; alcohol consumption = 1, other = 0	0.268	0.282	0.264
		(0.443)	(0.450)	(0.441)
House	Dummy variable; owning a home = 1, others = 0	0.849	0.815	0.859
		(0.358)	(0.388)	(0.348)
Lnexp	The logarithm of household monthly spending	8.300	8.463	8.250
		(2.107)	(2.094)	(2.109)
Iv_percentage	Instrumental variable; the proportion of transferred land in the village	11.23	16.46	9.631
		(15.75)	(18.08)	(14.61)
Iv_migration	Instrumental variable; the number of households that have permanently moved out of the village	8.480	13.06	7.078
		(28.60)	(39.04)	(24.37)
Observations		10045	2352	7693

Note: Standard deviations are shown in parentheses.

5. Results and Discussions

5.1. Effect of Land Circulation out on Farmer Health

Table 2 presents the regression results of the ordered probit model and the endogeneity-corrected IV-ordered probit model. First, the regression results of the ordered probit model, as listed in column (1) of Table 2, reveal that land circulation out does not improve farmer health levels. The above-mentioned poor status of physical health in rural households transferring land is not consistent with the regression results. The reason could be attributed to the endogeneity problem. Columns (2) and (3) of Table 2 present the IV-ordered probit model's first- and second-stage regression results, respectively. The results indicate that after correction for endogeneity, land circulation out shows a promotional effect on farmer's physical health ($p < 0.01$). This proves that including instrumental variables in a model can overcome the endogeneity problem, and thus, the estimates will be more effective.

Table 2. Effect of land circulation out on farmer health status.

	Ordered Probit	IV-Ordered Probit	
Variable	**(1) Health**	**(2) First-Stage**	**(3) Second-Stage**
Land out	9.81×10^{-5}		0.0717 ***
	(0.0346)		(0.0243)
Age1	−0.0292 ***	−0.0423 ***	−0.0496 ***
	(0.0117)	(0.0122)	(0.0128)
Age2	0.000127	0.000226 **	0.000269 ***
	(9.56×10^{-5})	(9.67×10^{-5})	(0.000102)
Gender	0.144 ***	0.0795 ***	0.0756 ***
	(0.0312)	(0.0237)	(0.0243)
Elementary	0.0581 **	−0.00714	0.0121
	(0.0267)	(0.0258)	(0.0264)
Middle	0.118 ***	0.139 ***	0.162 ***
	(0.0308)	(0.0292)	(0.0292)
High	0.173 ***	0.174 ***	0.198 ***
	(0.0485)	(0.0440)	(0.0417)
College	0.443 **	0.492 ***	0.397 **
	(0.212)	(0.169)	(0.155)
Marriage	−0.0367	0.0500 *	0.0490 *
	(0.0290)	(0.0265)	(0.0266)
Pension	0.0107	0.100 **	0.117 ***
	(0.0383)	(0.0407)	(0.0389)
Cigar	−0.0814 ***	−0.0602	−0.0131
	(0.0299)	(0.0610)	(0.0619)
Drink	0.241 ***	0.192 ***	0.224 ***
	(0.0271)	(0.0247)	(0.0259)
House	0.0845 **	0.0383	0.0182
	(0.0396)	(0.0291)	(0.0284)
Lnexp	−0.0285 ***	−0.0482 ***	−0.0529 ***
	(0.00560)	(0.00480)	(0.00490)
Iv_percentage		0.0134 ***	
		(0.000969)	
Iv_migration		0.00238 ***	
		(0.000486)	
Province dummy	Yes	Yes	Yes
Observations	10045	10045	10045

Note: The numbers in parentheses are standard deviations; *, **, and *** indicate statistical significance at the 0.1, 0.05, and 0.01 levels, respectively, and hereinafter.

The prerequisite for using instrumental variables is that the model does have an endogeneity problem. Therefore, it is necessary first to test whether or not the model has endogenous variables before using instrumental variables, namely whether or not land circulation out is an endogenous variable. Previous studies using IV-ordered probit models often adopt two-stage least squares (2SLS) regression to analyze the variable endogeneity problem and the effectiveness of instrumental variables [42]. This method is also adopted here to test the validity of instrumental variables. First, the model variables are tested for endogeneity using a Durbin–Wu–Hausman test. The test statistic is 25.10 ($p = 0.000$), therefore rejecting the hypothesis at the 1% significance level that land circulation out is an exogenous variable; that is, the model has an endogeneity problem. Second, the correlation condition of the instrumental variables is tested. Multiple tests are performed to determine whether or not there is a weak instrumental variable problem. The Kleibergen–Paap rk LM statistic is 193.829 ($p < 0.01$), rejecting the hypothesis that the instrumental variables are not identified at the 1% significance level. The Kleibergen–Paap rk Wald F statistic is 97.104 and the Cragg–Donald Wald F statistic is 127.99, both higher than the Stock–Yogo critical value of 19.93 of the weak instrument variable test at the 10% significance level. Therefore, there is no weak instrumental variable problem. Finally, the instrumental variables are tested for exogeneity, using an overidentification test. The Hansen J statistic has a *p*-value of

0.9464, indicating that the overidentification hypothesis for instrumental variables cannot be rejected at the 10% significant level; the instrumental variables are exogenous and valid. In summary, the instrumental variables in this study meet the requirements, and accordingly, the model results are valid.

The results of other control variables are basically in line with the expectations. The health level of farmers declines with age and does not show the inverted U-shaped pattern observed in previous studies. This is because the subjects in this study are over 45 years old, whereas the apex of the inverted U-shaped pattern is at 30–35 years in previous studies [43]. The data points of the subjects are distributed to the right of the vertex; thus, there is a negative correlation between age and farmer health level, which agrees with the findings of previous reports. Moreover, gender significantly affects farmer health, with male farmers having a higher health level than female farmers do, which is consistent with the findings of previous studies. Education has a significant promotional effect on farmer health, with a higher degree of education having a greater effect. Education affects the health level of individuals mainly by changing their health behaviors and socioeconomic conditions [44]. The higher the education level, the fewer the harmful health behaviors, such as smoking and alcohol consumption, and the more the healthier behaviors, such as physical exercise and leisure. Moreover, the higher the education level, the higher the income, and the greater the ability to invest in health with relatively high investment efficiency. Old age care insurance has a positive and significant effect on farmers' health. Smoking and alcohol consumption have very different health effects because old age insurance can improve health by ensuring income. Smoking hurts farmer health, and it has been widely accepted that smoking harms health. However, alcohol consumption has a positive effect on farmer health, which is attributed to the fact that, in general, a small amount of alcohol consumption has certain benefits to the body, although alcohol abuse causes significant damage to health. The relevant variable used in this study is "alcohol consumption" rather than "alcohol abuse," which may explain why the above positive effect is observed. Owning a home has positive effects on farmer health, but it is not significant. Again, monthly consumption expenditure has a negative effect on farmer health, which may be attributed to the fact that the expenditure includes health care costs and thus is subject to self-selection bias.

5.2. The Underlying Mechanism of the Effect of Land Circulation out on Farmer Health

According to the Grossman model, the effect of land circulation out on farmer health can be realized through multiple pathways. First, a direct effect is that land circulation out reduces the amount of farmland farmers cultivate, thereby reducing labor time investment and, in turn, the depreciation rate of health. Second, with the reduction in agricultural time, farmers can allocate more time to leisure and entertainment, thereby improving their physical health. Last, the reduction in agricultural production gives farmers more time to engage in non-agricultural production to increase income; therefore, the household budget constraints are alleviated, and farmers can increase their investment in medical care and old age care, thereby promoting farmer health levels. As the health depreciation rate cannot be directly estimated, the underlying mechanism governing the land effect on farmer health is explored mainly from two aspects: time allocation and household income.

5.2.1. Effect of Land Circulation out on Income

One pathway through which land circulation out affects farmer health is to increase farmer income and alleviate household budget constraints. Table 3 presents the effects of the land circulation on farmers' agricultural, and non-agricultural wages, business, and lease income [4]. The results show that land circulation out reduces agricultural income. However, land circulation out increases not only farmers' non-agricultural wage income but also business and lease income. The increase in non-agricultural wage income and business income is caused by the increase in time allocated to non-agricultural work and business operations as a result of the reduction in agricultural time after land circulation

out. The increase in land lease income largely contributes to the increase in lease income. Calculations based on the sample data reveal that each household owns 5.79 Chinese mu (1 Chinese mu = 666.67 m^2) of land on average, and the average lease price per Chinese mu of land is CNY 582. If all the land is leased out, the total lease income is CNY 3370, accounting for 23.06% of the rural per capita net income in 2018 [5]. An increase in the scale of land circulation will effectively promote the scale production of agriculture and in turn increase the lease price of land, which will further increase the land lease income of farmers [4,45]. In addition, with the increase in the amount of land lease out, the proportion of non-agricultural work will increase, which in turn will increase the wage income of farmers [46]. The result is in line with the findings of Hong and Lou [47], and Li et al. [22] who showed that household income enhancement plays significant roles in household welfare development, including quality health services.

Table 3. Land circulation out and farmer income (2SLS).

	Agricultural		**Non-Agricultural**		**Business**		**Lease**	
	First	**Second**	**First**	**Second**	**First**	**Second**	**First**	**Second**
Land out		−1.233 ***		0.731 **		0.939 **		0.674 ***
		(0.349)		(0.320)		(0.444)		(0.236)
iv_percentage	0.003 ***		0.004 ***		0.007 ***		0.004 ***	
	(0.000)		(0.000)		(0.001)		(0.000)	
iv_migration	0.001 ***		0.001 ***		0.003 ***		0.001 ***	
	(0.000)		(0.000)		(0.000)		(0.000)	
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−0.341 ***	7.153 ***	0.0144	10.98 ***	−0.213	9.786 ***	−0.172	0.141
	(0.164)	(0.693)	(0.256)	(1.286)	(0.681)	(2.586)	(0.146)	(0.199)
Observations	7057	7057	2460	2460	682	682	10,045	10,045

Note: The numbers in parentheses are standard deviations; ** and *** indicates statistical significance at the 0.05 and 0.01 level, respectively.

5.2.2. Effect of Land Circulation out on Time Allocation

Table 4 shows the effect of land circulation out on the time allocation of middle-aged and older farmers, analyzed from multiple aspects, which mainly includes whether or not they are engaged in agricultural production, the number of months spent on agricultural production each year, the status of their social activities within the last month as of the survey date [6], and whether or not they are engaged in non-agricultural work. The results show that land circulation out significantly reduces the possibility of engaging in agricultural production. However, for farmers still engaged in agricultural production, land circulation out does not significantly reduce their annual agricultural production time. The main concern here is how the time originally devoted to agricultural production is allocated after the land has been transferred. The regression results in columns (3) and (4) of Table 3 present the effect of land circulation out on social activities and non-agricultural work, respectively. As is shown above, land circulation out has not improved farmer health by increasing social activities, leisure, or physical exercise. Therefore, farmer health level improvement may be attributed to non-agricultural work increasing household income and alleviating household budget constraints, thereby allowing farmers to invest more in health to improve their health levels. The result is in line with that of Paggi et al. who showed that allocating some time for other activities aside from work improves individuals' healthy living [48].

Table 4. Land circulation out and time allocation by farmers.

	(1) Binary Probit	(2) 2SLS	(3) Binary Probit	(4) Binary Probit
Variable	**Agricultural Production**	**Months to Agriculture**	**Social Activities**	**Non-Agricultural Work**
Land out	−0.875 ***	0.069	0.0085	0.040 ***
	(0.177)	(1.014)	(0.014)	(0.005)
Other controls	Yes	Yes	Yes	Yes
Observations	10,045	6609	10,045	10,035

Note: The numbers in parentheses are standard deviations; *** indicate statistical significance at the 0.01 level. Because of space limitations, only the estimated coefficients of land circulation out are listed; the regression results of other variables are available on request.

5.3. Robustness Test

Other measures of health levels are also used to verify the effect of land circulation on farmer health, and the gender differences in the effect are also analyzed. The regression results are shown in Table 5. Given the availability of data, the activities of daily living (ADL) scale is adopted to measure the health level. The ADL scale consists of six activities: feeding, dressing, getting in or out of bed, bathing, toileting, and continence. Each activity is assessed in terms of four difficulty levels: easy to complete, difficult but completable by the farmers on their own, difficult but completable with the assistance of other people, and incompletable, with the first level being scored 0 and other levels each being scored 1; that is, the higher the total score, the more severe the damage to the ADL. The regression results based on the ADL scores are presented in column (1) of Table 5, revealing that land circulation out leads to a reduction in the damage possibility of farmer ADL, namely leading to an improvement in farmer health levels; therefore, the conclusion of this study is relatively robust.

Table 5. Different measures of farmer health levels and robustness test.

Variable	**(1) ADL**	**(2) Health**	**(3) ADL**
Land out	−0.178 ***		
	(0.0640)		
Land in		−0.0248	−2.041 *
		(0.135)	(1.134)
Other controls	Yes	Yes	Yes

Note: The numbers in parentheses are standard deviations; * and *** indicate statistical significance at the 0.1, and 0.01 levels, respectively. The results in column (1) and (3) are obtained using the 2SLS estimation method, and the results in columns (2) are obtained using the IV-ordered probit model.

Land circulation includes two aspects: land circulation out and land circulation in. Columns (2) and (3) of Table 5 present the effect of land circulation in on farmers' health results. It is observed that no matter which assessment indicator is used, land circulation in has no significant effect on farmer health. This may be attributed to China's low land circulation levels and thus land lease in is hardly able to meet the minimum requirement for scale production. That is, the fragmentation of agricultural production still fails to be effectively resolved, resulting in low production efficiency and a limited promotional effect on farmer income.

6. Discussion

China has experienced large-scale rural–urban population migration in the past decade or so, with a significant number of young rural laborers moving to cities to seek non-agricultural employment, resulting in farmland being mostly cultivated by older farmers [9]. The issue with small-scale farming is that it is not conducive to the adoption of agricultural technologies such as machinery, leading to lower production efficiency. Moreover, with the trend of family transfer in China, the phenomenon of land abandonment has become increasingly prominent [49]. At the same time, China's agricultural land is decreasing year

by year. In order to alleviate the land shortage dilemma and improve land use efficiency, the Chinese government has successively introduced various policies to encourage the transfer of farmland management rights [30]. The reason for the low willingness to transfer land is the uncertainty in expectations regarding land and its associated rights and interests. For that reason, it is necessary to promote further the determination of rural land rights to provide an institutional basis and guarantee for land circulation. An improvement of land circulation levels would be conducive to promoting the appropriate large-scale operation of agricultural production, improving agricultural production efficiency. Insufficient awareness of the benefits of land transfer is also an important reason for the inadequate level of land transfer. Farmers overly focus on the income from land transfer while neglecting other aspects, such as health benefits. When middle-aged and older farmers are liberated from heavy physical labor, they face the issue of time allocation. This time allocation is also an important mechanism affecting labor health. On the one hand, they can engage in non-agricultural employment. On the other hand, participating in leisure and sports activities is beneficial to physical health [48]. However, the research findings of this article do not support this mechanism. A possible reason is the lack of leisure and entertainment facilities in rural areas and the absence of a conducive atmosphere.

In China, farmers have a strong dependence on land, considering it not only as a means of production but also as a guarantee of their livelihood. Therefore, it is necessary to improve the level of medical care and old age care in rural areas, as an increase in the level of formal social security such as medical care and old age care would directly affect the health level of farmers, and more importantly, would have an indirect promotional effect on farmer health by promoting land circulation [48]. Rural land serves as a means for farmers to obtain agricultural income from agricultural production. More importantly, it provides informal social security, which is one of the reasons for the low level of land circulation in China [30]. Establishing and improving formal social security, such as medical and old age care, would weaken the security effect of land and promote China's land circulation.

7. Conclusions

At present, China's land circulation is experiencing a "low-level dilemma". Simultaneously, rural population aging is becoming increasingly severe and thus, protecting the health of the middle-aged and older rural population is an essential countermeasure for aging. This study uses the China Health and Retirement Longitudinal Survey (CHARLS) 2018 data to empirically analyze the effect of land circulation out on the physical health of farmers and resolves the endogeneity problem in the model by introducing instrumental variables. The main conclusions drawn are as follows. First, after correction for endogeneity, land circulation out shows a promotional effect on farmer health, improving the self-assessed health status of farmers and reducing the possibility of ADL damage. Second, the positive effect of land circulation out on farmer health levels is mainly attributed to the fact that land circulation out promotes the probability of non-agricultural work and increases farmer income, thereby alleviating household budget constraints and increasing health investment. Although land circulation out makes some farmers no longer work in agriculture, there is no evidence that land circulation out increases farmers' time engaging in social and leisure activities. Third, land circulation in has no significant effect on farmer health.

The limitations of the study are as follows. First, the study focuses mainly on the middle-aged and older rural population due to data availability. However, the health status of these selected household populations affects other household members; therefore, future studies can expand the focal population to an entire household in such a study if data are made available. Second, the study used the self-reported health status of the farmers. We encourage subsequent studies to use a medically reported health status when carrying out a similar analysis for deeper understanding. Finally, other potential channels aside from time allocation and household income can be explored when examining the relationship

between land circulation out and the health status of the middle-aged and older rural population if data are available.

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Notes

1 The traditional standard of the United Nations for aging is that older people over 60 in a region account for 10% of the total population. The new standard states that when older people over 65 account for 7% of the total population in a region, that region has an aging society.

2 Land circulation is divided into land circulation out and land circulation in. This study focuses on land circulation out, that is, land being leased out.

3 The selection of instrumental variables needs to satisfy two requirements, namely correlation and exogeneity. The correlation requirement requires that the selected instrumental variables have a strong correlation with the endogenous explanatory variables, whereas the exogeneity requirement requires that the instrumental variables are not related to the explained variable; that is, the effect of the instrumental variables on the explained variable can only be realized through endogenous explanatory variables.

4 Business income refers to household self-employment or private enterprise income, and lease income refers to income obtained by leasing land out, real estate, and other assets. All incomes have been converted to logarithmic values.

5 According to the 2018 National Economic and Social Development Statistical Bulletin, China's rural per capita net income is CNY 14,617.

6 This variable is derived from the question in the questionnaire: "Have you performed the following social activities in the past month?" The answer options are: "visiting and socializing with friends"; "playing mahjong, chess, and cards, or going to the community clubhouse"; "providing free help to your loved ones, friends, or neighbors"; "going to the park or other places to dance, exercise, or practice qigong, etc."; "participating in community activities"; "participating in volunteer activities or charity activities"; "providing free care for patients or people with disabilities who do not live with you"; "going to school or taking training courses"; "speculating stocks (funds and other financial securities)"; and "using the Internet." This variable scores 1 if at least one activity is conducted, otherwise it scores 0.

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Review

Indigenous Knowledge, Gender and Agriculture: A Scoping Review of Gendered Roles for Food Sustainability in Tonga, Samoa, Solomon Islands and Fiji

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Abstract: This scoping review examines the state of academic knowledge around gender and its role in Indigenous/traditional knowledge for food sustainability in Tonga, Samoa, Solomon Islands and Fiji. The different roles played by all genders—men, women and non-binary—in the Pacific Islands can contribute to climate adaptation and knowledge preservation for sustainable food production. The gender lens is especially relevant given the fact that women's knowledge has, in recent years, been disregarded and marginalised as a consequence of colonial influences and increasing reliance on imported foods. We analysed 14 studies published in English between 2015 and 2024—six from refereed journal articles and eight from grey literature. Three themes emerged linking agriculture, gender and traditional knowledge, as follows: (1) there is a gendered division of labour and culturally defined roles between women and men, although the roles played by non-binary groups remain unclear; (2) intergenerational traditional knowledge transmission has declined; (3) climate change adaptation could be reinforced through passing on traditional knowledge. The findings demonstrate that gendered knowledge is distinct and complementary, and this knowledge should be integrated into Pacific agricultural production to achieve resilient and sustainable farming in the face of climate change.

Keywords: Pacific Islands; gender; agriculture; food security; Indigenous knowledge; traditional knowledge

1. Introduction

This article presents and synthesises existing academic knowledge on the linkage between gender and the role of Indigenous/traditional knowledge for food production in Tonga, Samoa, Solomon Islands and Fiji. These are four independent Pacific Islands states all of which had populations in 2021 of under one million [1]. They are generally regarded as 'small states' due to their geographic size, population and limited economies. They represent four of the 22 Pacific Islands Countries and Territories (PICTs), which are themselves often divided into three subgroupings: Polynesia (many islands), Micronesia (small islands) and Melanesia (black islands) [2]. The largest PICT, Papua New Guinea, contains 83.5% of the entire PICT land area and has a population of almost nine million (2021 figure); all other PICTs are far smaller and have populations under one million. The smallest

of the Melanesian PICTs (Vanuatu) is still four times larger than the largest Polynesian PICT (Samoa). Polynesia is geographically diverse, including volcanic archipelagos and low-lying atolls. The states studied are from Melanesia (Solomon Islands and Fiji) and from Polynesia (Tonga and Samoa), however Fiji exhibits attributes of Polynesian social structure (Table 1).

Table 1. Land area and populations in select PICTs [1].

PICT	Population (2021)	Land Area (in km^2)
Papua New Guinea	8,934,475	462,840
Fiji	898,402	18,333
Solomon Islands	728,041	28,230
Vanuatu	301,295	12,281
Samoa	199,853	2934
Tonga	99,532	749

On average, 80% of people living in PICTs grow most of their own food or are engaged in family farming for subsistence and to support livelihoods [2,3]. This reliance on home-grown produce makes the smaller PICTs vulnerable to the adverse effects of climate change and climate-related natural disasters. Such challenges contribute to the degradation of natural ecosystems and resources, thereby posing a significant threat to sustainable agriculture, resulting in food insecurity and livelihood challenges for affected communities [4]. As climate impacts increase and intensify, numerous scholars argue that understanding traditional and Indigenous knowledge and practices is crucial for responding to the various climate effects that impact agricultural production [5–9].

A focus on gender in agriculture is of relevance for two reasons: (1) historically, European administrators looked to men rather than women to discuss agriculture [10], and post-colonial states continued this error [11]; (2) an increasing reliance on imported foods has led to disengagement in agriculture [12]. Together, these factors have led women's knowledge to be disregarded and marginalized.

These links between gender and Indigenous/traditional knowledge for agricultural production are important for PICTs as Indigenous agricultural knowledge emphasises sustainable food production methods that are adapted to local environmental conditions. These methods include crop diversification, intercropping, and water management systems that contribute to food security by reducing vulnerability to climate-related disruptions in food supply [13]. As researchers, we are engaged in a funded project to explore how gender roles and traditional knowledge can assist communities to be strategic about community planning for sustainable food production in the face of climate change, hence our focus on just the four PICTs of Tonga, Samoa, Solomon Islands and Fiji. We adopt the UNESCO definition of 'Traditional Knowledge' as it acknowledges the cultural dimensions of agricultural production:

> . . .knowledge, innovations, and practices of Indigenous and local communities around the world. It is developed from experience gained over centuries and adapted to the local culture and environment; traditional knowledge is transmitted orally from generation to generation. It tends to be collectively owned and takes the form of stories, songs, folklore, proverbs, cultural values, beliefs, rituals, community laws, local language, and agricultural practices including the development of plant species and animal breeds. Traditional knowledge is mainly

> of a practical nature, particularly in such fields as agriculture, fisheries, health, horticulture, forestry, and environmental management in general (Secretariat of the Convention on Biological Diversity, 2007).

Indigenous knowledge extends into cosmology. Vunibola, et al. (2024) observe that Indigenous agricultural practices often emphasise a holistic understanding of the interconnectedness between humans, nature and the spiritual realm [13]. They further argue that this worldview guides sustainable resource management, respect for the land and a deep appreciation for the natural environment, fostering resilience by promoting harmony between people and their surroundings [13].

A significant portion of traditional knowledge in PICTs is dedicated to the preservation of terrestrial biodiversity. This includes efforts to protect native and endemic species, particularly in response to the negative impacts of introduced species, as well as the upkeep and restoration of diverse native ecosystems that are more beneficial to communities reliant on subsistence living. Given the close proximity of many people in PICTs to the ocean and their use of marine resources, there is a wealth of traditional knowledge focused on the sustainable management of marine ecosystems, particularly for those near the shore, which is heavily utilised [8]. This knowledge encompasses practices related to mangrove ecosystems, which historically adhered to strict guidelines aimed at maintaining productivity but have since been lost. [8].

Our focus, however, is on the land, particularly on agricultural production, as Pacific communities have traditionally relied on agriculture to ensure food security and reduce their dependency on external sources. Ferguson et al. (2022) note that during the COVID-19 pandemic, traditional practices and local knowledge were vital in enhancing the resilience of Pacific food systems by promoting community cohesion, supporting local food production and fostering adaptive capacity in the face of external shocks [14]. They found that despite challenges such as market integration and changing values associated with modernity, the cultural rootedness of traditional social systems provided a foundation for resilience in Pacific communities. Local knowledge and traditional agricultural practices facilitated increased local food production, which served as a key adaptation strategy during the pandemic. Meanwhile, the reciprocal exchange of resources and knowledge through food-sharing networks helped communities cope and recover [14].

When commenting on sustainable agricultural production, McMillen et al. (2014) note that the integration of biocultural diversity into agricultural production systems is crucial for enhancing resilience and adaptive capacity in the face of climate change and effective education and knowledge transmission efforts on sustainability and resilience are necessary for adapting to climate change in agriculture [6].

Yet, while it is important to acknowledge the key roles and functions of traditional/Indigenous knowledge in maintaining and supporting food production across the Pacific, it is also critical to recognise that within PICTs, food production is itself highly gendered. While the female/male gender binary is well known, it is an imposed concept, and in the Pacific Islands, gender is complex and multifaceted.

In Western societies, gender is understood as a binary system of male or female that is heavily intertwined with norms of heterosexuality, and it is often based on the idea that gender is determined by biological sex [15]. We acknowledge this understanding is often contested by gender activists and advocates. In the Pacific Islands, gender is, however, defined by one's role in social life and is centred on the individual's expected contribution to collective life [16]. A focus on gender identity is particularly appropriate for the Pacific region as there are several groups in Pacific societies—*fa'afāfine* and *fa'afatama* (Samoa), *fakaleitī* (Tonga), *mahu* (Tahiti), *pinapinaaine* (Kiribati), *vakasālewalewa* (Fiji) and *'akava'ine*

(Cook Islands)—that do not conform to the binary Western understanding of gender [17]. In Pacific societies, gender identities vary from culture to culture and are embedded in cultural identities and roles that may not equate to recognised multi-country identities (i.e., transgender or intersex) [18]. Wilson (2022, 20 citing New Zealand Human Rights Commission, 2020, p. 62) notes that "identities such as *whakawāhine* (Māori), *fakaleitī*, also called *leitī* and *fakafafine* (Tonga), *fa'afāfine* (Samoa), may be more closely associated with 'familial, genealogical, social, and cultural selfhood'" than centring around an individual's gender identity, that underpins Western concepts of gender [19]. A full explanation of all of these Pacific non-binary genders is beyond the scope of this paper. We refer interested readers to a source that contests the universality of Western gender binaries that contains a discussion of third and fourth genders in Samoa that explains that, "Fa'afafine and fa'afatama are fluid gender roles that move between male and female worlds." [20].

It is well known that women and men in the Pacific Islands often have very specific roles within agricultural production, including when working with particular crops [2,21,22]; at other times, men and women work together to harvest or plan the growth and sale of new crops [23]. In attempting to understand how binary and non-binary genders articulate with agricultural production, we have surveyed the existing literature to seek studies on how non-binary genders contribute to agricultural production. Moving past a gender binary promotes gender inclusivity, social justice, and accurate representation of cultures and practices. A gendered lens enables a more nuanced understanding of local cultures, social structures and agricultural practices, which leads to more effective and sustainable food outcomes.

2. Methodology and Methods

This scoping review is informed by an understanding of society as non-binary in terms of gender, wherein we assert that society is not merely divided into two gender groups—male and female—but also encompasses those whose gender identity exists outside of this binary man/woman. With this starting point, we adopt the standard Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping review (PRISMA-ScR) [24].

This scoping review uses the PCC (population or participants/concept/context) framework to identify the main concepts in the primary review question and informs the search strategy [25].

2.1. Eligibility Criteria

2.1.1. Participants

In this review, we focus on Pacific gender identities and not sexual identities, as gender identities are culturally embedded and emphasised over sexual identities [19]. Apart from the usual male/female binary, Pacific Islands societies have several well-established non-binary genders—in Samoa, *fa'afāfine* and *fa'afatama*; in Tonga-*fakaleiti*; and in Fiji-*vakasalewalewa*—which, despite the efforts of missionaries, still maintain a high degree of social acceptance [17]. With respect to Solomon Islands, we have not yet encountered any literature that relates to a non-binary group in the same sense as in Polynesia; however, we are aware of gender-diverse communities, especially in Honiara.

2.1.2. Concept

The main aim of this article is to identify and explore the influence of gender on Indigenous/traditional knowledge and practices that shape food production systems in the Pacific, particularly in agricultural production, including cultivating, planting, raising and harvesting crops. As our focus is on gender and agricultural production in the food system,

non-agricultural food sources, such as fisheries, animal husbandry and shops/markets, are not included in this review, with one notable exception (see below in study selection).

2.1.3. Context

The data and findings from this review inform an Australian–Canadian co-funded aid project on food loss—ACIAR/CS/2020/191: Adopting a gender-inclusive participatory approach to reducing horticultural loss in the Pacific. CS/2020/191 is a project supported by the Australian Centre for International Agricultural Research (ACIAR) and Canada's International Development Research Centre (IDRC). It aims to reduce post-harvest agricultural waste in four Pacific Island countries—Samoa, Tonga, Fiji and the Solomon Islands [26]. This review is thus restricted to these four states.

2.2. Search Strategy

An initial limited search of ProQuest Central was undertaken to identify articles on the topic. Studies published in English were included as the majority of literature across the Pacific on this topic is published in English. Studies published from 2015 to 2024 onwards were considered for the scoping review as that year marks the beginning of the United Nations Sustainable Development Goals (SDGs), which has had considerable influence on global and regional policies, research agendas and funding priorities [27]. The SDGs provide a comprehensive framework for addressing global challenges, including SDG5: Gender Equality and SDG2: Zero Hunger. Further, SDG2 has as its target Goal 2.4 of 'Sustainable food production and resilient agricultural practices', which provides scope for the contributions of traditional/Indigenous knowledge.

This scoping review considered peer-reviewed articles and other scholarly studies, such as reports and working papers. Scholarly studies included all study designs, i.e., quantitative, qualitative and mixed methods approaches. Grey literature sources, such as project reports, evaluation reports and other relevant documents, were also included. In line with the method outlined by Hilary Arksey and Lisa O'Malley (2005) [28], editorials, reviews, opinion pieces, news articles, dissertations and theses and books were excluded.

- The databases searched were Scopus, ProQuest Central, ProQuest Agricultural and Environmental Science Collection, Science Direct and Taylor & Francis Journals. The journals that were searched were the *Journal of Agriculture and Food Security, Regional Environmental Change, and Journal of Sustainability.* Lastly, a search was conducted of the websites of the following organisations, due to their specific programmatic focus on gender in agriculture in the Pacific:
- Development of Sustainable Agriculture in the Pacific;
- Food and Agriculture Organisation (FAO);
- Secretariat of the Pacific Community (SPC);
- United Nations in the Pacific;
- United Nations Women;
- International Women's Development Agency.

2.3. Exclusion Criteria

Studies were excluded if they were:

- Published outside the time frame of 2015–2024 or conducted in countries outside of Fiji, Tonga, Samoa or Solomon Islands;
- Published in languages other than English;
- Editorials, reviews, opinion pieces, news articles, dissertations and thesis and books;

- Did not assess the influence of gender dynamics on Indigenous knowledge on agricultural production and sustainable food systems.

2.4. Search Terms

A full search strategy for ProQuest Central was developed using the text keywords contained in the titles and abstracts of relevant articles. The search strategy, including all identified keywords, was adapted for each database and journal. The reference lists of all included sources of evidence were screened for additional studies.

The following keywords were used to search the databases to identify relevant studies:

(gender OR male OR men OR female OR women OR third gender OR *fa'afafine* OR *fa'afatama* OR *fakaleiti* OR *vakasalewalewa* OR trans-diverse)

Inclusion of 'trans-diverse' as a search term recognises the broader spectrum of gender identities, such as gender fluidity, transgender and non-binary identities, in Pacific Island societies, which reflects traditional and cultural practices [29,30].

AND

(food security OR agriculture OR horticulture OR small holder farm OR small holder agriculture OR fresh food OR local OR sustainable agriculture OR family farming OR fresh produce OR crops OR vegetables OR food systems)

AND

(Indigenous knowledge OR Traditional knowledge OR knowledge OR practice OR share OR local knowledge)

AND

(Pacific Island OR Tonga OR Samoa OR Fiji OR Solomon Islands OR Melanesia OR Polynesia)

2.5. Study Selection

All identified studies in the search were imported into EndNote, and EndNote software was then used to remove duplicates. The selection of studies for analysis was conducted by (1) manually screening the titles to remove any obviously irrelevant studies, (2) reading abstracts to confirm eligibility and relevance, and (3) reviewing the full texts of remaining studies against the inclusion criteria, pending final inclusion. One grey literature study on non-binary gender and fisheries was included, as it had directly relevant information on agriculture; indeed, it was the only source located that made these linkages.

The final studies selected were then imported into a Microsoft Excel data sheet. The final listed studies were then screened, and the reason for excluding any studies was noted in the Excel sheet. One author made the final selection of articles and studies for the scoping review, and the lead author was consulted in any case of uncertainty.

2.6. Data Extraction

Data were extracted from papers included in the scoping review using a piloted form developed by the authors. The data extraction flow is summarised in Figure 1. The data extracted included specific details about participants, concepts, context, study methods and key findings relevant to the review question. All study details are captured in Table 2. The final number of records analysed was 14, with 6 academic papers and 8 studies from the grey literature. The larger number of germane studies from grey literature may be explained by the fact that most research on linkages between gender, agriculture and food production in the Pacific Islands is performed by international agencies such as UN Women as part of their remit to empower women economically and politically.

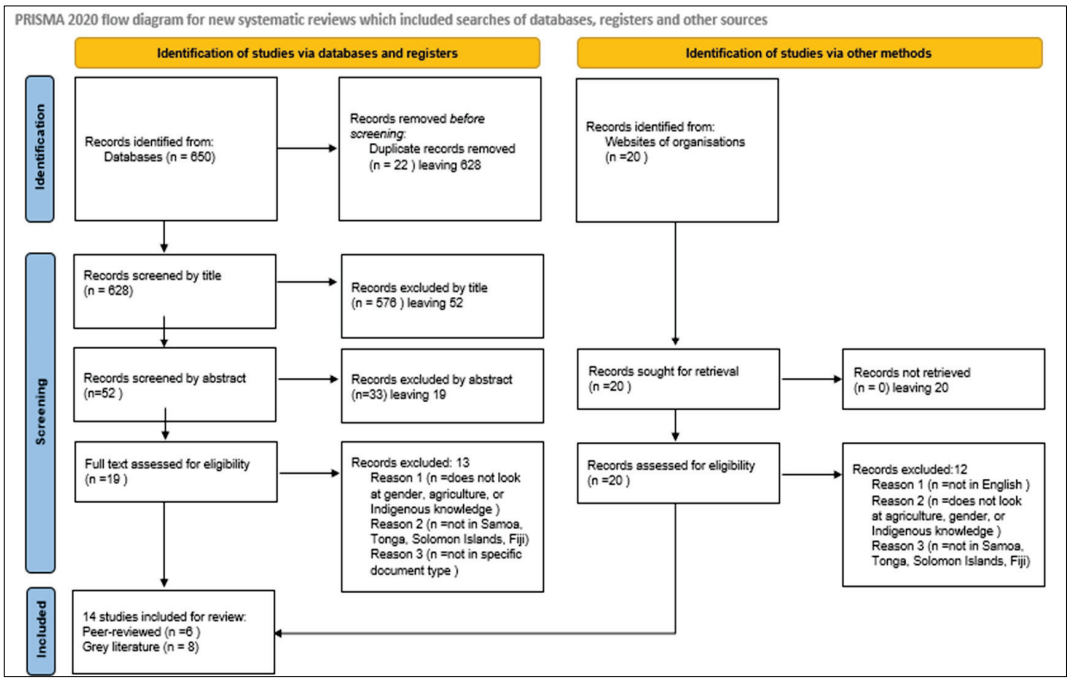


Figure 1. Study selection flow chart.

2.7. Data Analysis and Presentation

A thematic and comparative analysis was used for the scoping review. We utilised Braun and Clarke's (2011) [31] coding process to identify relevant themes to summarise the common aspects of the data. Data were coded using the six-step process: (i) familiarisation with the data by reading and re-reading the included studies; (ii) generating initial codes; (iii) grouping the codes into developing relevant themes; (iv) reviewing the themes against the coded extracts and the data extracts and create a thematic 'map'; (v) defining and naming the themes and sub themes; and (vi) writing the results. The final analysis entails a description and explanation of the similarities and differences of the gender dynamics in Indigenous and traditional knowledge of agricultural production and sustainable food systems across Tonga, Samoa, Fiji and the Solomon Islands. Similarities and differences are thematically organised based on the cross-cutting themes identified.

3. Results

This scoping review employed a gendered analysis to examine the social roles of different genders in agricultural production and the impact of these roles on food security across the four Pacific Islands countries: Samoa, Tonga, Fiji and Solomon Islands. Examining the data through a gendered lens provided valuable insights into social constructs, gender and responsibilities that influence the development of agricultural knowledge and skills that shape decision making across all stages of agricultural production, processing, and market participation, consumption and well-being outcomes. By recognising and valuing these different forms of knowledge, we can then promote more sustainable agricultural practices that are rooted in local contexts and responsive to community needs.

Three main themes emerged from the literature:

1. Gendered division of labour and culturally defined gender roles;
2. Decline in intergenerational traditional knowledge transmission; and
3. Climate change adaptation and traditional knowledge.

3.1. Theme 1: Gendered Division of Labour and Culturally Defined Gender Roles

In the Pacific Islands, agricultural production is intertwined with gendered roles and responsibilities, and these vary across different Pacific cultures and communities. Specific gender roles are shaped by historical, cultural and social factors, and understanding these roles is key to developing effective agricultural policies and practices that are inclusive and equitable. In agriculture, men's roles are oriented around work such as clearing and ploughing land and planting root crops. In contrast, women's roles are commonly centred around household food production as well as planting and harvesting in gardens that are run by their families or community members [32–35].

In Pacific Islands communities, men and women play distinct roles in agricultural decision making, production, and market sales. Across various Pacific societies, cultures, and geographies, individuals possess knowledge and skill sets derived from their varied gendered experiences and roles in agricultural production. Exploring agricultural production through a nuanced gendered perspective elucidates gendered knowledge of indicators of change or environmental stress, highlighting diverse insights and capabilities, as well as complementary resources in responding to climate change, thereby enriching the overall resilience of the community. We suggest that these different knowledge sets show interdependence rather than hierarchy to produce symbiotic knowledge sets.

When considering how to create sustainable food systems for people living in PICTs, it is important to acknowledge that interventions can affect gender relations and gender roles. For example, a program that introduces high-value cash crops into a family farming situation might reinforce male economic and decision-making dominance, which can negatively impact gender relations [36].

In Pacific Islands, agricultural roles are influenced by factors such as age, geography, gender, culture and ethnicity. This is also the case when an individual is residing in their own village or the village of their spouse [37]. This is evident in Tonga, where the influence of Christianity has greatly impacted culture and gender roles. Men are primarily responsible for labour work in the fields, while women are expected to take care of the household. This cultural norm has also affected agricultural practices [34].

3.1.1. Gendered Roles and Responsibilities

Traditional knowledge about agricultural practices has been transmitted orally through generations. It is place-specific and critical for managing sustainable agricultural production in a specific place. Historically, village elders taught young people which practices were appropriate for each situation. Knowledge sharing was often passed down through new generations learning gender roles. For example, women elders would teach girls how to garden, prepare meals and conduct household chores, while male elders taught young boys the skills of hunting and harvesting. Along with these practical skills, elders would also share stories, traditions, and knowledge about biodiversity utilisation [38]. This intergenerational passing of knowledge therefore supported and perpetuated a gendered division of labour around particular activities.

The gendered division of labour can be explored through the different roles and responsibilities held in agricultural production. Notably, in Solomon Islands, although there is nearly an equal number of women and men actively working in subsistence farming, there is still a gendered division of tasks, responsibilities, and knowledge; for instance, men engage in heavy planting and harvesting tasks while women tend to home gardens and domestic work which involves caring for their immediate household and extended family members [33]. Across Fiji, Samoa, Solomon Islands and Tonga, women typically undertake

labour-intensive tasks such as garden maintenance and weeding, while men undertake sporadic, strenuous work such as clearing gardens and harvesting [2].

In Fiji, the traditional gender role for men in agriculture involves clearing and ploughing land, cash cropping, post-harvest processing, market sales and raising livestock [35], while women's roles include weeding, maintenance, processing of subsistence crops, raising household livestock, niche agricultural ventures and handicrafts [35].

In Samoa, there are gendered social norms in agriculture: men's roles are considered to be labour-intensive, and activities include planting taro and clearing land [32]. Samoan women have traditional community roles, including responsibilities in reproductive tasks around the house and vegetable gardens, as well as productive tasks [39]. Their contribution to agriculture is tending to vegetable gardens and subsistence farming aimed at feeding their family [32]. With respect to village gardens, both men and women contribute—men conduct the initial set-up of gardens, such as digging the area for land preparation, while women plant, maintain and harvest [32].

In Samoan culture, the *Fa'afafine* play an important role in performing traditionally female tasks such as subsistence farming and reproductive duties within their families. They learn these practices from their grandmothers and mothers, who pass down the knowledge of agricultural activities and other domestic skills [17]. *Fa'afatama* are more limited in their roles and may have restricted access to certain activities, including those traditionally seen as exclusive to men or women [17].

In Solomon Islands, men and women engage in similar agricultural work. Men's roles focus on clearing gardens, heavy planting, harvesting tasks, and production, and they are involved in the growth and sale of profitable cash crops such as watermelon [23]. Women are responsible for the production of the majority of subsistence foods in Solomon Islands [23]. They also have ongoing and labour-intensive tasks involving post-harvest processing and maintenance of seedlings and traditional gardens [33].

In Tonga, the division of labour is steadily becoming fluid. Both men and women perform the majority of agricultural tasks including clearing land, ploughing, planting crops (taro, cassava, tree fruits, and coconuts), post-harvest processing, and harvesting materials for handicrafts [34]. Additional men's roles include constructing sheds and agricultural infrastructure. In contrast, women's roles involve weeding and maintaining subsistence gardens, as well as holding primary responsibility for household labour [34].

3.1.2. Complementary Knowledge

The different roles of men and women result in differing experiences, knowledge, and skill sets that contribute to agricultural production [37]. When managing natural resources, adapting to climate change, and sustainably engaging in agricultural practices, men and women all possess distinctly valuable and complementary knowledge of their specific roles in agricultural production and of agricultural production and adaptation more broadly within their community.

The literature indicates men and women notice different indicators of stress and change in the environment, with the two knowledge sets complementing each other to contribute to better development and ideas. The examples below show how the gendered knowledge systems complement each other and work together to develop innovative solutions that cater to the diverse needs of their communities. For instance, women possessed a deep understanding of seasonal weather changes and were able to utilise this knowledge to determine which crops would grow better in the garden in various weather conditions. This enabled them to ensure a consistent supply of food and maintain food security for their families and communities [33]. In Solomon Islands, continuous rainfall and flooding

have caused many common crops to fail. In response to the situation, male farmers started planting swamp taro on swampland for consumption [33].

The assignment of gendered activities within agricultural production means that people of different genders may notice and respond to conditions in unique ways. According to UN Women (2022), in Tonga, men may be more likely to recognise soil degradation on farming land than women, who are less likely to work on agricultural land. However, women have a strong connection with home gardening, as they inherit knowledge from their elders about the importance of gardening and growing staple crops such as traditional root crops (yam, sweet potato and cassava) [40]. This has led to women becoming experts in home gardening and playing a crucial role in ensuring food security in their households and communities. Similarly, in Fiji and Solomon Islands, since the COVID-19 pandemic of 2020–2022, there has been an increase in food received from home gardens (fruits, vegetables and root crops), which demonstrates the cultural practice of sharing resources and knowledge [41]. Crop diversification is a direct result of social and cultural participation in sharing knowledge [2]. On Savo Island, Solomon Islands, subsistence production is organised, and food crops are grown by all members of the household, including children [23], thus allowing for different knowledge sets to be recognised and implemented.

Due to the different types of knowledge held by women and men, a gendered perspective is essential for making better decisions about agricultural production. Since people have different experiences and knowledge of a situation, a gendered perspective can offer a unique and beneficial insight. Making workable adjustments to things that may not be otherwise working can assist in the long term and can lead to sustainable practices [42]. While all members of a community already are involved, it is crucial to ensure and enable the active participation of members in the planning and decision making of agricultural production.

3.1.3. Gender Inequality in Agricultural Decision Making

Across the four countries in the study, women held important roles in agricultural production. However, their contributions within the household and in agricultural production were not considered to be 'real work'; rather, these responsibilities were assumed to be a woman's duty. For example, in Samoa, women are not recognised as farmers; instead, due to the strong gendered norms and practices, they are viewed as 'helpers' of men in agriculture [32]. In Tonga, although women comprise 51% of the agricultural workforce, there is little recognition of women farmers in decision-making, as it is customary for men to hold decision-making power [34]. In Solomon Islands, at the household level, although husbands consult with their wives about decisions on agricultural resources and production, the ultimate decision-making power lies with the husband, even if the woman is the traditional landowner [23,33]. At the community level, decision-making positions are male-dominated, and women generally do not have a voice regarding agricultural planning and production. Participation in decision making is also limited for women in Fiji, who are usually excluded from formal decision processes concerning production and land, despite their participation in agricultural work—rural women worked (and were paid) for an average 28.3 h while rural men worked 35 h a week. However, women also engaged in unpaid household responsibilities for an average of 26 h per week, while men contributed only 10 h a week of unpaid work to the household [35]. As is the case in Africa and Asia, in the Pacific region, the lack of recognition of women's roles within the household and in agricultural labour is a direct result of cultural systems and traditional social norms and rules of community governance that create challenges for the advancement of equality for women. According to the Pacific Community report published in 2015, in Samoa, "at

the community level, due to traditional stereotypes and cultural attitudes, women lack the confidence and self-esteem to undertake decision-making responsibilities, and that community attitudes can constrain women from participating" [39]. Women's access to productive resources and opportunities, including assets, services, and interventions across a wide range of contexts, is hindered because their knowledge, skills, and participation in agricultural production are often overlooked [39].

The literature indicates that women are drivers of change as they tend to think about the future and plan accordingly [34]. However, it is also clear that women's knowledge is an underused asset in rural communities, and existing gender roles and power relations linked to decision making can constrain positive development [35]. Not acknowledging the full scope of the multiple roles conducted by women, particularly their traditional knowledge of agriculture and adaptation practices, can undermine food security in Tonga, Samoa, Solomon Islands and Fiji.

3.2. Theme 2: Decline in Intergenerational Traditional Knowledge Transmission

Knowledge transmission efforts on sustainability and resilience are necessary for adapting to climate change. Pacific communities place strong importance on the roles and responsibilities played in reviving culture and traditional agricultural practices. There has, however, been a decrease in the reliance on subsistence food sources due to the high consumption of processed foods, and this has led to a decline in knowledge transfer in PICT communities. In 2018, Samoa's communities reported a high overconsumption of imported food for each meal compared to 10 years ago, when most food was locally sourced and produced [32]. There has also been a shift from using produce from the family farming garden to buying produce and imported food, reflecting a shift from food use by necessity to food use by choice, which has resulted in losing traditional farming knowledge as young people, who are also increasingly pursuing formal education, are opting not to farm [40] and are seeking higher status jobs in urban centres. In Fiji, many communities are less reliant on home gardens, where local Indigenous knowledges and practices are shared, and they are increasingly relying on processed foods [32,40].

In the Solomon Islands, climate change is disrupting traditional knowledge and specific knowledge of local agrobiodiversity, as inconsistent seasonal weather patterns and periods of heavy rains challenge traditional Indigenous agricultural practices. Men and women connected climate change to biodiversity loss and shifting dietary practices. They also highlighted how this aligns with the growing dependence on imported foods, noting that this has led to the loss of traditional hunting methods and food preparation skills [39].

Another problem identified in Solomon Islands is that insufficient traditional knowledge is being transmitted between older and younger generations. The elders stated that young people are not interested in learning traditional knowledge and activities about agricultural practices and local food systems [38]. However, in the same focus area, young people emphasised the importance of learning traditional practices and wanted to learn how to grow crops on their family farms [38]. This disjuncture between older people's perceptions and younger people's values highlights a disruption in the oral traditions of knowledge sharing and points to a need to document traditional knowledge to preserve and transfer it to future generations. In Samoa, there is a strong presence of a cash-oriented production system where the majority of men go to work on plantations that focus on the export of cash crops such as cocoa, banana, noni, coffee, turmeric, breadfruit and taro [39]. Oral customs and teaching young men how to practice agriculture are declining. It is now mostly the older generation that remembers and practices traditional farming methods [39].

3.3. Theme 3: Climate Adaptation and Traditional Knowledge

The Pacific Island countries are experiencing an increase in 'slow-onset' impacts of climate change, such as rising sea levels, increased temperatures, the number of hot days and changes in precipitation patterns. These hazards can cause severe losses to the yields of traditional food crops and increase the risks of famine and food insecurity in Pacific Island communities [41]. Traditional gender roles shape how people interact with the environment. Cassinat et al. (2022) reported that men were more likely than women to prioritise agricultural adaptation in a survey when disasters or environmental changes occur [42].

Changing weather patterns have led to a decrease in garden productivity, increased fallowing times and an increase in pressure on land use. Knowledge of when to plant root crops and other crops is required, especially when weather changes are affecting the soil fertility in agriculture. However, weather changes are challenging Indigenous agricultural practices, especially knowledge of planting seasons and crop harvests [38]. For example, a village elder recalled that traditional Samoan crops, such as swamp taro, which were traditionally grown and eaten, are no longer farmed due to the changing nature of the soil in the village [32].

Iese et al. (2021) [41] observed that the COVID pandemic heightened vulnerabilities and economic challenges, and agricultural sectors in PICTs are likely to suffer from reduced investment, labour shortages due to illness or mobility restrictions, and potential supply chain disruptions. In turn, this can lead to decreased agricultural productivity [41]. They also found that as a means to protect food security, new farmers are practicing unsustainable and non-resilient cropping systems. They noted that the intense cultivation of land to increase crop production in the short term can cause the decline of soil fertility and reduce/affect long-term agricultural production in the area.

Resilient Cropping and Farming

The effects of climate change have resulted in some farmers returning to Indigenous and traditional methods of agriculture, such as planting climate-resilient crops and conserving seeds [43]. A traditional agricultural practice is fallowing—leaving one area unplanted (or 'fallow') for a period of time—which enables land nutrients to regenerate after a harvest, ensuring restoration of soil fertility for the next crop [43]. Some 62% of men are likely to practice fallowing as they work on large agricultural land where crop spacing, mixed cropping and intercropping are used; in comparison, 33% of women practice fallowing as the majority of agriculture undertaken is in home gardens [43].

In Fiji, agricultural production is shifting from intensive cultivation to sustainable farming. Farmers are relocating to new land after two to three cropping sequences, which involve a vegetable harvest, followed by a root crop and a fallow period that allows for the future use of the land [35].

In terms of climate resilience, men and women harvest crops while they are still edible and plant crops that will mature the fastest (roughly three months) [34]. The choice of crop or vegetable depends on the temperature; in Fiji, men and women harvest taro and cassava as the warmer temperatures permit for a better harvest of these crops [35].

Crop diversification is being practised to combat climate change pressures. In Solomon Islands, farmers are growing more sweet potato (*kau kau*) than in previous years due to the high yield after a short fallow period, and because *kau kau* requires less weeding and maintenance than yam [2]. Planting non-seasonal crops that can grow well in poor or sandy soils, is an important adaptive strategy, especially if they are drought-tolerant and resistant to pests.

Table 2. Summary of included studies.

Peer-Reviewed Journal Articles					
No.	**Author/Year/Title**	**Study Objective**	**Population or Region**	**Study Methodology**	**Key Findings**
1	Cassinat et al. (2022) [42] 'Traditional village roles and gender shape Samoan perceptions of climate change'	- Examine how gender and traditional village roles shape perceptions of climate change and adaptation response	Fa'asalele'aga district in Savaii, Samoa. Participants: 12 women and 15 men.	Semi structured interviews	- How people interact with the environment is shaped by their traditional village role. - Pay attention to the environment and it will assist in long-term planning and sustainability. - Men were more likely to put agricultural adaptation as a higher priority than females due to their role in agricultural production.
2	Georgeou and Hawksley (2017) [23] 'Challenges for sustainable communities in Solomon Islands: Food production, market sale and livelihoods on Savo Island'	- Examines the challenges of community sustainability	Savo Island	-Focus groups -1-on-1 semi structured interviews -Observations	- Subsistence farming is organised by all members of a household (deciding what will be grown and working together). - Men and women engage in similar agricultural work. - Women are responsible for the production of the majority of subsistence foods. - Men focus on clearing gardens, heavy planting, harvesting tasks and sale of profitable cash crops.
3	Georgeou et al. (2022) [2] 'Food Security and small holder farming in Pacific Island countries and territories: a scoping review'	- Assess the relationship between smallholder farming and food security	Pacific Island countries and territories	Scoping review of literature	- Gendered division of activities. - Women and children undertake labour-intensive tasks, while men undertake sporadic strenuous work. - Crop diversification is a result of sharing knowledge and increased social, cultural, economic and political participation. - More research is needed on the role of gender in agricultural production in the Pacific.
4	Guell et al. (2021) [40] '"We used to get food from the garden." Understanding changing practices of local food production and consumption in small island states'	- Aim to understand the interlinkages and dynamics of local food production, preparation and consumption	Urban and Rural Fiji Participants: 76 men, women and youth.	Focus groups	- Participants credited their knowledge of home gardens and food to their forefathers, where knowledge was passed down from generations. - Importance of growing staple food/crops such as traditional root crops. - Shift from home gardens/farming to buying processed and imported foods. - Shift from necessity to a choice of farming.
5	Iese et al. (2021) [41] 'Impacts of COVID-19 on agriculture and food systems in Pacific Island countries (PICs): Evidence from communities in Fiji and Solomon Islands'	- Understand the implications of COVID-19 for Pacific Island countries - Identify knowledge gaps requiring further research and policy attention	Fiji and Solomon Islands	-46 focus group discussions -425 household interviews -Literature review	- Covid-19 led to 'new farmers' practicing unsustainable cropping systems, reducing short- and long-term agricultural production. - Covid-19 prompted traditional knowledge and practices to be implemented as well as emphasis on sharing knowledge/resources. - Traditional knowledge is a better alternative, which focuses on the resilience of agricultural production. - In Fiji and Solomon Islands, increase of food received from home gardens (fruits, vegetables and root crops).
6	Vogliano et al. (2021) [38] 'Dietary agrobiodiversity for improved nutrition and health outcomes within a transitioning indigenous Solomon Island food system'	- Assess dietary agrobiodiversity's relationship with nutrition indicators related to diet quality and anthropometrics - Evaluate the contribution of agrobiodiversity from the local food system to diet quality	Baniata village, Solomon Islands Participants: 14 groups with men, women and youth	-Survey -Focus group discussions	- Weather changes are challenging Indigenous agricultural practices including knowledge on planting seasons and crop harvests. - Traditional knowledge occurs for women during gardening and cooking and for men during hunting and harvesting. - Traditional knowledge and knowledge of local agrobiodiversity is declining. - Men and women stated traditional language, hunting techniques and food preparation techniques are being lost due to increase of reliance and consumption of imported foods.

Table 2. *Cont.*

Grey literature					
No.	**Author/year/title**	**Objective**	**Population or region**	**Methodology**	**Key findings**
1	FAO & SPC (2019) [35] 'Country gender assessment of agriculture and the rural sector in Fiji'	- Analyse the agricultural and rural sector in a gender perspective at the policy, institutional, community and household levels	Rural Fiji (Ba Province and Viti Levu) Participants: men, women and 11 representatives	- Desk review of literature - Focus group discussions - Stocktake of policies and strategies - Consultations with civil society organisations	- Gendered division of labour activities. - In Fiji, decrease in reliance of subsistence food sources due to high consumption of processed foods. - Knowledge on when to plant root crops/other crops is required, especially when weather is frequently changing. - Women's knowledge is an underused asset in rural communities. - Gender roles and power relations can constrain positive development. - Women and men recognise different indicators of environment stress/change. The two knowledge sets complement each other.
2	FAO & SPC (2019) [32] ' Country gender assessment of agriculture and the rural sector in Samoa'	- Aims to identify ways in which socially constructed gender roles and patriarchal norms in Samoa defines men's and women's access to and control over resources, including land and labour	Rural Samoa (Lotofaga and Falevao/Lalomauga) Participants: men and women	- Desk review of literature - Focus group discussions - Stocktake of Ministry of Agriculture and Fisheries, Ministry of Women, Community and Social Development - Consultations with two communities	- Gendered division of labour in agricultural activities. - Men roles are considered labour-intensive (planting taro and clearing land). - Women spend most of their time doing subsistence farming to feed their families. - Women have a significant role but are not recognised as farmers instead as helpers. - Traditional Samoan crops that were grown and eaten are no longer farmed such as swamped taro due to changing nature of soil. - Higher consumption of imported food at each meal.
3	FAO & SPC (2019) [33] 'Country gender assessment of agriculture and the rural sector in Solomon Islands'	- Analyse the agriculture and rural sector at the policy, institutional, community and household levels from a gender perspective	Rural Solomon Island (Guadalcanal and Malaita) Participants: government officials	- Desk review of literature - In-depth interviews - Consultations with civil society organisations - Site visits to communities	- Nearly equal number of women and men actively working in subsistence farming. - Gendered division of tasks, responsibilities and knowledge. - Men roles include clearing gardens, heavy planting and harvesting tasks. - Women do ongoing and labour-intensive tasks involving maintenance. - Strong emphasis on traditional food gardens. - Men and women have complementary knowledge sets on how to adapt to change and sustainably grow crops.
4	FAO & SPC (2019) [34] 'Country gender assessment of agriculture and the rural sector in Tonga'	- To improve awareness and understanding of gender perspectives in rural livelihoods in order to develop effective strategies to support food security, nutrition and resilience	Rural Tonga (Tongatapu) Participants: government officials	- Desk review of literature - In-depth interviews - Consultations with civil society organisations, private sector representatives and development partners - Field visits to communities in Tongatapu	- Men are considered to be the main breadwinners and decisionmakers, while the role of women is to take care of the household. - Division of farm labour is slowly but steadily becoming more fluid with majority of agriculture tasks completed by women and men (clearing land, ploughing, planting and harvesting materials). - Women have additional roles including weeding and maintenance of subsistence gardens. - Women are considered to be drivers of change, they forward think about the future. - For climate resilience, women and men planted crops that would mature the quickest (3 months).
5	Kenny & Tapu-Qiliho (2022) [17] 'Exploring the access to, and experiences of people of diverse sexual orientation and/or gender identity engaged in fisheries: a scoping review'	- Map participation and perceptions of people and communities of diverse SOGIE engaged in fisheries - Understand the economic and social contribution, experiences and treatment of SOGIE individuals in fisheries - Identity barriers to full participation of such individuals -Develop place-based research	Samoa (Savai'i, Upolu, Apia)	- Talanoa and storytelling - Formal and informal discussions and interviews - Participant observation	- Fa'fafine are taught by grandmothers and mothers the traditional way of doing agricultural activities. - Fa'fafine are often confined to subsistence farming rather than being able to access the full range of agricultural activities. - Fa'afatama do not have access to men's activities and have limited access to women's activities. - More research is needed on Fa'fafine and Fa'afatama roles in agriculture.

Table 2. *Cont.*

Grey literature					
No.	**Author/year/title**	**Objective**	**Population or region**	**Methodology**	**Key findings**
6	Loganimoce & Meo (2023) [37] 'The significance of traditional practices in the Lau Islands, Fiji, and their importance to women for sustainable protection and production'	- Reports on the outputs and outcomes of the Gender Inclusion Consultation with women	Fiji (Lau Province)	- Face-to-face interviews through targeted focus group discussions - Semi-formal discussions	- Agricultural roles are generalised and is influenced by factors of age, geography, culture, ethnicity and whether an individual is residing in one's original village or spouse's village. - Differences in roles result in knowledge and skillsets that are assigned to women or men. - Activities women perform are not considered real work rather considered a household responsibility. - Men roles include clearing gardens, maintaining large root crops and planting and tending to cash crops. - Women roles include weeding and maintenance of subsistence gardens, processing and cash crops. - Strong importance of traditionally practicing their roles and responsibilities in reviving culture and traditional practices.
7	Percy et al. (2022) [39] 'Gender, agrifood value chains and climate-resilient agriculture in small island developing states'	- Explores the interconnections between gender equality, climate resilience and agrifood value chains in small island developing states, from a food systems perspective	Samoa and Tonga	- Desk review of secondary data and literature - Interviews with FAO staff and relevant regional and subregional offices	- Gendered social norms. - Samoan and Tongan women are less active in production, instead have a greater role in food preparation, storage and value addition. - Men roles include clearing land, planting taro. - Community level, due to traditional stereotypes and cultural attitudes, women lack confidence and self-esteem to assume decision-making responsibilities. - Mostly the older generation remembers and practices traditional farming practices due to cash-oriented production system.
8	UN Women (2022) [43] 'Gender and Environment survey 2022 report, Kingdom of Tonga'	- Provide nationally representative and sex-disaggregated statistics across several thematic areas	Tonga (Nuku'alofa, Tongatapu rural, Vava'u, Ha'apai, 'Eua, Niuas) Participants: 2136 women and 2014 men	- Household survey	- Fallowing is most likely to be practices by men at 62% compared to women at 33%. - Men work on large agricultural land, using different techniques (crop spacing, mixed cropping and intercropping). - Women mainly perform agriculture activities in home gardens. - Men and women will notice different conditions occurring depending on their assigned activity, e.g. men in Tonga will likely notice soil degradation on farming land.

4. Discussion

The scoping review has synthesised the existing literature to understand the role of gender in the practice and sharing of Indigenous and traditional knowledge in agricultural production in Tonga, Samoa, Solomon Islands and Fiji.

4.1. Gendered Division of Labour and Culturally Defined Gender Roles

This review finds that agricultural production is gendered, culturally specific and contextual. Within diverse geographical and cultural contexts, men and women develop different knowledge sets, as they have different experiences and interactions within agricultural production. Men and women have different roles when engaging in the same agricultural production activity. It is, therefore, essential to provide opportunities that enable men and women to share their complementary perspectives and knowledge of agricultural production. For instance, Peralta (2022) highlights that men and women in Vanuatu are involved in similar agricultural activities, such as the production and postharvest of food and cash crops [21]. This collaboration provides an opportunity and an important platform for the sharing of traditional knowledge and ideas between genders, which can improve agricultural production. Contrary to previous literature, this new finding contributes positively to understanding the gendered transmission of knowledge.

Women are significantly knowledgeable about agriculture, particularly in managing home gardens and understanding which crops are best for each season. Ramirez-Santos et al. (2023) emphasise that women in Asia and Africa are crucial in maintaining home gardens and food preparation, which contributes significantly to food security [44]. However, this knowledge is often overlooked despite the importance of sustainable agricultural production, where women are undervalued, have little participation in discussions about agricultural production and are limited in decision making at a community level [34,35,39]. Women's diminished decision-making can, in part, be attributed to the impacts of Western colonisation, initially through Christian missionaries and religion, which enforced binary practices that disrupted the Pacific Islands' traditional gender roles and how people are seen, heard, included and involved in decision making [16,19,45,46]. For example, historically, men and women were equally important in decision making and their contribution to the household and community. However, colonisation resulted in men being viewed as the providers of the family, while women were considered physically inferior and limited to maternal duties [7,16,21]. In agricultural decision making, the erosion of platforms for women to share their knowledge and perspectives on agriculture is concurrent with the breakdown of traditional leadership structures and the adoption of Western social structures that emphasise the power of village leaders and chiefs (who are typically male) [5,7]. McLeod et al. (2018) [7] advocate for enhancing and strengthening the roles of women in agriculture through their culture and traditions. They contend that by valuing pre-colonial traditional forms of leadership and greater recognition of the diversity of ways women participate in decision making within Pacific societies, women will gain greater influence in decision making [7].

Singh et al. (2021) [5] highlight the importance of integrating gender perspectives into community discussions and programs. This enables all community members to have equal access to resources [5] and ensures they are provided with the opportunity to contribute equally and actively in decision-making processes. The significance of a gendered perspective is demonstrated in a Samoan village, where a female high chief was appointed. Her knowledge of the environment enabled improved planning and management of agriculture in the village [42].

There are similar examples seen across the world. In a project in Uttar Pradesh in India, women are involved as equal partners in decision making on agricultural and post-production services [47]. This work showcases that women were able to talk freely and discuss issues relating to sustainable agriculture; this involvement increased overall productivity and income [47]. In rural communities of Burundi, Central African Republic, Democratic of Congo, Mali, Niger, Ghana and Senegal, there are 'Dimitra' Clubs[1], which strengthen the participation and leadership of men, women and youth in community self-organisation. Women account for two-thirds of member attendance in Dimitra Clubs. All members are able to contribute and inform decision-making on a community level regarding varying issues, including agriculture and sustainable development [47]. The integration of gendered knowledge into discussions and decision-making allows for unique insights and provides an opportunity to use traditional knowledge in agriculture and adaptation to climate change. A gendered perspective is required when analysing any agricultural system. However, although non-binary people have an extensive history in Pacific cultures, in particular in Polynesia and Micronesia, in academic work, at least, there has been little attention devoted to understanding how non-binary genders contribute to and support agricultural food production [18]. For instance, an ethnographic study of four farms in Switzerland explored queer farming practices and how they navigate gender normativity. These individuals are discouraged from farming as a livelihood on the basis of their sex, gender or sexuality, while they de- and re-construct gender and farming identities. [48] Raj, G. (2024), further discusses insights into the complexities, contradictions and limitations of empowerment experienced by queer farmers within community supported agriculture. [49] On the other hand, there is increased recognition of the growing role of non-binary people in organic farms on Long Island and across the United States [50]. This literature review highlights an important gap in scholarly approaches to research on gender and agricultural production in the PICTs, one which not only perpetuates binary conceptions of gender but also renders invisible parts of Pacific populations.

4.2. Decline in Intergenerational Traditional Knowledge Transmission

Previously, communities were self-sufficient in the production of traditional food crops; however, globalisation has led to a shift from traditional diets and practices to modern diets consisting of imported food that is readily available and cheaper in supermarkets [51]. In Fiji, most of the population is heavily dependent on cheap imported foods due to the belief that traditional practices are time-consuming and labour-intensive [35,51]. Similar examples are seen in other countries; in Papua New Guinea, traditional crops, such as yam, sweet potato and taro, have been replaced by imported rice, and traditional sources of fish and meat were substituted for imported tinned meat and fish [52]. In South Africa, traditional diets have been replaced by 'Western' diets that are centred around highly processed imported foods [53]. This has, therefore, led to a decline in local production and consumption of traditional staple crops, resulting in a decrease in traditional agricultural knowledge transfer.

This review finds that there is an intergenerational gap in traditional knowledge transfer. In the Pacific Islands, there is an overreliance on imported food, which has accompanied a decline in the practice and sharing of gendered traditional knowledge between older and younger generations. This finding implies that there is a communication barrier, as elders believe that young people do not want to learn about traditional agricultural practices, when young people are reportedly motivated and eager to learn how to farm. However, Ramirez-Santos et al. [44] and Thow et al. [54] highlight that new generations

are less likely to conduct traditional agricultural practices (labour-intensive farming and food preparation) due to their different diets when compared with their parents and grandparents. Further, the sharing and passing down of gendered traditional knowledge is affected by younger generations wanting to work on larger plantain farms or work outside the agriculture sector. This is explored by Borda et al., who identified that the lack of motivation to engage in subsistence farming contributes to a widening gap in agricultural knowledge transmission from one generation to another [55]. In support of this claim, Shah et al. [51] and Nunn et al. [8] demonstrate that women are unable to share Indigenous practices of maintaining home gardens or food shortage practices. For instance, in Fiji, practices such as sun drying food and shavings of root crops or storing yams in heaps covered in soil and banana leaves are now unable to be taught [51]; men are not engaging in subsistence farming as frequently; therefore, men are also unable to teach and share traditional knowledge with each other or to teach young boys [38,39].

There is a clear link between maintaining local food production and dietary patterns and the preservation of gendered traditional knowledge, which emphasises the importance of encouraging the continuous transmission of traditional knowledge both between genders and between older and younger generations. With the advent of online platforms that allow for a reimagining of gender roles in a digital economy, female entrepreneurship stemming from traditional knowledge may be passed on through rural e-commerce. In Fiji, one such organisation, Rise Beyond the Reef, has, from 2015, produced handmade artisanal products (e.g., baskets, fans, screen-printed items and tapa wall hangings) for direct sale to consumers [56].

4.3. Climate Adaptation and Traditional Knowledge

The review finds that integrating knowledge of men and women results in resilient farming in the face of climate change. Each gender understands the environment differently. However, both sets of knowledge together contribute to Indigenous and traditional practices that better enable adaptation to climate change. This finding is explored in Phiri et al., where gender integration incorporates the unique abilities, knowledge and skills that are needed to respond to climate change [57].

The review suggests that crop diversification is occurring and is important when responding to drought or pests. Phiri et al. state that diversifying crop production supports current cropping systems' resilience to adverse climate change impacts [57]. Bryan et al. further emphasise the importance of diversified crops by highlighting their benefits, which include reducing climate risks to production and livelihoods and providing better environmental sustainability [58].

Diverse and integrated traditional knowledge and understanding of crops, from men and women, can assist in providing food security. For example, in Bangladesh, women are moving away from rice production to other more nutritious and climate-resilient crops, such as pulses, maize and vegetables (pumpkins) [58,59], while in Fiji, women are growing root and tuber crops, such as yam and taro, as these crops mature quicker and are readily available [5]. Additionally, in Malawi (sub-Saharan Africa), men and women are using Indigenous knowledge for household and climate resilience by keeping and sharing seeds and maintaining home gardens [57].

Traditional agricultural knowledge is crucial for managing climatic stressors. McLeod et al. (2018) reiterate the importance of this amidst the rise in extreme weather events [7]. They found that in the PICTs, women are revitalising traditional practices, such as laying palm leaves over the soil to keep it cool, covering young taro plants, transferring young

shoots to shady areas, and mulching around taro patches, to mitigate climate changes such as increased heat and soil infertility [7].

Therefore, capturing and integrating the knowledge of different genders into agricultural practices, policies and programs is vital for coping with climate change. This will produce resilient farming strategies that are sustainable and ensure food security.

4.4. Strengths and Limitations

A strength of this scoping review is its systematic and comprehensive approach to reviewing relevant literature, including peer-reviewed journal articles and grey literature on gender, Indigenous knowledge, and agriculture in Fiji, Samoa, Tonga and the Solomon Islands. This allowed for mapping and analysing studies from multiple sources.

The limitations of this scoping review include the following: the studies were restricted to journal articles in English, which could have excluded key studies in non-English languages; published studies covered only from 2015 to 2024; the review was limited to Fiji, Tonga, Samoa and the Solomon Islands. These states do, however, represent examples of the challenges that larger PICTs are facing, and the review captures the range of different Polynesian and Melanesian social, economic and ecological environments.

5. Conclusions and Implications

Pacific Island communities are heavily dependent on growing their food and engaging in family farming for subsistence and livelihoods. However, the Pacific region is currently experiencing the ongoing effects of climate change on agriculture. Understanding and adapting to climatic conditions is an emphasis, which will contribute positively to food security in the Pacific.

This scoping review aimed to elucidate how men, women and non-binary identities are recognised in the Pacific Island region and how they develop distinct yet complementary knowledge and skills in agriculture that are crucial for the sustainability of food systems. It expanded on the limited literature on gender dimensions of Pacific Islands agricultural food systems.

This literature has revealed there is little mention of non-binary people in scholarly literature concerning Tonga, Solomon Islands, Samoa and Fiji. In Samoa, the *Fa'afafine* and *Fa'afatama* have been researched in relation to their roles and activities in fisheries, but there are little data available on their role in agricultural production [17]. More research is required to understand the gendered experiences of access to resources, division of labour, decision making and knowledge in agricultural production in PICTs. With respect to the division of labour, to better understand the roles played by non-binary people and the gendered use of time in communities [32–35], future research could further examine the roles of non-binary people in agricultural production and how their traditional knowledge, unique experiences and skill sets can contribute to food sustainability.

While people of non-binary genders in PICTs tend to adopt domestic roles similar to women, there is a knowledge gap around their contribution to agricultural production, and much more research is needed. At a minimum, we need to know if the *fa'afāfine* (Samoa), *fakaleitī* (Tonga), *mahu* (Tahiti), *pinapinaaine* (Kiribati), *vakasālewalewa* (Fiji), and *'akava'ine* (Cook Islands) represent significant proportions of the agricultural labour force in individual PICTs, and, if so, whether there is specific gendered knowledge they hold that is different from that of women and men. If not, does the adoption of women's roles by non-binary groups release other female labour into the agricultural production cycle? Another important question is whether these genders experience challenges (cultural or otherwise) in gaining access to resources or knowledge needed to engage in the agricultural

production landscape and to gain insight into how these challenges can be managed, for example, through land access and training). Future policies and programs should, therefore, incorporate the perspectives and views of men, women and non-binary people on agricultural production.

The findings of this review add to the global knowledge of the relationship between gender and sustainable agricultural production, utilising Indigenous and traditional knowledge. The research will positively contribute to future policy and program development in the Pacific Islands, as it suggests that men, women and non-binary people should be equally involved in decision making and that gendered traditional knowledge should be integrated into agricultural production for increased effectiveness. This review generates evidence for the SDGs (Goals 2 and 5) to ensure sustainable food systems are achieved through the implementation of traditional agricultural practices.

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Abbreviations

The following abbreviations are used in this manuscript:

ACIAR	Australian Centre for International Agricultural Research
FAO	Food and Agriculture Organisation
IDRC	Canada's International Development Research Centre
PCC	Population or participants/Concept/Context
PICTs	Pacific Islands Countries and Territories
SDGs	Sustainable Development Goals
SPC	Secretariat of the Pacific Community

Notes

1 Dimitra Clubs are voluntary groups of people work work together to address community issues and bring about change. The Food and Agriculture Organization of the United Nations (FAO) states that "the goal of the clubs is to help rural communities become more organised and resilient, and to move away from being dependent on external aid" (FAO, 2017. FAO-Dimitra Clubs: Stepping stones for action in rural areas. [available at: https://www.fao.org/gender/resources/videos/videos-detail/FAO-Dimitra-Clubs-Stepping-stones-for-action-in-rural-areas/en] (accessed 7 November 2024)

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Review

Unveiling the Trajectories and Trends in Women-Inclusive City Related Studies: Insights from a Bibliometric Exploration

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Abstract: Despite the ongoing discrimination that hinders women's full participation in urban life, the International Agenda 2030 and its Sustainable Development Goals (SDGs) emphasize the eradication of violence against women and underscore the need for regulatory measures, local governance, and equitable practices for sustainable urban development focusing on women's needs. The women-inclusive cities related (WICR) studies, which have been gaining academic attention since the late 1990s, remain broadly explored yet lack a holistic trajectory and trend study and a precise women-inclusive city concept framework. This study applies bibliometric analysis with R-package Bibliometrix version 3.3.2 and a systematic review of 1144 articles, mapping global trends and providing a framework for women-inclusive city concepts. The findings show that WICR research increased significantly from 1998 to 2022, indicating continuous interest. Gender, women, and politics are the top three most frequent keywords. Emerging research directions are expected to focus on politics, violence, and urban governance. The findings also indicate a clear tendency for researchers from the same geographical backgrounds or regions to co-author papers, suggesting further international collaboration. Although no explicit definitions were found in the articles used, the prevailing literature consistently suggests that a "woman-inclusive city" ensures full rights, equal consideration of needs, and the active participation of women in all aspects of urban life.

Keywords: women-inclusive cities; feminist urbanism; urban equity; bibliometric analysis; science mapping; Bibliometrix

1. Introduction

While cities theoretically provide equal opportunities for all, fostering a diverse and economically rewarding life [1], urban structures have mainly been male-centric, often overlooking the female experience. Despite constituting half of the global population, women have historically faced discrimination and inequality in areas such as mobility, urban utilities, economic opportunities, and politics [2–4]. International commitments play a crucial role in advancing women's rights and inclusivity in urban spaces. Agenda 2030's SDG #5 mandates gender equality and women's empowerment, recognizing their significance for sustainable development. It also calls for the eradication of all forms of violence against women and highlights the importance of regulatory action and local governance. SDG #11 aims to ensure access to safe, inclusive, and green public spaces for all, particularly women, children, the elderly, and people with disabilities. It emphasizes women's active participation in urban planning and local government decision making [5], underscoring the need for a more equitable approach to the achievement of sustainable urban development.

The concept of an inclusive city emerged in the late 1990s and has gained prominence in academic discourse over the past few years. Prominent international organizations have prioritized this idea since 2002 [6]. An inclusive city, derived from the concepts

of inequality and exclusion, is generally defined as a city that promotes development while emphasizing fairness of access. UN-Habitat describes an inclusive city as one where individuals of all backgrounds can access the urban areas' social, economic, and political opportunities [7,8]. Liang et al. [9] identify five dimensions of an inclusive city: spatial, social, economic, environmental, and political, which provide a comprehensive framework for understanding and implementing the concept of an inclusive city.

To date, some related concepts have been introduced worldwide, such as feminist cities, women-friendly cities, and women-inclusive cities. Any of these concepts are generally acceptable and applicable to describe a women-inclusive city since they share a common goal, which is to promote access, representation, and equity, particularly for women in urban environments. Women-friendly cities emerged as a response to conventional urban planning practices. Initiated by the UN in 2006, the Women-Friendly Cities Program strives to create urban spaces that promote women's active participation in decision making and ensure equal access to services [10]. Seoul pioneered this initiative in 2007, focusing on enhancing women's well-being [11]. Another influential concept is the Feminist City, which critiques the patriarchal and capitalist influences on architecture and urban planning that disadvantage women. It proposes a new urban framework that considers communal resources, housing, public spaces, transportation, safety, sustainability, and architectural design from a feminist perspective [12,13]. Finally, we discussed the idea of women-inclusive cities, a subset of the broader gender-inclusive city idea. This concept ensures equal access to urban services and opportunities for all, regardless of gender, and addresses urban socioeconomic disparities [7]. It also considers the rights of marginalized or previously excluded groups in urban policy and planning [14,15]. Vienna is a notable example of a city pioneering gender-inclusive urban planning [16]. While the concept of an "inclusive city" has been explored in various contexts, its specific application to women remains under-researched. Prior studies have examined women's perceptions and gender differences in urban experiences [17–19]. They have also looked at women's participation and the gender gap in politics [10,20,21], the economy [22,23], and technology [24–26]. However, no single study explicitly defined the concept of "women-inclusive cities". Considering the significant global inequalities women face and the built environment's profound impact on daily life and social interactions, it is crucial for urban planning and design to strive for greater equity. This includes creating women-inclusive cities. The existing gap in the literature underscores the need for further research to understand and articulate this concept better.

Recent studies have shown that women and girls worldwide suffer safety concerns while accessing public facilities [27,28], encounter significant hurdles in achieving gender equality in the workforce [29], and experience a noticeable leadership gap [30]. The persistent gender inequities that women encounter in urban settings prompt immediate corrective action to establish more inclusive cities for women. While valuable research exists on how urban environments affect women's access to opportunities such as economic prospects, safety, mobility, public services, infrastructure, housing and land ownership, decision making, and leadership, this information is currently dispersed across multiple sources. Our study's significance stems from its capacity to collect and synthesize the scattered information of "Women-Inclusive Cities Related" (WICR) studies into a centralized reservoir. This reservoir makes critical information accessible for urban planners, legislators, and other stakeholders working on women-inclusive cities. This reservoir catalyzes worldwide programs promoting gender equality (SDG 5), inclusive cities (SDG 11, New Urban Agenda), and women's fundamental "right to the city". It aligns with and strengthens intersectional approaches to urban equity by amplifying and prioritizing women's perspectives and demands. The centralized knowledge hub provides a comprehensive picture of the current state of WICR studies, identifies gaps and areas for further investigation, lays a solid foundation, and directs future research efforts. It also has the potential to accelerate real progress in achieving SDGs. Additionally, critical findings extracted from the reservoir serve as cumulative evidence, assisting decision makers in

clarifying what constitutes a women-inclusive city and translating academic insight into best practices and practical recommendations to inform future gender-responsive urban policies and initiatives.

This study employs a combination of quantitative and qualitative approaches. The bibliometric analysis, conducted using the "R-package Bibliometrix", [31] examines the global research trajectories and trends of WICR studies. The systematic review is used to define the "Women-Inclusive Cities". The dataset comprises WICR keywords retrieved from the Web of Science Core Collection spanning 1998 to 2022. Bibliometric analysis, a quantitative method, tracks a field's evolution, identifies research gaps, and establishes cooperative ties between academic institutions or nations [32,33]. Recognized as an efficient approach for studying research patterns within a specific field over time [34], it uses statistical computation to objectively compare scientific research across different countries, institutions, journals, and authors. It also traces research trajectories and emerging fields of inquiry, providing objective insights into a particular research field's scientific output [35]. While bibliometric analyses are commonly employed in urban women studies [36–38], their use specifically in WICR studies is yet to be found. Accordingly, this study aims to:

1. Identify the leading journals and authors in WICR studies.
2. Identify the leading research articles and co-citations in WICR studies.
3. Map the changing trends in WICR studies.
4. Map the collaboration pattern in WICR studies.
5. Define a "women-inclusive city" term from the existing literature.

By meeting these objectives, we hope to provide a comprehensive understanding of WICR research's evolution over the past two decades, aiding academics and practitioners in this field's framework. The review paper begins with an introduction, discusses data gathering and processing techniques, presents the findings, summarizes the study, discusses the limitations, and suggests future research directions.

2. Materials and Methods

Clarivate's Web of Science Core Collection (WoSCC) was used as this review paper's data source. Recognized as a leading bibliographic database, WoSCC is widely accepted for various academic purposes [39,40] and is compatible with the selected bibliometric mapping software for result visualization, making it a reliable choice [31,39]. Only items with one of the following terms found in the article topic were included in the analysis: "Women Inclusive Cities", "Women Inclusive Urban", "Women Friendly Cities" "Women Friendly Urban", "Feminist Cities", "Feminist Urban", "Women Inclusion in Cities", and "Women Inclusion in Urban". These terms, commonly referred to Women-Inclusive Cities Related (WICR), share a common goal despite their differences. The selection of these keywords was guided by the research objective, and only English articles were reviewed. The PRISMA screening process was applied in this study (see Figure 1). Initially, 2631 articles were discovered; however, to focus our search, we narrowed down the interdisciplinary term of WICR by refining the article categories related to urban planning, architecture, transportation geographical studies, social and behavioral science, economic science, political science, and environmental science with a particular emphasis on the dimension of the inclusive city, as described by Liang et al. [9]. This refinement, emphasizing the dimension of the inclusive city, resulted in a final inventory of 1144 articles for study analysis using the R-tool "Bibliometrix".

This study examines the research fronts in the WICR fields, essential articles, authors, journals, references, and nations participating in this field of study and their relationships using bibliometric analysis. Bibliometrix offers a systematic analysis of large bodies of information, identifying trends over time, research themes, changes in disciplinary boundaries, and the most productive scholars and institutions [31]. Our study incorporates descriptive analysis, scientific mapping, and systematic review approaches. Bibliometric science mapping allows for the comprehensive examination and visualization of literature review collections [39]. Bibliographic coupling, co-citation, co-word, and collaboration are the four

main tiers of classification in bibliometric mapping analysis [33,41]. This research utilized the Bibliometrix R-package for bibliometric analysis, an open-source software package that is compatible with other statistical programs in the R language environment [31]. Figure 1 depicts the complete scheme of the data and methodology used in this study.

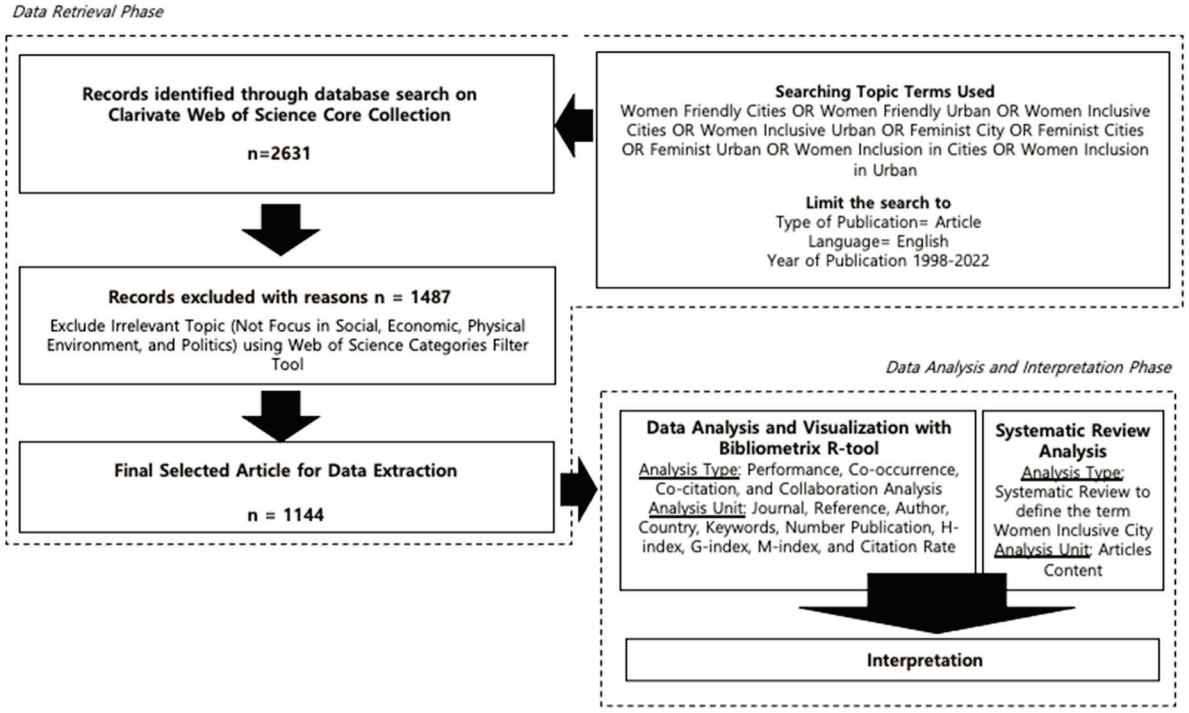


Figure 1. The scheme of review process. The data retrieval phase adapts the PRISMA flow diagram of the search strategy for the bibliometric analysis of WICR studies.

3. Results and Discussion

3.1. Leading Journals and Authors in WICR Studies

Our findings indicate that between 1998 and 2022, 1144 articles were published across 481 journal sources, with an annual publication growth rate of 12.32%, involving 2110 authors in total with an average of two co-authors per document, 3449 keywords, 58,275 references, and 14.03 average citations per document, as determined by Bibliometrix. The inaugural publication on WICR appeared in Urban Geography Journal in 1998, titled "Gender, Class, and Urban Space: Public and Private Space in Contemporary Urban Landscapes". This study explores gender and urban space, using Edinburgh as a case study. Bondi's [42] work on public–private area divisions in Edinburgh demonstrates how gender and class influence public and private situations. Subsequently, an additional 1143 articles were published through to the end of 2022. With 195 articles published, 2022 has become the most productive year. The most recent article, authored by Vijayakumar [43], "Labors of Love: Sex, Work, and Good Mothering in The Globalizing City", highlights sex work's role as a good mother, providing social and economic resources and enabling cisgender women to attain respectable femininity, challenging patriarchal ideals of masculine protection and upward mobility.

The findings reflect that even since The United Nations Millennium Declaration set the goal for addressing gender equality in September 2000, and UN Women published the practical guide for building safe and inclusive cities for women in 2011, the annual number of publications on WICR has not been significant. However, after the 2017 Women's March took place in the United States, sounding a protest against Trump's misogynistic policies that threatened women's rights, scholars worldwide began to focus more on women's rights and power dynamics in the cities, and the total publications each year in related subjects increased significantly. Figure 2 provides empirical support for the changing trends

in publication patterns observed throughout the study period. Notably, the initial WICR studies publication was low, but it grew gradually after that. This graphical representation helps with the projection of an estimated quantity of upcoming articles by leveraging previous patterns.

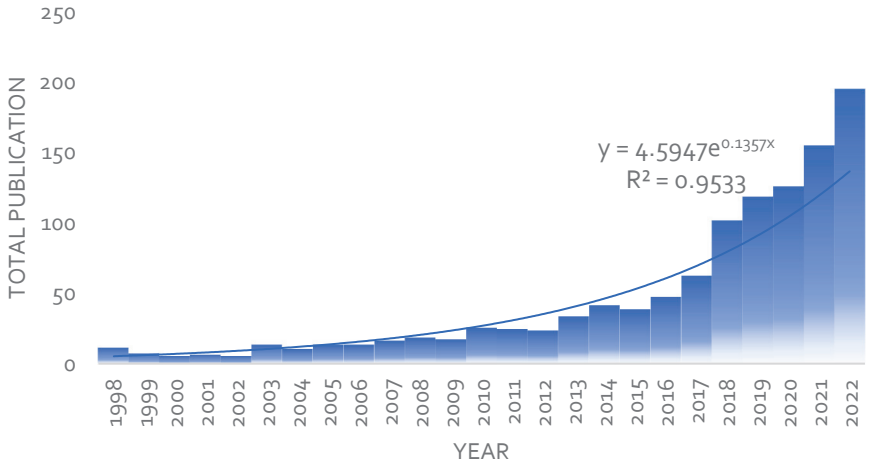


Figure 2. WICR studies publication growth trend 1998–2022.

Identifying significant sources, authors, institutions, and countries is critical for researchers to collaborate effectively with other research groups at various levels. Tables 1 and 2 and Figure 3 show key scientific groups that can be used to identify notable sources, authors, and countries in WICR studies. Table 1 presents the 25 most impactful journals. This study lists each journal's H-index, G-index, M-index, total citations, number of articles published, and the year of first publication. The findings reveal that the journals Gender, Place, and Culture (GPC), Antipode, and Plos One have significantly influenced women-inclusive city studies due to their high H-index, with GPC leading in publication frequency by issuing 89 papers since 2005. Table 2 highlights the authors with the highest H-index, including Prof. Wright [44], whose pivotal work "A Manifesto Against Femicide" examines gender and class in Ciudad Juárez, and Prof. Fenster [45], who explores urban gender dynamics in "The Right To The Gendered City". Prof. Parker B.'s [46] research on economic factors in female crime also stands out.

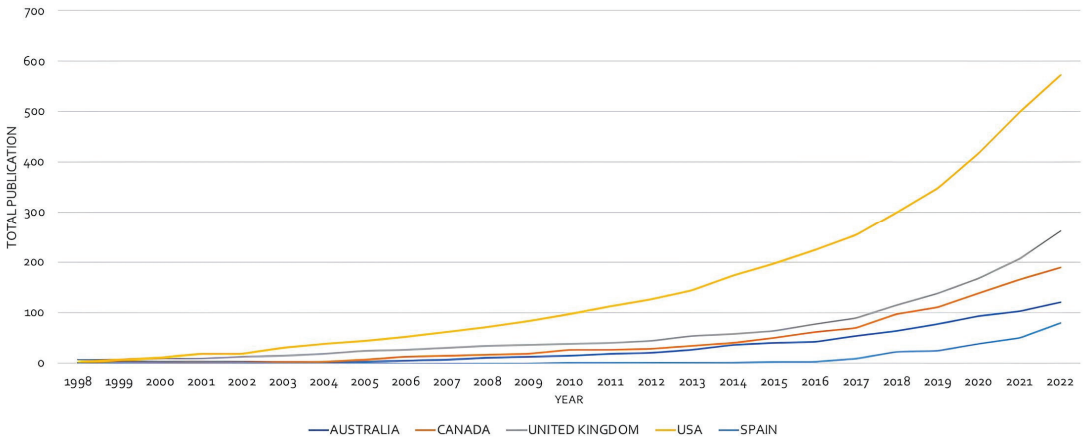


Figure 3. The most productive countries of WICR studies generated from Bibliometrix.

Table 1. The most notable sources of WICR studies based on H-index *.

R	Journal Name	H-Index	G-Index	M-Index	TC	NP	PY-Start
1	Gender Place And Culture	20	37	1.053	1611	89	2005
2	Antipode	14	24	0.609	586	28	2001
3	Plos One	13	21	0.929	451	22	2010
4	Geoforum	10	18	0.769	531	18	2011
5	International Journal Of Urban And Regional Research	9	13	0.36	425	13	1999
6	Women's Studies International Forum	9	15	0.346	265	27	1998
7	Environment And Planning A-Economy And Space	8	11	0.381	234	11	2003
8	Journal Of Rural Studies	8	10	0.421	311	10	2005
9	Progress In Human Geography	8	8	0.421	390	8	2005
10	Social & Cultural Geography	8	12	0.444	159	15	2006
11	Urban Studies	8	15	0.444	233	15	2006
12	Environment And Planning D-Society & Space	7	11	0.35	311	11	2004
13	Political Geography	7	10	0.35	454	10	2004
14	Transactions Of The Institute Of British Geographers	7	11	0.368	128	11	2005
15	Urban Geography	7	12	0.269	163	13	1998
16	Affilia-Journal Of Women And Social Work	6	10	0.261	141	10	2001
17	Annals Of The American Association Of Geographers	6	10	0.857	308	10	2017
18	Cities	6	11	0.3	224	11	2004
19	European Journal Of Women's Studies	6	7	0.24	63	7	1999
20	Feminist Media Studies	6	9	0.667	100	13	2015
21	Gender & Society	6	6	0.261	252	6	2001
22	Journal Of Gender Studies	6	12	0.316	255	12	2005
23	Feminist Economics	5	7	0.294	85	7	2007
24	Feminist Review	5	10	0.294	108	12	2007
25	Sustainability	5	6	1.25	50	11	2020

* Abbreviations: R = rank; TC = total citations; NP = number of publications; PY-start = publication year start.

Table 2. The most notable authors of WICR studies *.

R	Authors	H-Index	G-Index	M-Index	TC	NP	PY-Start
1	Wright Mw	6	6	0.261	199	6	2001
2	Fenster T	4	5	0.211	206	5	2005
3	Parker B	4	4	0.5	75	4	2016
4	Truelove Y	4	5	0.308	343	5	2011
5	Waitt G	4	5	0.364	130	5	2013
6	Yeoh Bsa	4	4	0.16	182	4	1999
7	Andrew C	3	3	0.273	39	3	2013
8	Britto S	3	3	0.167	98	3	2006
9	Houston D	3	3	0.3	59	3	2014
10	Huang S	3	3	0.12	121	3	1999
11	Hubbard P	3	3	0.273	77	3	2013
12	Klodawsky F	3	3	0.167	56	3	2006
13	Maclean K	3	3	0.429	15	3	2017
14	Mclean H	3	3	0.3	85	3	2014
15	Mcrobbie A	3	3	0.188	163	3	2008
16	Misgav C	3	3	0.333	24	3	2015
17	Morrow O	3	3	0.429	41	3	2017
18	Parikh A	3	3	0.5	29	3	2018
19	Vieraitis Lm	3	3	0.167	98	3	2006
20	Williams Mj	3	3	0.429	128	3	2017
21	Ababio-Donkor A	2	2	0.5	12	2	2020
22	Ajibade I	2	2	0.182	171	2	2013
23	Alam A	2	2	0.333	47	2	2018
24	Alda-Vidal C	2	2	0.286	14	2	2017
25	Aldred R	2	2	0.25	172	2	2016

* Abbreviations are the same as in previous table.

Penn State University and the University of North Carolina lead in publications, reflecting a broader trend of such research predominantly emanating from developed countries, including the United States, the United Kingdom, Canada, Australia, and Spain (Figure 3). This pattern underscores the rising focus on gender-inclusive urban planning in affluent nations, supported by the World Economic Forum's findings that North America has made significant strides in closing its gender gap and has made the most progress globally [30]. However, South Asian countries lag in contributions to women-inclusive city research, underscoring a global disparity and the need for broader engagement.

3.2. Leading Articles and Co-Citation in WICR Studies

Our finding indicates the diversity of the research categories among the top 100 most-cited publications over the past three years. It reveals that 44% of these papers, spanning areas such as mobility, active transportation, economic opportunities, ecology, climate justice, and digital technology, suggest a strong preference for empirical studies. Theoretical conception is next at 21%, emphasizing the need to generate new theories and frameworks to increase understanding in various domains. Survey and ethnographic research, accounting for 18%, continue to be prevalent among scholars. Review studies account for 9%, emphasizing the importance of synthesizing current research to provide thorough overviews and identify gaps. Policy studies and experimental research are the least represented at 3% and 4%, respectively, demonstrating their importance for future research but also their low number of references compared to other research categories.

For bibliometric analysis, we utilized the Bibliometrix-R Package to identify the most cited works globally and locally. Cobo et al. [47] and Beliaeva [48] describe "Global Citation (GC)" as the total number of citations a document receives from all publications indexed in databases like Scopus, WOS, or Google Scholar. "Local Citation (LC)" denotes the citation count from within a specific, highly specialized set of publications under review. This differentiation in citation analysis aids in recognizing a document's genuine impact, highlighting foundational and interdisciplinary research within the field [49]. Our study introduces crucial insights that are absent from prior literature reviews and bibliometric analyses. Table 3 lists the twenty-five most globally cited papers in WICR studies, with empirical research constituting half of these articles and the remainder spanning theoretical, review, and policy research. The most cited work is "Rethinking Water Insecurity, Inequality, and Infrastructure Through an Embodied Urban Political Ecology" by Truelove [50]; it contributes to urban political ecology by examining less explored aspects of water inequality. Following closely, Doan's [51] study uses autoethnography to explore transgender individuals' experiences of gender oppression in both public and private spaces. Till's [52] work, ranking third, advocates for the understanding of inhabitants' lived experiences to drive ethical and sustainable urban transformations.

Table 3. The most influential globally cited articles of WICR studies *.

R	Articles	TC	TCY
1	"Rethinking Water Insecurity, Inequality And Infrastructure Through An Embodied Urban Political Ecology" [50]	239	18.38
2	"The tyranny of gendered spaces—reflections from beyond the gender dichotomy" [51]	206	14.71
3	"Wounded cities: Memory-work and a place-based ethics of care" [52]	201	16.75
4	"The right to the gendered city: Different formations of belonging in everyday life" [45]	174	9.16
5	"The personal is political: Developing new subjectivities through participatory action research" [53]	151	8.88
6	"Households matter: the quiet demography of urban transformation" [54]	148	7.79
7	"Text-Message-Based Drinking Assessments And Brief Interventions For Young Adults Discharged From The Emergency Department" [55]	144	12
8	"Young Women and Consumer Culture—Intervention" [56]	139	8.69
9	"Just How Do I Love Thee?: Marital Relations In Urban China" [57]	137	5.71
10	"Urban Flooding In Lagos, Nigeria: Patterns Of Vulnerability And Resilience Among Women" [58]	134	12.18
11	"Does More Cycling Mean More Diversity In Cycling?" [59]	134	16.75
12	"Practising Urban And Regional Research Beyond Metrocentricity" [60]	124	8.86
13	"Migration And Infant Death: Assimilation Or Selective Migration Among Puerto Ricans?" [61]	121	5.04
14	"Elites In The City Of London- Some Methodological Considerations" [62]	120	4.62
15	"En-Gendering Effective Planning: Spatial Mismatch, Low-Income Women, And Transportation Policy" [63]	118	5.9
16	"Gender, Urban Space, And The Right To Everyday Life" [64]	107	15.29

Table 3. *Cont.*

R	Articles	TC	TCY
17	"Bodies, Borders, And Sex Tourism In A Globalized World: A Tale Of Two Cities—Amsterdam And Havana" [65]	103	4.48
18	"What's In A Label? The Relationship Between Feminist Self-Identification And "Feminist" Attitudes Among Us Women And Men" [66]	100	5.26
19	"The Two-Ness Of Rural Life And The Ends Of Rural Scholarship" [67]	100	5.88
20	"Engendering Social Capital: Women Workers And Rural-Urban Networks In Indonesia's Crisis" [68]	98	4.67
21	"Staging The Nation—Gendered And Ethnicized Discourses Of National Identity In Olympic Opening Ceremonies" [69]	97	4.62
22	"Working The Socio-Natural Relations Of The Urban Waterscape In South Africa" [70]	97	5.71
23	"Posthuman Agency In The Digitally Mediated City: Exteriorization, Individuation, Reinvention" [71]	93	13.29
24	"Feminist Digital Geographies" [72]	92	15.33
25	"Gender and Adolescent Relationship Violence—A Contextual Examination" [73]	88	4.19

* Abbreviations: R = rank; TC = total citations; TCY = total citations per year.

Further examination of the most locally cited WICR articles reveals a focus on more recent publications (Table 4). Fenster's [45] study on "The Right To The Gendered City" has garnered significant attention, emphasizing the necessity of scrutinizing patriarchal power to mitigate its long-term negative impacts on diverse individuals' access to urban areas. Following this, Truelove [50] and Beebeejaun [64] address gender, urban space, and the rights to the city, underscoring the critical role of gender considerations in urban planning for creating inclusive urban environments. The leading global and local citations collectively stress the importance of addressing gender inequality towards achieving sustainable and equitable urban futures, highlighting the urgent need for broader urban inclusion.

Table 4. The most influential locally cited articles of WICR studies *.

R	Articles	TC	LC/GC Ratio (%)
1	"The Right To The Gendered City: Different Formations Of Belonging In Everyday Life" [45]	27	15.5
2	"(Re-)Conceptualizing water inequality in Delhi, India through a feminist political ecology framework" [74]	18	7.5
3	"Gender, Urban Space, And The Right To Everyday Life" [64]	18	16.8
4	"The Twenty-First-Century Quest For Feminism And The Global Urban" [75]	15	26.8
5	"The Tyranny Of Gendered Spaces—Reflections From Beyond The Gender Dichotomy" [51]	11	5.3
6	"The No. 1 Ladies' Poultry Farm: A Feminist Political Ecology Of Urban Agriculture In Botswana" [76]	10	12.5
7	"Wounded Cities: Memory-Work And A Place-Based Ethics Of Care" [52]	10	5.0
8	"Feminist Forays In The City: Imbalance And Intervention In Urban Research Methods" [46]	9	28.1
9	"The Personal Is Political: Developing New Subjectivities Through Participatory Action Research" [53]	8	5.3
10	"Urban Political Ecology III: The Feminist And Queer Century" [77]	8	21.1
11	"Gender, Class, And Urban Space: Public And Private Space In Contemporary Urban Landscapes" [42]	7	8.8
12	"Nourishing Women: Toward A Feminist Political Ecology Of Community Supported Agriculture In The United States" [78]	7	8.6
13	"With, Against And Beyond Lefebvre: Planetary Urbanization And Epistemic Plurality" [79]	7	9.1
14	"From Protests To Politics: Sex Work, Women's Worth, And Ciudad Juarez Modernity" [80]	6	8.3
15	"Partnerships For Women's Safety In The City: "Four Legs For A Good Table" [81]	6	40.0
16	"Women, Communities, Neighbourhoods: Approaching Gender And Feminism Within Uk Urban Policy" [82]	6	27.3
17	"Does More Cycling Mean More Diversity In Cycling?" [59]	6	4.5
18	"Finding Mobility: Women Negotiating Fear And Violence In Mexico City's Public Transit System" [83]	6	10.5
19	Walking, Mothering And Care: A Sensory Ethnography Of Journeying On-Foot With Children In Wollongong, Australia" [84]	6	19.4
20	"Care-Full Justice In The City" [85]	6	9.1
21	"Cities Of Care: A Platform For Urban Geographical Care Research" [86]	6	15.4
22	"The Paradoxical Relationship Between Gender Inequality And Rape—Toward A Refined Theory" [87]	5	6.1
23	"Paradoxes, Protests And The Mujeres De Negro Of Northern Mexico" [88]	5	18.5
24	"Not Everyone Has (The) Balls: Urban Exploration And The Persistence Of Masculinist Geography" [89]	5	6.3
25	"Digging Into The Creative City: A Feminist Critique" [90]	5	9.8

* Abbreviations: R = rank; TC = total citations.

Meanwhile, co-citation analysis evaluates scientific articles, journals, and authors based on how often other researchers cite them. It complements the traditional publication metrics, such as impact factors, h-index, and publication count, and may indicate the research field's intellectual structure and evolution [91]. A co-citation network is established if two documents are cited in the same document. Research clusters may emerge when multiple authors co-cite the same pairings of papers, and the co-cited papers within these clusters may share a common theme. Figure 4 depicts a co-citation network map of the 50 most cited articles, which are categorized into nine clusters based on the Walktrap algorithm. At the same time, Table 5 provides a comprehensive list of the most effective references associated with each cluster and the detailed key content of each reference.

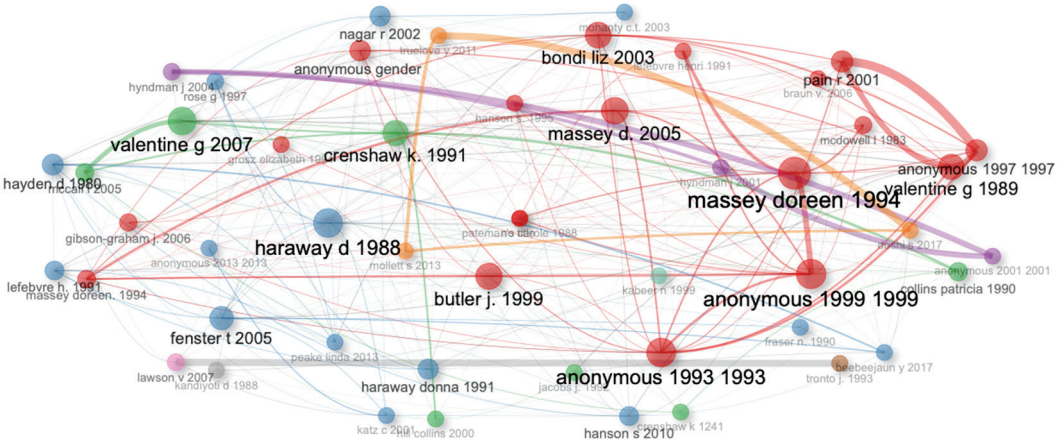


Figure 4. The co-citation network analysis of the 50 most cited articles of the total of 1144 articles generated from Bibliometrix. Each node represents an individual paper, the edges connecting them indicate co-citation relationships, implying that the related works are cited together in other academic papers, and the various colors represent clusters based on the Walktrap algorithm.

Table 5. Most effective references in WICR studies field by co-citation analysis of documents *.

Authors	Title	Key Content	BW	CS
Cluster 1 (in Red) Feminist Geography				
Massey D., 1994 [92]	"Space, Place, and Gender"	Highlights the dynamic nature of space, intersecting with social relations and gender. The book intertwines economic geography with feminist and postcolonial critiques, enhancing social theory debates. It advocates an open, provisional concept of "places", emphasizing identity and urban change ethics.	155.34	0.010
Valentine G., 1989 [93]	"The Geography of Women's Fear"	Highlights the male violence that influences women's spatial fear. Women's mental maps of fear limit public space use and reinforce gender stereotypes. The findings showed that patriarchy limits women's spatial use.	35.58	0.009
Bondi Liz, 2003 [94]	"Empathy and Identification: Conceptual Resources for Feminist Fieldwork"	Incorporates psychoanalysis into feminist fieldwork, emphasizing empathy and identification as key tools for analyzing power dynamics in research partnerships.	49.63	0.009
Cluster 2 (in Blue) Women's Role in Society and Gender Inequality				
Fenster T., 2005 [45]	"The Right to the Gendered City: Different Formations of Belonging in Everyday Life"	Critiques the Lefebvrian concept of the right to the city, emphasizing how patriarchal power dynamics influence women's daily experiences, sense of belonging, and involvement in urban settings.	43.22	0.008
Mohanty C.T, 2003 [95]	"Under Western Eyes Revisited: Feminist Solidarity through Anticapitalist Struggles"	Promotes reflective feminist scholarship, recognizing global injustices to foster transnational activism, critique global capitalism, and build cross-cultural solidarity for inclusivity.	12.06	0.008
Haraway D., 1988 [96]	"Simians, Cyborgs, and Women"	Discovers how gender, class, and society have shaped nature and science; contests scientific interpretations, emphasizes human–animal and organism–machine interactions, and analyzes cultural and natural limits blending with technology advancement; and criticizes gender inequality and its oppressive structures.	40.17	0.009

Table 5. *Cont.*

Authors	Title	Key Content	BW	CS
Cluster 3 (in Green) Intersectionality				
Valentine G., 2007 [97]	Theorizing and Researching Intersectionality: A Challenge for Feminist Geography"	Feminist geography that applies intersectionality to grasp gender, race, and sexuality interplay, urging deeper focus on power, social inequalities, and the significance of spatial dynamics in identity formation.	269.05	0.011
Crenshaw K., 1991 [98]	"Mapping the Margins: Intersectionality, Identity Politics, and Violence against Women of Color"	Emphasizes the need for an intersectional framework in effectively addressing violence against women of color, arguing for a more comprehensive understanding of social justice that accounts for the complicated realities of all individuals.	41.75	0.009
Mccall L., 2005 [99]	"The Complexity of Intersectionality"	Discusses three ways to investigating intersectionality: anticategorical, intracategorical, and intercategorical complexity, while emphasizing challenges and calling for methodological inclusion.	32.57	0.009
Cluster 4 (in Purple) Feminist Geopolitics				
Hyndman J., 2004 [100]	"Mind the gap: bridging feminist and political geography through geopolitics"	Argues for the integration of feminist and political geography through feminist geopolitics, with an emphasis on embodied responses to security, mobility, and violence at all scales.	36.69	0.008
Hyndman J., 2001 [101]	"Towards a feminist geopolitics"	Describes the primary steps in creating a feminist geopolitical framework, emphasizing the need for feminist and political geography to merge. A theoretical reorientation and practical application of feminist principles to geopolitical analysis that emphasizes human security, challenges entrenched public/private divides, and examines global politics mobility from a feminist viewpoint.	18.69	0.008
Cluster 5 (in Orange) Political Ecology				
Truelove Y., 2011 [74]	"(Re-)Conceptualizing water inequality in Delhi, India through a feminist political ecology framework"	A feminist political ecology that explores water inequities in India, examining community politics, sanitation, water compensation, and their impacts on daily life and rights through a lens of social diversity.	14.30	0.008
Doshi S., 2017 [102]	"Embodied urban political ecology: five propositions"	A feminist, anti-racist, postcolonial embodied urban political ecology that explores metabolism, social reproduction, intersectionality, emotion, and political subjectivity to broaden our understanding of environmental politics and potential transformation.	35.94	0.009
Mollett S., 2013 [103]	"Messing with gender in feminist political ecology"	A feminist political ecology that integrates gender for understanding race and racism. Postcolonial intersectional theory applied to race, gender, whiteness in Honduras, revealing complexities.	5.59	0.008
Cluster 6 Ethic of Care				
Tronto J., 1993 [104]	"Moral Boundaries. A Political Argument for an Ethic of Care"	Care encompasses preservation, including bodies and the environment. Tronto outlines four sub-elements: awareness, responsibility, competence, responsiveness; criticized for broadness.	0.00	0.006
Cluster 7 Geographies of Care				
Lawson V., 2007 [105]	"Geographies of Care and Responsibility"	Urges geographers to tackle market extensions, personal responsibility discourses, and public support withdrawals. Care ethics need to emphasize social construction and mutuality.	90.45	0.009

Table 5. *Cont.*

Authors	Title	Key Content	BW	CS
Cluster 8 Patriarchy				
Kandiyoti D., 1988 [106]	"Bargaining with Patriarchy"	Classic patriarchy refers to the cycle of women's submission to authority, affection, and approval. Challenges arise as women's options expand. Women's involvement in anti-feminist movements is attributed to the patriarchal bargain.	48.45	0.008
Cluster 9 Women's Empowerment				
Kabeer N., 1999 [107]	"Resources, Agency, Achievements: Reflections on the Measurement of Women's Empowerment"	Examines women's empowerment and life choices, contrasting instrumentalist advocacy with comprehensive understanding of individual choice and its components.	0.00	0.006

* Abbreviations: BW: degree of betweenness; CS: degree of closeness.

3.3. Changing Trends in WICR Studies

3.3.1. Popular Themes in WICR Studies

The study utilizes a clustering algorithm and regularization for co-occurrence network analysis of the top 10 KeyWords Plus, which comprises terms found in references but not in their corresponding titles, to identify the growth trend in WICR studies. The KeyWords Plus algorithm in Clarivate databases enhances cited-reference searches by identifying articles with common citations across different fields. Figure 5 illustrates the significant influence of the temporal dimension, as it reveals that gender, women, and politics consistently ranked as the top three keywords across various periods. One interesting observation is the significant rise in "gender", "women", "politics", and "city" occurrences, particularly after 2015. This spike corresponds with all United Nations members adopting the 2030 Agenda for Sustainable Development in 2015. The increased emphasis on gender equality (SDG 5) and inclusive cities (SDG 11, New Urban Agenda) have contributed to the observed trends as organizations and governments ramp up their efforts to fulfill the SDGs globally. Additionally, the terms "politics", "space", and "violence" appeared to grow positively over time, while the rise was not significant; however, they may be considered as emerging research directions.

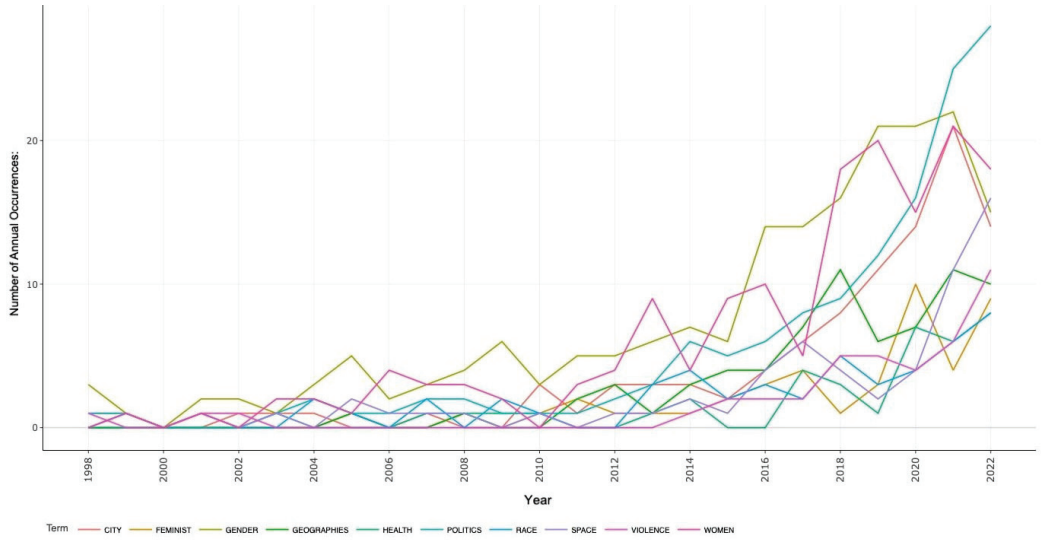


Figure 5. Growth trend of the top 10 KeyWords Plus generated from Bibliometrix.

3.3.2. Thematic Evolution in WICR Studies

The analysis employs two distinct measures: Callon centrality, indicating research field significance, and Callon density, measuring theme development [108]. Thematic evolution maps are divided into four quadrants, with the motor topics in the upper-right quadrant considered to be well developed and relevant. The core concepts in the lower-right quadrant are deemed significant but underdeveloped; the emerging or declining themes are seen as poorly or marginally developed; and the niche themes are rapidly developed. Figure 6 depicts thematic evolution across four periods from 1998 to 2022.



Figure 6. Thematic evolution map illustrates the author's keyword co-occurrence network clusters throughout four periods generated from Bibliometrix. Callon's centrality and density rank display co-occurrence network clusters as bubbles. Keyword occurrences in the cluster determine the bubble size. The X-axis depicts centrality (the degree of interaction of a network cluster in contrast to other clusters) and also indicates the significance of a theme. The Y-axis represents density (the internal strength of a cluster network), which can measure the theme's development [109].

In the early 20th century, the global feminist movement advocated for equal opportunities in politics, work, family responsibility, and sexuality. During the initial period (1998–2014), scholars favored clustered themes such as "identity-agency-difference", "intersectionality-black women-culture", and "public space-democracy-diversity". In the second period (2015–2019), WICR studies broadened to include subjects like "mobility-assemblage-ethics of care" and "ethnography-homeliness-narratives". Social reproduction and ethics of care remained central until the final period (2022), while the focus shifted to "place-reflexivity-ethnography" and "displacement-urban geography-Africa" in the third period (2020–2021). In 2022, inclusivity-related themes like "financial-digital-housing inclusion" emerged as fully developed. Future research may delve into niche themes

such as "informal settlement", "local government", "policies", "participation", "feminist theory", and "power relations".

The findings reveal shifting interests in WICR discussions and research over time. Despite feminist progress, women still encounter urban disadvantages compared to men. Scholars stress the urgency of promoting urban inclusivity and accelerating gender equality for a sustainable, resilient, and inclusive future. The field's future appears promising as scholars expand the thematic scope of WICR studies over 20 years.

Using the Bibliometrix R-package, we employed multiple correspondence analysis (MCA) to visualize the relationships between the top 50 author keywords in the WICR research and K-means clustering to identify groups of similar concepts, thereby improving keyword homogeneity within the map [31]. This method, commonly used for clustering alongside MCA, displays keywords in a two-dimensional plot, emphasizing relevant keywords and their associations and developing research trends [110]. Figure 7 depicts the resulting map, which uses the x-axis (16.61%) and the y-axis (15.54%) to reflect the proportion of total variation explained by each dimension. These percentages are derived using the eigenvalues associated with each dimension. In MCA, the eigenvalues represent the variation explained by each dimension [111]. The first dimension explains 16.61% of the variation, associated with feminist geopolitics and geography, while the second dimension explains 15.54%, associated with urban space and equal opportunities for women. Additionally, the conceptual structure map also offered fresh insights, categorizing the most frequently used keywords into five clusters, each highlighted in different colors indicating the main thematic areas of the WICR research: feminist perspectives in urban settings, socio-spatial and politico-ecological inclusion, urban violence and safety, housing, and terms related to race, sexuality, and class.

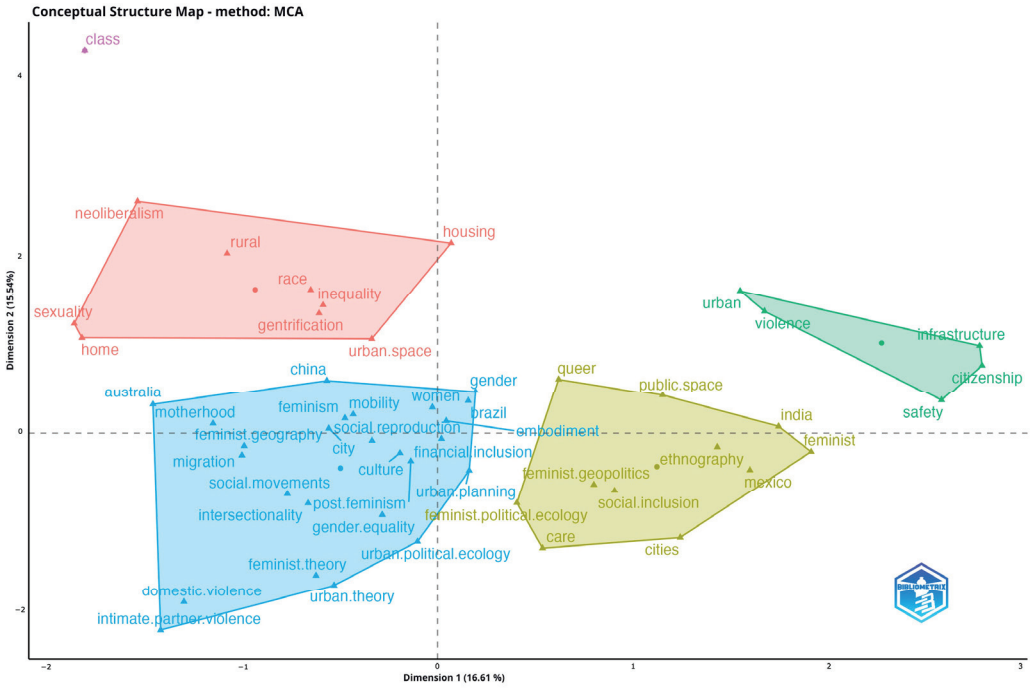


Figure 7. Conceptual structure map of the top 50 author keywords using the MCA method generated from Bibliometrix. The two dimensions retained from the MCA explain 32.15% of the total variance. Keywords are represented as points in a low-dimensional Euclidean space, where the proximity of points indicates the similarity in their usage across the dataset. K-means clustering creates 5 color-coded clusters.

Using the same dataset, the MCA method is used to generate a dendrogram that illustrates the hierarchical relationships among objects based on their similarities or dissimilarities. Figure 8 illustrates a dendrogram of correlation criteria among keywords in a

hierarchical framework. The keywords were classified according to their similarity using hierarchical clustering. The y-axis "Height" represents the distance between the cluster and the keywords. The chi-square distance is a common metric used in MCA. The height of each branch denotes the degree of dissimilarity between keywords or clusters: more dissimilar keywords or clusters are displayed higher, while more similar ones appear lower. The relationships between distinct keywords can be understood by observing the height and placement of the connecting lines. The two themes at the bottom of the dendrogram, "gentrification" and "equality", for instance, are highly similar and are thus linked by a short connecting line at a relatively low height. In the presented dendrogram, the dashed line is drawn at a height of 2. This line sets a merging threshold to count clusters. Clipping the dendrogram at a height of 2 can determine the number of clusters. In this case, approximately five clusters form and are coded in different colors. Clusters that merge at a height of around 1.5 are highly similar. In contrast, those merging at higher heights are less similar. This helps determine the optimal cluster size and theme hierarchy. The resulting map reveals five distinct clusters displayed in different colors. The primary cluster, highlighted in orange, addresses fundamental issues such as motherhood, migration, feminist geography, mobility, gender, embodiment, and urban planning. Other clusters intersecting at similar heights signify their significant impact and the evolving themes in WICR studies.

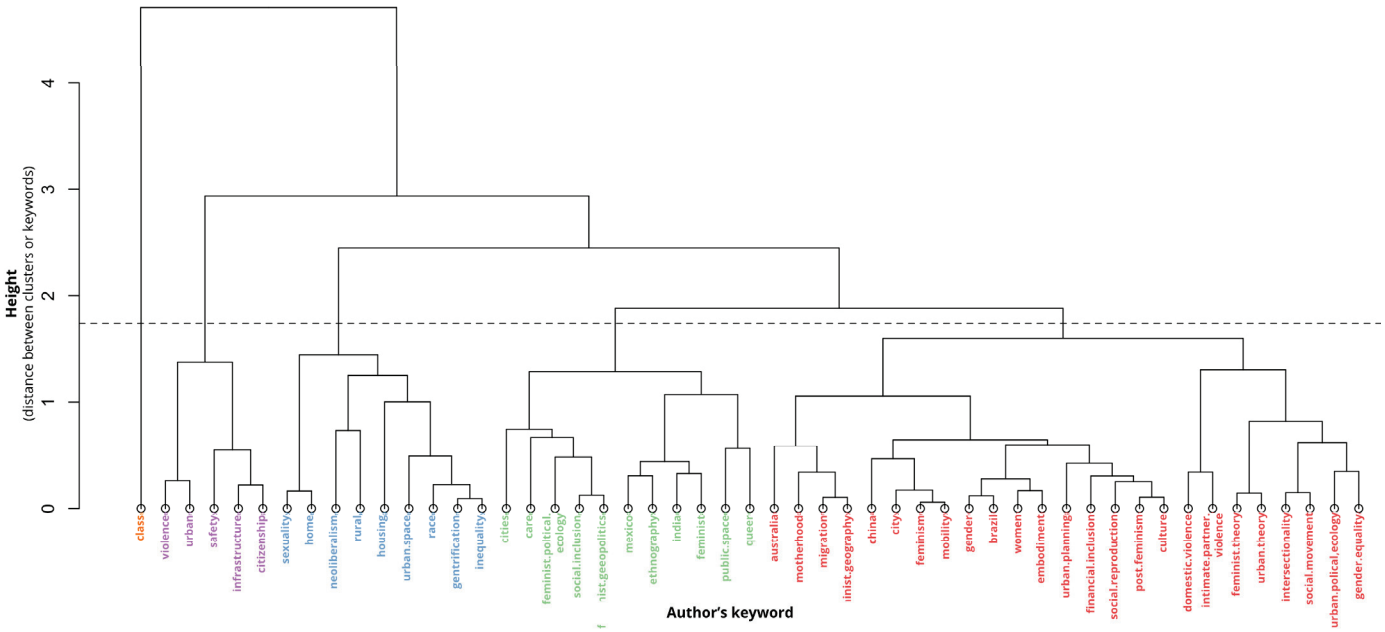


Figure 8. Dendrogram of the top 50 author keywords using MCA method generated from Bibliometrix. The x-axis indicates the data points being clustered, which are the author keywords, color-coded by cluster, while the y-axis reflects the distance at which clusters or keywords are merged during hierarchical clustering.

3.4. The Collaboration Pattern in WICR Studies

Collaboration and research partnerships can produce different levels of creativity and impact [112,113]. According to Ceballos et al. [114], research collaboration positively impacts production. WICR research has enhanced published co-authorship and national and institutional partnerships. Figure 9a shows the trajectory of international collaboration and country productivity correlation. The gradient of color indicates each country's article publication count. The thickness of the edges indicates the level of collaboration between countries. The figure shows that the USA is the most active contributor to WICR research, publishing 572 articles and showing evidence of strong international collaborations. The USA often collaborates with the UK and Canada (more than eight times each), followed by the UK, Mexico, Australia, China, India, and Ireland. Similarly, the United Kingdom

has a wide range of collaborations, most notably with India and South Africa, indicating a concentration on research ties with emerging economies. While the other nations have fewer collaborations, the figure highlights how crucial it is for countries to collaborate to progress scientific research in WICR, as some countries play a central role in the WICR research community.

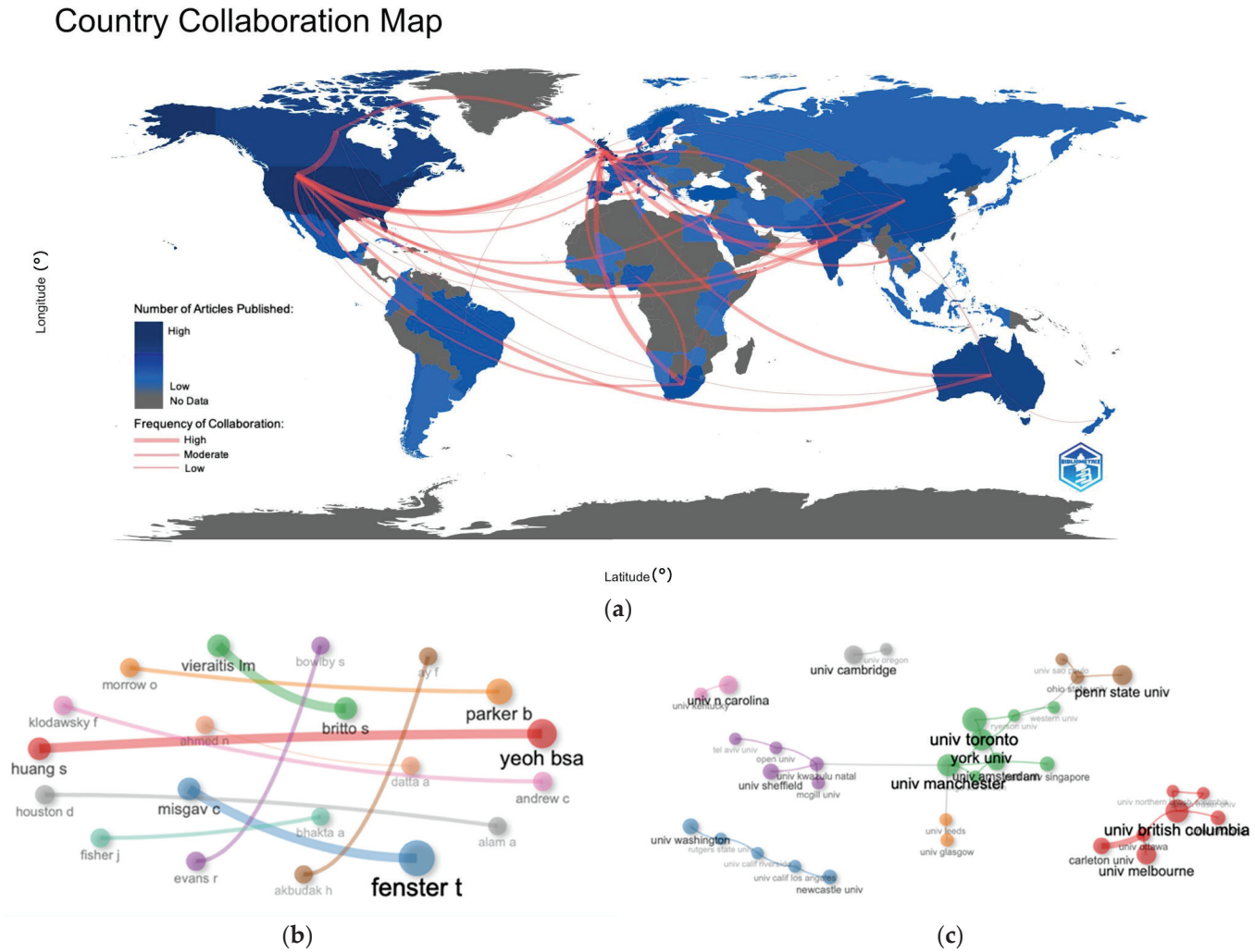


Figure 9. (**a**) Country collaboration network; (**b**) authors collaboration; and (**c**) institutional collaboration network generated from Bibliometrix. (The (**b**,**c**) networks include the 20 most active authors and the 34 most active universities contributing to the WICR studies. The edge thickness shows collaboration strength, the circle node size represents collaboration weight based on the number of publication counts, and the color represents clusters based on the Walktrap algorithm).

The author collaboration network illustrates the total number of co-authored papers. The network includes the 20 most active authors contributing to WICR research (Figure 9b). The nodes represent authors, with thicker edges suggesting more frequent collaboration and larger circle nodes presenting collaboration weight based on publication counts. Moreover, ten clusters were created using the Walktrap algorithm. Each color denotes a cluster of authors. Our findings show that collaborators from the same nation or region are common; the collaboration between Fenster T. and Misgav C. is the most central in the collaboration network, followed by Yeoh BSA. and Huang S.; the brown and pink cluster studies women-inclusive cities; the green–orange cluster addresses urban crime and violence; and the red cluster focuses on migrant workers, and the rest address infrastructure and politics.

Figure 9c shows the institutional partnership network. The size of the nodes reflects each institution's number of publications, and the edge thickness shows their collaboration strength. The figure depicts eight major research clusters created using the Walktrap algorithm, each denoted by a different color. The USA, UK, and Canadian universities dominate. The green cluster is the largest cluster, wherein the University of Toronto becomes the center of the collaboration network.

One of the issues that emerges from these findings is that the collaboration between countries, institutions, and collaboration topics still needs to be improved. International scientific collaboration may encounter challenges, such as a shortage of researchers in relevant fields, inadequate funding, restrictions on exchanging materials and data, and disparities in academic standards [115,116]. By addressing these issues, we anticipate that WICR studies may grow and attract global interest to address the issue of gender inequities in urban areas.

3.5. Defining the Term "Women Inclusive City"

The Sustainable Development Goals #5 and #11, alongside the New Urban Agenda, underscore the importance of gender equity and the creation of safe, resilient, and inclusive cities. These serve as fundamental references for urban geographers globally, offering a comprehensive framework to explore the intricate connections between gender, urbanization, and sustainability [117–119]. Incorporating gender equity into the SDGs and the New Urban Agenda underscores the inseparability of urban development from social justice and human rights principles. By focusing on gender equality within urban environments, these documents challenge the entrenched norms and power dynamics that foster inequality and exclusion, which particularly affect women and marginalized groups [120]. The idea of an inclusive city extends beyond mere rhetoric to the use of innovative methods and technologies that empower women and girls, enabling them to become proactive participants in urban development [121,122].

Although the term "women-inclusive city" is not explicitly defined in the articles, they address related concepts, like gender inclusivity within urban contexts, women-friendly cities, and the broader idea of inclusive cities. Some authors reference definitions of an inclusive city provided by the United Nations and the Asian Development Bank. Chang et al. [123] cite the United Nations' definition of an inclusive city as one where all individuals can actively and positively participate in the urban environment's opportunities, regardless of socio-economic status, gender, age, ethnicity, or religion. He connects the concept of inclusivity to the women-friendly city concept in Korea, explaining that the term arises from gender mainstreaming and equity, acknowledging that women and men experience the urban environment differently. Thus, he promotes gender equality in participation and benefit sharing, emphasizing women. Some others adopt the Asian Development Bank's definition of an inclusive city as one that equally values the needs of all its residents, creating a safe living environment with inexpensive and equitable access to urban and social services, as well as livelihood opportunities for everyone [121,124]. Varona [125] describes an inclusive city as user-friendly and a space that offers individuals the chance to develop skills for navigating challenges and engaging with diverse groups. Additionally, some authors also refer to cities of care where the city should embrace disability and disadvantaged people [126–131].

Our findings suggest that equality, accessibility, safety, democracy, female representation, and attention to ethics of care are all crucial factors a city should prioritize regarding its socio-economic and physical settings to create more inclusive cities for women. The most influential author in WICR studies, Beebeejaun [64], argues that recognizing multiple rights to the city and the contested publics that coexist within urban spaces can help identify more effective approaches to integrating diverse experiences into planning practices. Bondi's [42] work emphasizes the impact of emancipatory notions of gender on public and private places. It highlights the intertwining of gender and class, with traditional gender implications frequently associated with wealthy middle-class lifestyles. Other academic

researchers have established a connection between the idea of inclusive cities and both social sustainability and spatial accessibility. In their extensive work on the right to the city, they did not explicitly address gender in their conception of this right.

Nevertheless, equal access for all residents is encompassed by the right to the city [123]. Accessibility, a vital aspect of the physical structure of public areas, plays a crucial role in creating democratic spaces. It enables both locals and visitors to engage in community and civic events. Spaces that offer unrestricted access to diverse social groups serve as agents of transformation and nurture a communal sense of identity and belonging. A democratic public space, welcoming a myriad of diverse groups, mirrors the world's diversity by fostering an environment where different communities coexist harmoniously [132]. Access to urban public places is critical for city democracy, as it represents the expansion of democratic rights. For public spaces to be genuinely democratic, two principles must be recognized: first, the city must be inclusive of all its inhabitants, with human rights as a fundamental requirement; and second, these spaces must provide a variety of values and qualities to meet the diverse needs of their diverse users [133–136]. Some authors discussed the importance of user-friendliness [137], safety [138], and participation in decision making [139] in the built environment. While some authors discussed the accessibility to urban physical settings, such as public space [118,132,140] and transportation [119,141–143], others discussed the accessibility in economics, politics, and technology. In the context of the economic aspect, some authors argue that the city should support women's social reproduction of value [144], provide equal opportunities for employment [145], promote women's empowerment and entrepreneurship [146,147], and ease women's access to mobilize and pursue careers outside the home [148]. Additionally, in the context of politics, WICR should guarantee the freedom of women's representation in public [149], participation in policy and decision making [150], and equal opportunities to become leaders in society [151]. Lastly, digital technology is crucial for all women and girls to access information and communicate their perspectives. It helps to promote their inclusion, participation, and rights in society. Some authors believe that intersectional theory is essential for understanding how people live and function well in various urban settings because digital technology is deeply affected by social and spatial processes of exclusion, inclusion, and enrichment [152,153]. Furthermore, some authors discuss the challenges faced by women in accessing electricity and digital inclusion [154] and how women derive advantages from the implementation of technology [155].

Overall, although the term "women-inclusive city" is explicitly undefined, the prevailing literature consistently implies a city where women's rights are fully upheld, their needs are considered equally important, and their disabilities and disadvantages are accommodated. It ensures equal access for women to actively and positively engage in all facets of urban life, including its physical environment, economy, politics, and technology. This approach allows women to enjoy the same opportunities for self-development and representation as other genders, regardless of their socio-economic status.

4. Conclusions

Women have always suffered prejudice, which has limited access and opportunity in urban life. The critical importance of addressing these issues is recognized. Despite years of study, WICR studies keep expanding their scope, and the concept of "Women-inclusive cities" lacks a specific definition, highlighting the need for further equity-focused urban research. Through bibliometric analysis, we offer a comprehensive overview of WICR by analyzing its conceptual, intellectual, social, and descriptive dimensions, aiding academics and practitioners. A detailed analysis of WICR research published in WOSCC-indexed English articles from 1998 to 2022 was conducted, incorporating descriptive analysis and scientific mapping to trace the evolution and trends in WICR. Furthermore, systematic review approaches were employed to define the concept of a women-inclusive city.

In 1998, Bondi's [42] work in Urban Geography Journal featured the first WICR publication. This groundbreaking work explores how gender and class shape urban public

and private spaces, and it illuminates spatial equality and inclusivity, asking how cities may adapt to meet the different demands of their residents, while the most recent article challenges patriarchal ideals by portraying sex work as empowering for cisgender women, fostering social and economic resources. The annual growth of publications was not significant until the 2017 Women's March took place in the United States, which sounded a protest against Trump's misogynistic policies that threatened women's rights. Scholars worldwide began to focus more on women's rights and power dynamics in the cities, and the total publications each year in related subjects rose significantly.

Our study found that 44% of the top 100 cited papers over the previous three years have come from various empirical studies on mobility and active transportation, economic opportunities, ecology and climate justice, and digital technology. According to our study, scholars still use theoretical conceptions, surveys, and ethnographical investigations. Notable works include Truelove's [50] exploration of gender inequality in urban political ecology, Doan's [51] study of gendered space, and Till's [52] discourse on the ethics of care. The co-citations are organized into nine distinct categories and cover different aspects of scholarly discourse, exploring important topics, such as feminist geography, which looks at how gender influences experiences in different spaces; intersectionality, which examines how social identities and systems of oppression intersect; feminist geopolitics, which analyzes the gendered dynamics of power and politics on a global scale; and women's empowerment, which focuses on strategies and initiatives to enhance women's agency and autonomy in urban areas. The categorizations presented here provide a detailed understanding of the complex nature of the research in the field of WICR, offering valuable insights for future exploration and analysis.

Thematic evolution maps have revealed a swift expansion in WICR research interests and have especially highlighted urban women's disadvantages. Through the KeyWords Plus algorithm, we have observed a modest yet notable rise in studies focusing on "politics", "space", and "violence". Despite their slight growth, these areas are emerging as significant future research directions in WICR. Additionally, our analysis forecasts a broadening research landscape from 2023, shifting towards topics like "informal settlement," "local government", "policies", "participation", "India", "feminist theory", and "power-relation". The study landscape is broadening as interest in gender, urban policy, and societal structures grows across geographical and cultural contexts.

Meanwhile, we found a clear tendency for researchers from the same geographical backgrounds or regions to co-author papers. This pattern suggests a somewhat closed-off approach to collaboration, which may hinder the exchange of ideas and methods across different intellectual domains. The clusters identified in this analysis primarily address significant topics, including the feminist interpretation of urban spaces, the impact of urban crime and violence on women, the difficulties experienced by migrant workers, and the connections between infrastructure development and gender politics. The results emphasize the significance and immediacy of promoting greater international diversity in collaborative endeavors. Promoting cross-border collaboration is not only advantageous but also essential for enhancing the research domain of WICR. Collaborations between different cultures and academic disciplines can bring new viewpoints, creative approaches, and a more comprehensive examination of gender dynamics in urban environments.

Although we found that the term "women-inclusive city" does not have a precise definition, the available literature on the topic presents a coherent and persuasive vision. The text briefly overviews an urban environment that prioritizes the recognition, protection, and promotion of women's rights. In such cities, women's particular needs and viewpoints are treated equally with those of all other citizens, ensuring that gender inclusion is included in all aspects of urban design and government. Efforts must be made to recognize and tackle the unique challenges, disabilities, and disadvantages that women may encounter. These solutions should seamlessly integrate into the city's infrastructure and social systems. Embracing a comprehensive and interconnected approach creates a space where women can confidently pursue equal opportunities for personal and professional growth,

alongside men and individuals of other genders. This indicates a transition towards a fairer urban society, where the efforts and ambitions of women are recognized and encouraged regardless of their socio-economic status.

This review, conducted using the R-package Bibliometrix, provides an in-depth understanding of the trends, impact, collaboration, and visibility in WICR studies. It underscores the existing knowledge gap and emphasizes the need for further research to address the challenges women face in urban life, such as ethics of care, digital inclusion, geopolitical diversity, and queer issues. It also highlights the urgency of ensuring equal access for women to achieve a women-inclusive city. An analysis spanning two decades has illuminated this domain's social and intellectual structure, unveiling emerging subjects and settings and potential partnerships for future scholars. Importantly, by defining the term "Women Inclusive City", this study fills a conceptual gap, providing valuable insights for researchers and policymakers engaged in WICR studies. However, this study has several limitations. The first significant limitation is the restriction of keywords and selection criteria. Upon conducting a thorough keyword analysis, we discovered that WICR studies extend beyond the keywords set in this study, encompassing broader terms such as "Gender Equal Cities" and "Care Cities". Future studies should consider incorporating these keywords for a more holistic and accurate view of WICR study trends. Secondly, an inherent bias exists in the data sources used. This study relies on the Web of Science Core Collection, suggesting that future research should consider expanding the bibliographic source databases for a more comprehensive and accurate representation of WICR studies. Thirdly, this bibliographic analysis was primarily conducted using a quantitative method. Future research could benefit from a thorough qualitative approach to validate or expand upon the findings of this study, considering that the interpretation of selected publications in the qualitative analysis may vary among researchers due to differences in expertise.

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