buildings

MDPI

Article

Optimizing Public Space in High-Rise Residences: A Whole Life Cycle Perspective with Kruskal Algorithm—A Case Study of a Shanghai High-Rise Residential Project

Jingwen Li †, Yaodong Han †, Qinyi Li * and Daizhong Tang *

School of Economics and Management, Tongji University, Shanghai 200092, China; jingwen_li0910@163.com (J.L.); hyd@tongji.edu.cn (Y.H.)
* Correspondence: qinyi.lee@outlook.com (Q.L.); tdzhong@126.com (D.T.)
† These authors contributed equally to this work and should be considered co-first authors.

Abstract: In response to the intensification of urbanization, characterized by increasingly dense land use, the proliferation of high-rise residences has emerged as a predominant housing solution, particularly evident in developed cities like those in China. With a primary aim of enhancing the residential living environment within high-rise structures, this study advocates for a comprehensive whole life cycle perspective. By employing digital technology and conducting experiments centered on a representative case study, this paper focuses on optimizing the functional layout of public activity spaces within high-rise residential projects. Specifically, this article aims to address challenges such as the inadequate configuration and articulation of various public spaces, along with the underutilization of peripheral activity areas. Central to the optimization efforts is the utilization of the Kruskal algorithm, which enables the analysis of flow lines and functions, ultimately leading to the derivation of optimal solutions. Through a detailed analysis of our case study, this paper provides actionable insights into enhancing the feasibility and effectiveness of public spaces within high-rise residential projects. Recognizing the pivotal role of public space layout in shaping residents' living experiences, the importance of addressing this issue early in the design phase was emphasized. By integrating scientifically driven digital technology solutions, smart, inclusive, and convenient communities that cater to the diverse needs of their inhabitants are aspired to be created.

Keywords: high-rise residence; public space; Kruskal algorithm; whole life cycle theory

Citation: Li, J.; Han, Y.; Li, Q.; Tang, D. Optimizing Public Space in High-Rise Residences: A Whole Life Cycle Perspective with Kruskal Algorithm—A Case Study of a Shanghai High-Rise Residential Project. *Buildings* **2024**, *14*, 1769. https://doi.org/10.3390/buildings14061769

Academic Editor: John C. Brigham

Received: 12 May 2024
Revised: 5 June 2024
Accepted: 8 June 2024
Published: 12 June 2024

1. Introduction

With the acceleration of urbanization, the intensifying contradiction between population growth and available land resources necessitates innovative solutions to address residential demands, particularly in the core areas of large cities. Consequently, high-rise residences have gradually supplanted low-rise and mid-rise structures as the predominant form of housing in developed urban centers [1].

Residences and communities serve as foundational spaces for human life and activities [2], while simultaneously balancing economic considerations and operational efficiency. However, pertinent studies indicate that the efficiency of public space utilization in high-rise residences significantly lags behind that of low-rise and mid-rise residences [3]. These spaces fail to adequately accommodate the increasingly diversified and personalized spatial needs of urban residents [4].

Notably, the real-time interaction facilitated by smart city initiatives can significantly enhance the spatial value of public spaces within high-rise residences. Ensuring a participatory culture is crucial, involving stakeholders and leveraging the existing cultural momentum to bolster public engagement [5,6]. Simultaneously, enhancing the convenience and quality of life for community residents is essential, with a focus on coordinating multiple stakeholders and fostering social initiative to meet people's aspirations for a better life [7].

In an urban context, public space denotes open areas accessible to the public, primarily utilized for the daily and social activities of urban residents [8]. The public spaces within future residential developments will gradually assimilate into the broader urban public space system. Numerous scholars have made notable contributions to research concerning public spaces in residential communities, for example, necessitating a sustained connection and clear boundaries [9] and emphasizing the importance of material environmental variables [10]. Furthermore, amidst the burgeoning development of smart cities, an increasing number of scholars are delving into research pertaining to the application of digital technology in urban public spaces [11]. However, the existing research on urban public spaces predominantly concentrates on the physical attributes of urban environments and resident activities, often overlooking the distinctive features of public spaces within high-rise residential contexts.

The research findings, derived from the trajectory of social development, indicate that as economic growth transitions into a new incremental stage, the potential for a smart community system with virtual and real interactions looms on the horizon, and leveraging digital technology to achieve the early design optimization of high-rise residential common rooms from the perspective of smart city initiatives and augmenting the sense of happiness and belonging in high-rise residential public space research will constitute important trends in the future [12]. Furthermore, considering research methodologies, as humanistic urban practices advance, the integration of theory encompassing building project life cycle management, the utilization of graph theory algorithms, simulation modeling, and the establishment of interdisciplinary and multi-level research methods will inevitably emerge as essential trends in future high-rise residential public space research.

This paper aims to delve into residents' latent demands and scrutinize the primary issues and their underlying causes in the current public spaces of high-rise residences. Utilizing the graph theory Kruskal algorithm and Anylogic, the spatial structure of high-rise residential projects is simulated and optimized. Based on the findings, key challenges and areas necessitating optimization for public spaces in high-rise residences are pinpointed, and effective recommendations for enhancing the public space of high-rise residential areas from the perspective of smart cities are proffered. The practical significance of this paper lies in enhancing residents' happiness and satisfaction through spatial layout optimization, showcasing the fusion of community humanities and digital technologies within the future smart community system of virtual and real interactions.

2. Methodology

2.1. Minimum Spanning Tree (MST)

The minimum spanning tree (MST) is a fundamental concept in graph theory, particularly relevant to greedy algorithms in the domain of data structures and algorithms. Graph theory, at its core, deals with mathematical principles and research methodologies concerning graphs, composed of vertices and edges. Greedy algorithms, on the other hand, are optimization algorithms that seek to find globally optimal solutions by making locally optimal choices. Specifically, within the context of an undirected network, the minimum spanning tree is a tree that spans all the vertices of the network while minimizing the sum of edge weights. It is often referred to as the minimum cost tree in graph theory. Several algorithms exist for finding the minimum spanning tree, including Kruskal's algorithm, Prim's algorithm, Sollin's algorithm, and the cycle-breaking method [13].

Among these algorithms, Kruskal's algorithm stands out for its wide applicability in cost optimization. Kruskal's algorithm offers several advantages. Firstly, it can be applied to both directed and undirected graphs, making it versatile for various types of network structures. In contrast, Prim's and Sollin's algorithms are generally applicable only to undirected graphs. Moreover, Kruskal's algorithm supports parallelization, leading to better average time complexity performance. This capability allows for the efficient utilization of parallel computing, especially beneficial for large-scale graph processing, whereas Prim's algorithm is generally more difficult to parallelize. Additionally, the implementation of Kruskal's algorithm is relatively straightforward, with clear and comprehensible logic, making it easier for engineers and developers to adopt in practical applications. Given that the research problem prioritizes efficiency and general applicability, the advantages of Kruskal's algorithm align well with these requirements.

Numerous scholars also have conducted research on its effectiveness. For instance, Hua explored the optimization of e-commerce logistics distribution schemes using Kruskal's algorithm for the minimum spanning tree, validating its feasibility in logistics distribution [14]. Similarly, Huang investigated the optimization of public transportation networks leveraging graph theory and Kruskal's algorithm, achieving favorable outcomes [15]. Wang and He delved into optimizing transportation planning routes using Kruskal's algorithm for the minimum spanning tree, demonstrating notable improvements in transportation route efficiency compared to actual transportation samples [16].

2.2. Pedestrian Traffic Simulation Technology

Pedestrian traffic simulation technology plays a pivotal role in dissecting complex traffic issues within urban design, employing simplified mathematical models to tackle intricate traffic systems and furnish data support for subsequent urban design processes [17]. Fruin's publication, "Pedestrian Planning and Design," stands as a seminal work, establishing the theoretical bedrock for pedestrian flow by scrutinizing the correlation between average walking speed and crowd density, and introducing concepts such as service level [18]. Presently, scholars worldwide have delved deeply into pedestrian traffic simulation models, with the social force model emerging as one of the most widely utilized and acclaimed models for its accuracy and realism [19]. This model delineates and analyzes these relationships through the notion of social force, effectively simulating interactions among pedestrians in dense urban settings and their interactions with the environment.

In addition, the simulation software utilizing the social force model encompasses Vissim, SimWalk, Anylogic, Massmotion, and others [20]. Notably, Anylogic stands out as a multi-method modeling simulation platform that intricately embeds multi-agents into a social force model system, thereby adeptly delineating the movement patterns of pedestrian traffic and realistically capturing various scenarios, parameters, and interactions between individuals and their environment [21]. The simulation workflow in Anylogic entails drawing a spatial environment map and defining pedestrian behavior processes. This involves a series of specific simulation modeling steps, including on-site investigations, spatial mapping, behavior definitions, simulation debugging, and data output [22].

Indeed, numerous scholars have made significant advancements by leveraging Anylogic software to study spatial streamlines. Feng successfully optimized a dynamic battery logistics system through the Anylogic simulation software [23]. Ding et al. conducted streamline simulation modeling for concourses in rail transit stations using Anylogic, proposing optimization strategies for equipment layout and evaluation [24]. Tang simulated and verified the evacuation of large-space structures like sports stadiums using Anylogic, providing optimization strategies for spatial streamline evacuation [25]. Chen utilized Anylogic to simulate and optimize public space streamlines in intercity underground stations, proposing pertinent station optimization strategies [26].

3. Empirical Experiment

From the perspective of the entire life cycle, the optimization of public space should be contemplated from the design stage, encompassing spatial and functional requirements. However, some issues persist in optimizing the functional layout of public activity spaces in a high-rise residential project in Shanghai, including the insufficient configuration and articulation of various public spaces and a low utilization rate of peripheral activity spaces. In the process of optimizing the layout, the Kruskal algorithm is employed as an intelligent technology to analyze flow and function, ultimately yielding an optimal solution.

Drawing upon intelligent technology throughout the entire life cycle, the post-optimized scheme becomes more reasonable and feasible. In the post-optimized scheme, the east and west spaces are more closely interconnected, enhancing space utilization. Concurrently, the capacity of activity becomes more reasonable, with an overall balanced population flow density. The design intention of "double vitality circulation and double central garden" is effectively achieved, and spatial accessibility is significantly improved.

3.1. Optimization in Design Phase

Situated at the intersection of Lianyang Road and Huanghai Road in a certain district of Shanghai, a high-rise residential project is tailored to meet the demands of the rigid demand group, with a primary focus on enhancing living conditions. Embracing a modern architectural style, the project comprises 18 floors, with main unit types consisting of 100 m^2 three-bedroom, two-living room, two-bathroom units and 125 m^2 four-bedroom, two-living room, two-bathroom units. Spanning a land area of 41,576.9 m^2, the project boasts a total construction area of 91,469.18 m^2, featuring a plot ratio of 2.2, a greenery ratio of 0.35, and a planned total of 948 households.

The optimization of the public space design phase for the high-rise residential project in Shanghai revolves around considering the pertinent connotations of service value. This process entails strengthening customer demand orientation, organizing the functions of public space activities, optimizing the overall structure of public spaces, and leveraging digital technology to enhance accessibility. Subsequently, the feasibility and effectiveness of the post-optimized design are scrutinized through simulation.

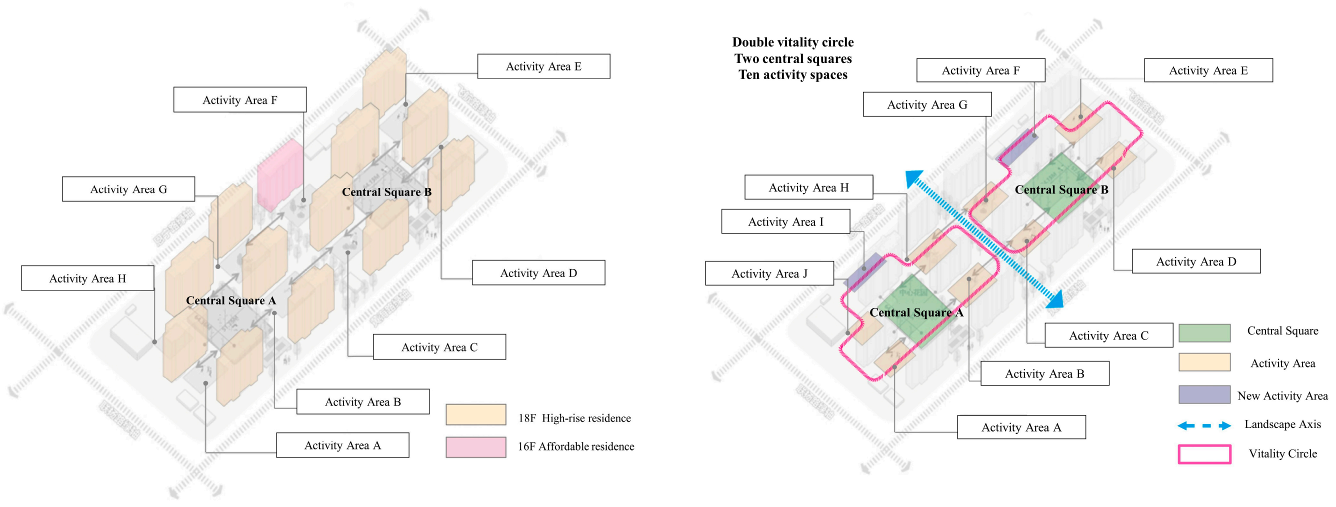
While the public space design of the high-rise residential project in Shanghai has already taken shape, encompassing well-designed aspects such as product distribution, activity spaces, and homecoming sequences, refinement is still warranted, particularly in the details. This includes optimizing spatial structures, organizing activity functions, and improving the accessibility of public space functions.

3.1.1. Optimization of Spatial Structure

A particular high-rise residential project in Shanghai has initially outlined the structure of public spaces, presenting a layout featuring "two central gardens and eight activity spaces." However, due to constraints imposed by planning conditions, the project is divided into two public spaces, namely, the east and west communities, with a natural north–south landscape axis running through the middle.

Upon re-examining the overall project plan, the author proposes a planning optimization scheme of "dual dynamic rings, two central gardens, and ten dynamic spaces." Firstly, the dual dynamic rings are introduced to address insufficient planning conditions, organizing the public spaces of the east and west communities, each centered around a central garden, with two landscape rings connecting five activity spaces in each high-rise residential public space. Secondly, two central gardens are positioned at the center of the east and west public spaces, reinforcing spatial centrality and enclosure. Lastly, the ten activity spaces are arranged around each central garden in the east and west public spaces.

The original plan had four activity spaces in each area, but through an in-depth exploration of the overall plan, the author identified the possibility of adding activity spaces on the north side of the plan, adjacent to Enning Road. As a result, an additional activity space is proposed in each of the east and west areas, totaling two new spaces. This is illustrated in Figure 1.



(**a**) Pre-optimization (**b**) Post-optimization

Figure 1. (**a**) Pre-optimization of public space; (**b**) post-optimization of public space.

3.1.2. Activity Function Sorting

As depicted in Figure 2, considering the project encompasses 12 areas suitable for activity function placement, it becomes imperative to assess the spatial basic conditions of these areas in alignment with planning requirements. The initial plan includes additional children's activity areas and elderly activity areas in the central squares of the east and west. Consequently, the project boasts a total of 14 designated areas (from A to N) for activity functions. The allocation of activity functions to edge activity spaces should be tailored to specific circumstances [27]. For instance, smaller spaces like A, B, C, J, and L could be designated for leisure and communication functions, while a larger space like K could incorporate functions such as a sub-center square based on the overall plan. The details are delineated in Table 1.

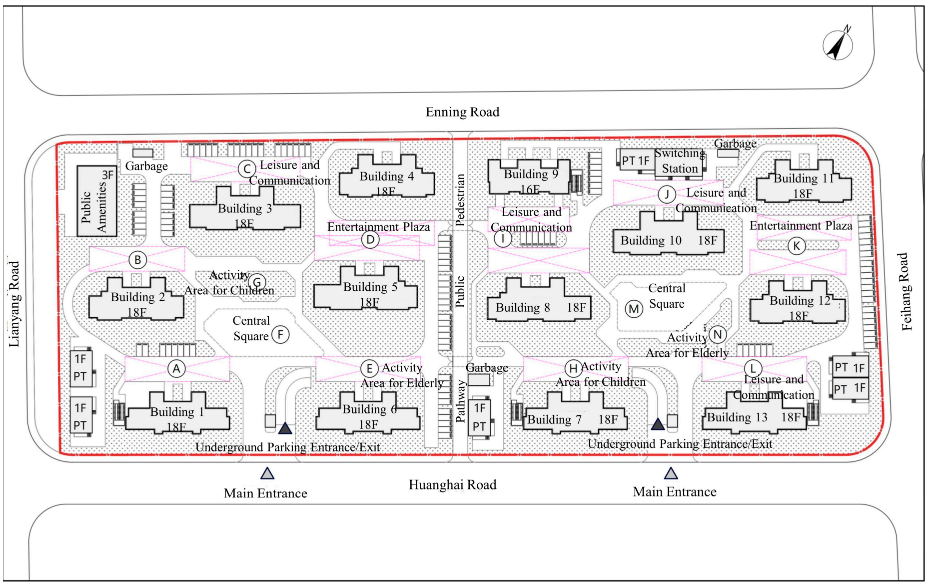


Figure 2. The master plan and distribution of public activity functions.

Table 1. Changes in function and location of activity space.

Functional Classification	Function of Space	Specifically Includes	Remarks
Leisure and communication space	Communication at leisure	A, B, C, I, J, L	Space function remains unchanged
	Cultural plaza	D, K	Increase recreation facilities
	Central square	F, M	Combined with fire climbing site
Sports and fitness space	Activity space for the elderly	E, N	Increase recreational space
Care space for the old and young	Children's activity area	G, H	Space function remains unchanged

A particular high-rise residential project in Shanghai has preliminarily outlined the activity functions of public spaces, highlighting two urgent optimization aspects. Firstly, there is a necessity to explore whether additional public spaces can be incorporated into the project. Secondly, the public space plan lacks detailed arrangements for activity functions, potentially resulting in a mismatch between activity functions and residents' latent needs. By combining activity function arrangement principles with spatial basic conditions, the main issues and solutions for optimizing the activity function layout in the public spaces of the Shanghai high-rise residential project can be outlined as follows:

1. Insufficient configuration in both east and west public spaces

The initial plan treats the east and west public spaces as a unified entity for activity function allocation. However, this approach may result in situations where residents must traverse pedestrian public passages to access certain activity functions, thereby potentially reducing the efficiency of public space activity function utilization.

To address this issue, the configuration of activity functions in public spaces should consider the division caused by pedestrian public passages. This entails ensuring that the core activity functions in the east and west public spaces are consistent, thereby improving the activity accessibility of pedestrians [28]. Complete activity functions for leisure, communication, sports, fitness, and care for the elderly and children should be provided, enhancing the ability of each public space to meet residents' needs.

2. Inadequate connection between the east and west public spaces

The connection between the east and west public spaces is lacking in the project. Moreover, actual activity functions are not designated for areas D, E, H, and I, potentially diminishing the efficiency of both public spaces in subsequent use.

Activity function planning for public spaces should prioritize considerations for enhancing the connection between the east and west areas. By implementing suitable functions in areas D, E, H, and I, the linkage between the two can be strengthened, thus improving residents' efficiency in utilizing public spaces and subsequently enhancing satisfaction.

3. Underutilization of edge activity spaces

The preliminary plan of the project assigns edge activity spaces A, B, C, J, K, and L with distinct purposes. However, this allocation may diminish the appeal of these public spaces to residents, potentially leading to an overall decrease in public space efficiency.

3.1.3. Functional Accessibility Optimization of Public Space

Using the Kruskal algorithm to formulate an optimization model begins with computing the straight-line distance matrix derived from the linear distances between building, activity function, and building–activity function pairs [29]. Subsequently, assigning distance values to each edge yields corresponding distance weights, thereby establishing an ideal distance abstraction graph for the public space model of a high-rise residential project in Shanghai.

Utilizing the ideal distance abstraction graph depicted in Figure 3, the application of the Kruskal algorithm in graph theory facilitates the derivation of the corresponding minimum spanning tree. This tree encapsulates the shortest paths devoid of cycles within the ideal distance abstraction graph.

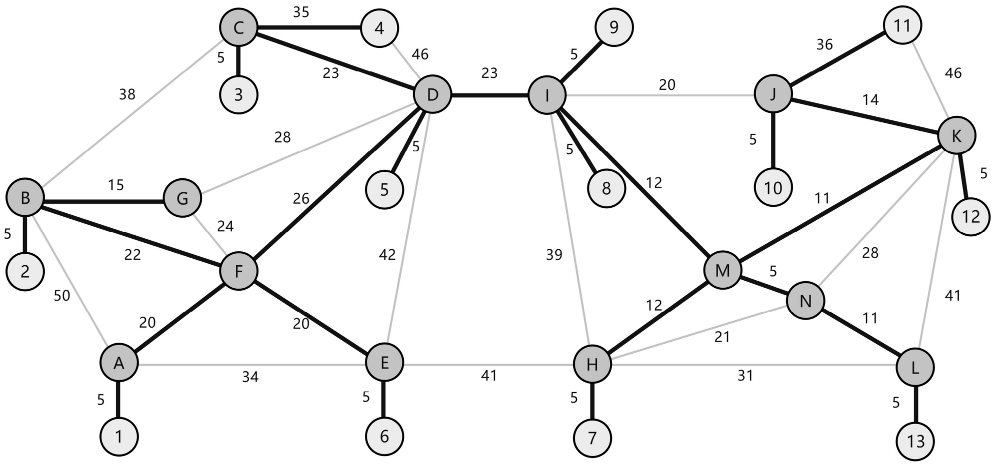


Figure 3. The ideal distance abstraction graph for public space. **Note**: Circles with numbers indicate buildings; circles with letters indicate spaces; values on line segments indicate distances.

The Kruskal algorithm functions by incrementally incorporating edges into the spanning tree, prioritizing edges based on their weights in an ascending order, while ensuring that the addition of any edge does not result in the formation of a cycle. Initially, the algorithm arranges all edges of the graph in a non-decreasing order of their weights and initializes an empty minimum spanning tree. Subsequently, it iterates through the sorted list of edges, evaluating each edge sequentially. Upon considering an edge, the algorithm examines whether its inclusion in the current spanning tree would result in the formation of a cycle. If no cycle would be created, the edge is incorporated into the minimum spanning tree. The algorithm halts its execution when all edges have been examined, or when the minimum spanning tree contains V-1 edges, where V represents the number of vertices in the graph. For the specific experimental design, it is stipulated that the tuple (1, A, 5) denotes the connection between Building 1 and Activity Space A, with 5 representing the distance between the two buildings. The detailed process unfolds as outlined below [29]:

1. According to the weights of edges in the ideal distance abstraction graph for public space in the high-rise residence in Figure 3, sequentially add (1, A, 5), (2, B, 5), (3, C, 5), (5, D, 5), (6, E, 5), (7, H, 5), (8, I, 5), (9, I, 5), (10, J, 5), (12, K, 5), (13, L, 5), (M, N, 5), (L, N, 11), (M, K, 11), (H, M, 12), (I, M, 12), (J, K, 14), (B, G, 15), (A, F, 20), (E, F, 20) to the minimum spanning tree. When adding (I, J, 20), (H, N, 21) produces a cycle, skip this edge.
2. Continue by adding (B, F, 22), (D, I, 23), (C, D, 23) to the minimum spanning tree. When adding (G, 4, 24) produces a cycle, skip this edge.
3. Add (D, F, 26) to the minimum spanning tree. When adding (D, G, 28) produces a cycle, skip this edge.
4. Skip (K, N, 28), (H, L, 31), (A, E, 34).
5. Add (4, C, 35), (11, J, 36) to the minimum spanning tree. All vertices are added to the minimum spanning tree at this point.

Afterward, overlay the cycle-free shortest paths (Kruskal minimum spanning tree) and the total graph of the project. The adjustments to the public space in the project are shown in Figure 4.

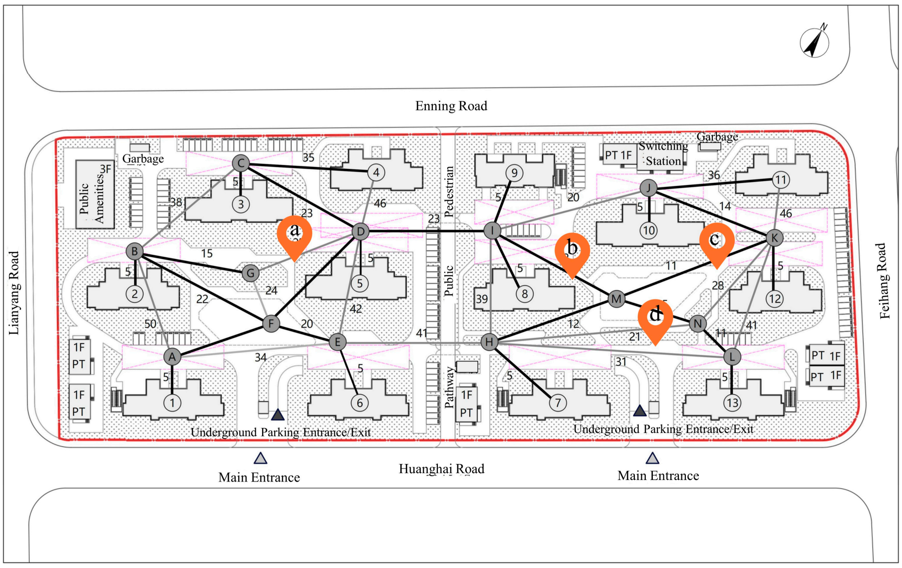


Figure 4. The adjustments to public space.

Based on the outcomes derived from Kruskal's algorithm, the significance of cycle-free shortest paths is underscored, indicating high potential for accommodating heavy pedestrian flow and facilitating efficient passage. Moreover, in light of "dual dynamic rings, two central gardens, and ten dynamic spaces", it is imperative for the plan to enhance accessibility to all activity areas, ensuring comprehensive connectivity and seamless movement throughout the space. The main adjustments are as follows:

1. The narrow pedestrian pathways a, b, and c in the total graph should be widened to match their potential pedestrian flow. The application of Kruskal's algorithm necessitates the establishment of wide pathways to connect activity areas F and D. The initial design plan indicates the presence of a narrow path, insufficient for accommodating potential pedestrian flow adequately. To fulfill the objectives of facilitating movement between the two vitality circles, widening the path becomes imperative.
2. A pathway at location d (between the elderly activity area N and leisure and communication area L) should be added to strengthen the connection between activity spaces L and N. In the eastern area, the pathway linking areas M, N, and L stands as the sole connection. Given the substantial pedestrian flow pressure experienced in area N, it becomes imperative to extend the pathway adjacent to area M. Introducing a new pathway, denoted as pathway d, emerges as a viable approach to alleviate the pressure and enhance connectivity.

3.2. Evaluation Strategy Based on Anylogic Simulation

3.2.1. Parameter Setting

The project offers four main types of units: 89 m^2 three-bedroom, two-living-room, one-bathroom (approximately 15% of the total), 100 m^2 three-bedroom, two-living-room, two-bathroom (approximately 65%), 125 m^2 four-bedroom, two-living-room, two-bathroom (approximately 11%), and 60 m^2 affordable housing (approximately 9%), totally 948 units.

For the parameter settings of public space simulation in a high-rise residential project in Shanghai, the resident composition, walking speed, and initial flow rates need to be determined based on the corresponding residential situations. As the project is in the schematic design phase, the age and gender composition of the residents must be calculated according to the target demographic and product mix.

In total, there are 948 units in such a project. At the same time, the project offers four main types of units:

1. 89 m^2 three-bedroom, two-living-room, one-bathroom (approximately 15%);
2. 100 m^2 three-bedroom, two-living-room, two-bathroom (approximately 65%);
3. 125 m^2 four-bedroom, two-living-room, two-bathroom (approximately 11%);
4. 60 m^2 affordable housing (approximately 9%).

Considering that the main target audience is the demand-improvement group, and for simulation purposes, the maximum carrying capacity of public spaces needs to be considered. It is recommended to calculate based on the scenario with the highest number of people. Please refer to the attachment for the specific calculation process. The final estimation of resident composition for the Shanghai high-rise residential project can be obtained by integrating calculations of total residents, product distribution, and living situations. Combining references for residents' walking speeds, the walking speeds for children and adolescents, as well as young, middle-aged, and senior adults, are collectively calculated, assuming an equal male-to-female ratio among residents [30], as shown in Table 2.

Table 2. Walking speed of residents at different ages.

Group of Residents	Calculate the Probability of Number (Person)	Distribution	Average Walking Speed (m/s)	
			Male	Female
Children and adolescents	972	0.22	1.36	1.28
Young people, young adults, and middle-aged groups	1896	0.43		
Old-age group	1584	0.35	1.2	1.12

3.2.2. Behavioral Modeling

The behavioral modeling analysis of residents' choices for public space activities is based on the following assumptions:

1. Each resident utilizes a public space activity in high-rise residential buildings only once a day.
2. Residents have an equal probability of choosing activities related to elderly care, physical fitness, and entertainment/leisure in public spaces, each being 1/3.
3. The probability of residents choosing an activity space for elderly care is inversely proportional to the distance. The correlation between probability and distance may manifest in diverse scenarios; however, within a specific residential context, distances typically do not exceed 1 km. Given this relatively short distance, it is common for two factors to exhibit an inverse relationship [31]. The probability calculation formula from point P to point A is as follows:

$$\mathrm{P(a)} = \frac{1}{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}} \times \frac{1}{a}, \tag{1}$$

where a is the distance between point P and point A, b is the distance between point P and point B, and c is the distance between point P and point C.

The behavioral process of residents selecting public space activities is outlined as follows: all residents residing in the high-rise residential project have an equal probability of visiting three types of spaces, including spaces for caring for the elderly and young, spaces for sports and fitness, and spaces for entertainment and leisure. Both the central square and the cultural square feature certain sports and fitness functions, and the intersection of functions between spaces is not considered here. Each type of space is divided into west and east areas separately. Furthermore, the probability of residents choosing to visit public spaces is inversely proportional to the distance.

By combining the aforementioned analysis of residents' choices for public space activities, the estimated probabilities of residents selecting activity spaces in a high-rise residential project in Shanghai can be obtained. These calculated probabilities will guide the subsequent logical modeling in Anylogic. In cases where there are multiple paths in the calculations, the one with the shortest distance is selected. Following the same approach, the authors can determine the activity space choices in the preliminary plan of a high-rise residential project in Shanghai. This facilitates a comparative analysis between the pre-optimized and post-optimized plans in the subsequent stages. The details are shown in Table 3.

Table 3. Probability of relevant residents choosing activity spaces for pre-optimization and post-optimization schemes.

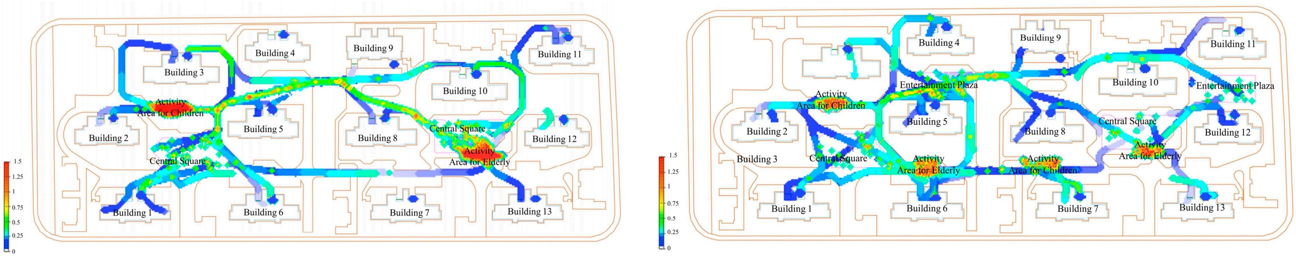
Number of Buildings	Pre				Post							
	Care for the Old and the Young	Sports Fitness	Entertainment and Leisure		Care for the Old		Sports and Fitness		Entertainment and Leisure			
	Activities for Children (Western)	Activities for the Elderly (Eastern)	Central Square		Activities for Children		Activities for the Elderly		Central Square		Cultural Plaza	
			West	East	West	East	West	East	West	East	West	East
1	1	1	0.9	0.1	0.68	0.32	0.75	0.25	0.68	0.08	0.19	0.06
2	1	1	0.85	0.15	0.86	0.14	0.72	0.28	0.55	0.09	0.28	0.08
3	1	1	0.67	0.33	0.69	0.31	0.64	0.36	0.25	0.12	0.54	0.09
4	1	1	0.71	0.29	0.63	0.37	0.68	0.32	0.25	0.11	0.54	0.1
5	1	1	0.77	0.23	0.65	0.35	0.7	0.3	0.11	0.03	0.84	0.02
6	1	1	0.81	0.19	0.42	0.58	0.93	0.07	0.56	0.13	0.22	0.09
7	1	1	0.23	0.77	0.09	0.91	0.4	0.6	0.15	0.51	0.16	0.18
8	1	1	0.21	0.79	0.31	0.69	0.43	0.57	0.11	0.44	0.29	0.15
9	1	1	0.3	0.7	0.41	0.59	0.53	0.47	0.13	0.31	0.4	0.15
10	1	1	0.27	0.73	0.4	0.6	0.37	0.63	0.09	0.25	0.16	0.5
11	1	1	0.23	0.77	0.45	0.55	0.31	0.69	0.09	0.3	0.14	0.47
12	1	1	0.11	0.89	0.29	0.71	0.22	0.78	0.02	0.16	0.03	0.79
13	1	1	0.15	0.85	0.27	0.73	0.19	0.81	0.09	0.51	0.09	0.31

3.2.3. Simulation

The specific process of the Anylogic simulation is as follows: it commences with physical modeling and process modeling. Subsequently, pedestrian flow is allocated to different buildings based on the calculated resident population. The basic settings are as follows:

1. Density display is set to its maximum, with a key density set to 1.5.
2. Simulated time is 360 min, equivalent to 6 h.
3. The pre-optimization scenario simulation includes four active functions: the west zone central plaza, children's activity area, east zone central plaza, and elderly activity area. The post-optimization scenario simulation includes eight active functions: each of the east and west zones includes a central plaza, entertainment plaza, children's activity area, and elderly activity area.

After completing physical modeling, process modeling, and parameter setting, the Anylogic software can be utilized to simulate the pre-optimized and post-optimized plans for public spaces in a high-rise residential project in Shanghai. This simulation provides the corresponding pedestrian flow density maps, as shown in Figure 5a,b.



(**a**) Pre-optimization (**b**) Post-optimization

Figure 5. (**a**) Pedestrian flow density maps for pre-optimization; (**b**) pedestrian flow density maps for post-optimization schemes.

3.3. Results

3.3.1. Improvements in Optimal Scheme

Through the comparison of pedestrian flow density maps between pre-optimized and post-optimized plans of a high-rise residential project in Shanghai, the differences and changes in the relevant public spaces before and after optimization can be visually discerned. Analyzing the results validates the rationality and feasibility of the optimization plan. The comparison of pre-optimized and post-optimized plans for public spaces in the high-rise residential project in Shanghai can be unfolded in accordance with the sequence of optimization strategies, encompassing spatial structure, activity functions, accessible pathways, and overall evaluation.

1. Spatial structure

In the preliminary plan, the pedestrian flow density is higher in the “central gardens” of the east and west, yet the “vitality loops” are not prominent, indicating that pedestrian traffic is predominantly concentrated in the central square and the corresponding activity areas. This spatial vitality imbalance may potentially lead to a decline in overall public space activity in the subsequent stages.

In contrast, the post-optimized plan demonstrates a more balanced overall pedestrian flow density. The “vitality loops” and “central gardens” are clearly delineated, achieving the intended design of public space. Both the east and west public spaces are interconnected yet maintain their independence, and the allocation of activity functions is more appropriate, thereby enhancing the overall vitality of public spaces.

2. Activity functions

In the preliminary plan of the high-rise residential project in Shanghai, there are fewer activity functions allocated to public spaces. Despite the separation of east and west public spaces in the planning, there exists an imbalance in the allocation of activity functions. The post-optimized plan addresses this by providing complete elderly care spaces, sports and fitness areas, and leisure and socializing spaces in both the east and west public spaces, thereby enhancing the overall vitality.

The analysis of pedestrian flow density maps reveals that the preliminary plan lacks activity functions, resulting in high pressure on activity spaces and an inability to achieve simulated flow rates in practical use. In contrast, the post-optimized plan features a more balanced distribution of activity functions, ensuring that the capacity of activity spaces is reasonable.

3. Accessible pathways

In the preliminary plan, the limited number of activity functions results in several areas with high pedestrian flow density in accessible pathways, highlighting the necessity for adjustments to activity function configurations or widening of local roads.

Conversely, the post-optimized plan reveals fewer areas with high pedestrian flow density between activity functions, indicating improved spatial accessibility and appropriate road widths between public space activity functions.

4. Overall Evaluation

The post-optimized plan for the public spaces of the high-rise residential project in Shanghai demonstrates a more balanced and reasonable design, effectively reflecting the design intention of "dual vitality loops and dual central gardens". The east and west public spaces are both interconnected and independently functional. The allocation of activity functions is appropriate, and spatial accessibility is improved.

Through an analysis of the spatial structure, functional activities, and accessible pathways within the public space of a high-rise residential project in Shanghai, this study aims to offer insights for enhancing the feasibility and effectiveness of public spaces within similar high-rise residential developments. The selected case study is deemed classical, representing a contemporary project with common characteristics shared by other high-rise residences. As cities evolve, the significance of public spaces transcends mere considerations of location, decor, and environment. Instead, emphasis is placed on addressing fundamental issues such as the layout of activity areas and the design of pathways.

The feasibility of optimizing public spaces is evaluated, affirming the efficacy and rationale of employing the Kruskal algorithm to enhance spatial accessibility. Furthermore, the utilization of the Anylogic simulation serves to refine the proposed solutions. This study not only offers insights into optimizing public spaces within high-rise residential projects but also suggests research directions for future endeavors in public space optimization within the Chinese context.

The methodology employed in this study, utilizing Kruskal's algorithm and Anylogic simulation, exhibits broad applicability across various types of buildings. However, the unique characteristics of different building types necessitate the consideration of distinct factors. This study specifically focuses on high-rise residences, prioritizing concerns regarding people's quality of life and accessibility. This choice is partly attributed to the versatility of Kruskal's algorithm. Additionally, given that the spatial configurations of these buildings often prioritize enhancing comfort and happiness, the Anylogic simulation method serves to verify and further optimize pedestrian flow density.

It is important to acknowledge that, while Kruskal's algorithm is effective for many scenarios, it may encounter challenges in dense or dynamic graph structures, potentially leading to reduced efficiency, especially in projects with complex functional layouts. Furthermore, high-rise residences are predominantly found in first-tier cities rather than developing ones. Economic disparities among citizens lead to varying preferences for residential settings, further influencing real-world conditions and outcomes.

3.3.2. Results from Empirical Experiment

Subsequently, the pedestrian flow density map of the post-optimized plan for the public spaces of the high-rise residential project in Shanghai is overlaid with the corresponding minimum spanning tree, as depicted in Figure 6.

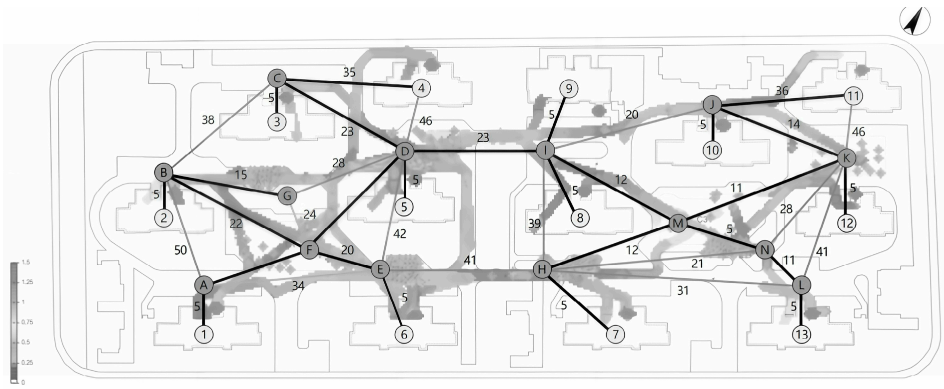


Figure 6. Superposition analysis of pedestrian flow density.

The analysis of the overlaid pedestrian flow density map and the corresponding minimum spanning tree for the public space optimization plan in a high-rise residential project in Shanghai yields the following findings:

1. High consistency

By comparing the graphs, it is evident that there is a high degree of alignment between the Kruskal minimum spanning tree and the simulated pedestrian flow density. The routes of the minimum spanning tree effectively reflect the primary pedestrian flow lines in the simulated density map. Therefore, the cross-utilization of both methodologies can guide subsequent optimization of public spaces.

2. Guide-enhanced public space accessibility

The Kruskal minimum spanning tree serves as guidance for further adjustments in the public spaces of the high-rise residential project in Shanghai. By optimizing the vertices (activity spaces) of the minimum spanning tree, subsequent layout improvements in public spaces can be achieved. Utilizing the shortest path without cycles guides the allocation of space resources, allowing for the expansion of the width of corresponding paths while appropriately reducing the width of others to achieve the most rational allocation of limited resources.

3. Guide-localized optimization of public spaces

Although the public space plan post-optimized through the Kruskal algorithm is relatively comprehensive, the Anylogic simulation can further refine the optimization. By analyzing the pedestrian flow density map, inadequacies in the plan become more apparent. Through the localized optimizations of public spaces, the overall public space plan for the high-rise residential project in Shanghai can be further improved.

4. Discussion

This article centers on the optimization research of public spaces within high-rise residential developments. By integrating project lifecycle management theory, Kruskal algorithm from graph theory, and Anylogic simulation modeling, a comprehensive optimization model and evaluation strategy are formulated for public spaces in high-rise residential projects. Effective recommendations are proposed for enhancing the public spaces of high-rise residential areas through the lens of smart city concepts. Subsequently, a specific high-rise residential project in Shanghai is utilized as a case study to assess the feasibility and efficacy of the proposed optimization strategies for public spaces in such developments. The findings of this study can be summarized as follows:

1. Adopting a whole life cycle perspective

The optimization of public spaces within high-rise residential projects necessitates a departure from traditional project management paradigms. Instead, it advocates for a comprehensive viewpoint that encompasses the entire project life cycle. Special attention should be directed towards the requirements of the post-construction phase and the integration of value-centric project management principles with service-focused management strategies. Thorough the examination of the distinct priorities of the proposal, construction and operational service phases are imperative [32]. Ultimately, the enhancement in project design should result in heightened operational efficiency during the subsequent stages, thereby achieving cost savings and efficiency advancements as primary objectives [33].

2. Using digital methods for the optimization of public spaces

Compared to the traditional project management optimization model, digital technology is employed to extensively analyze residents' perceptions, behaviors, and other experiential information [34]. The utilization of the Kruskal algorithm for optimizing public space represents a significant advancement, as its data computing power creates new avenues for the study of urban public space optimization. For many residences, the most important thing is experience. The entirety of the plan hinges on human decision making, a process prone to time consumption and inaccuracies. Leveraging digital methods can circumvent human errors and significantly expedite processes, thereby enhancing overall efficiency.

3. Constructing people-oriented optimization strategies

The article constructs principles for optimizing public spaces in high-rise residential projects based on project life cycle management theory. By leveraging the Kruskal algorithm from graph theory, a model for public space accessibility is established. The residents' elements (with their comfort and happiness as the main improvement objectives) are fully considered, and the composition of residents, walking speed, and initial flow are determined according to the corresponding living conditions. The effectiveness and rationality of the post-optimized accessibility paths are examined through AnyLogic simulation modeling, offering a foundation for subsequent adjustments in the optimization of public spaces within high-rise residential projects.

Recent research increasingly focuses on the relationship between people and physical space. For instance, Kan et al. used Spatio-Temporal Surveillance Systems (STSSs) to identify significant spatio-temporal clusters of disease locations based on various models, thereby studying the characteristics of different types of high-risk areas [35]. The spread of diseases is closely linked to public safety, and optimizing public spaces is fundamental to safeguarding residents' rights and interests. Ultimately, the study of living spaces aims to serve residents, with the goal of enhancing their quality of life and overall happiness.

4. Necessity for smart city-related industries

The simulation and optimization of urban high-rise public spaces embody the concept of smart city development. It has been demonstrated that industries related to smart cities can enhance public space planning with greater accuracy, proving to be effective and essential [36], and leading to promising practical outcomes and future prospects.

On the one hand, considering the importance of participatory culture in the concept of smart city and the emphasis on people as the core of urban development, this study focuses on the comfort and convenience of residents. On the other hand, smart cities also emphasize the integration of urban physical, IT, and social through digital technology. Through empirical research, this paper uses digital technology to propose scientific optimization strategies for the project and carries out rationality verification.

Many countries are striving to establish smart city platforms that integrate multiple dimensions of urban life. For example, a smart city virtual service platform leverages strong R&D capabilities and proprietary technology transformation to develop core services such as big data foundations and virtual reality operation control [37]. This platform can integrate various community components, from hardware elements like streetlights and manhole covers to software applications such as e-government, big data platforms managing people's livelihood data, energy control, and AI-driven data mining.

This precise integration of information enhances the accuracy of data from the initial stages of public space optimization, thereby improving the algorithm's effectiveness. Additionally, optimizing public space configurations can support the development of community hardware settings, aiding in the implementation of smart city initiatives and enhancing residents' overall happiness. Logistics plays a crucial role in urban design and significantly impacts community size. In the future, public spaces in smart construction will serve multiple functions, including logistics, communication, and transportation. Samireh Kadaei et al. identified 23 challenges that must be addressed to implement reverse logistics effectively and achieve sustainability in the construction industry [38]. Numerous researchers examine public spaces from various angles to support smart city construction, underscoring the necessity for smart city-related industries.

However, the study still exhibits certain limitations that warrant improvement through further analysis and research:

1. Overlapping activity functions in public space

There are primarily three types of spatial functions in the public spaces of high-rise residential buildings, namely, care for the elderly and children, sports and fitness, and leisure exchanges. The activity functions of these spaces may overlap due to the diverse user groups. Therefore, further investigation can explore the interconnectedness of the activity functions of public spaces to enhance the rationality of functional configuration and increase the realism of subsequent simulations.

2. Deepening the study in the urban context

Public spaces within high-rise residential projects are not isolated entities but are rather integrated into the broader urban context. In line with the principle outlined in the 2016 Central Urban Work Conference, which emphasizes that new residential areas should generally not be enclosed, the public space system of residential areas will gradually merge with the urban public space system. Future research on optimizing public spaces in high-rise residential projects must take into account the urban context.

Relevant studies should adopt a macroscopic perspective aligned with the development trends of human-oriented smart cities. This includes several aspects. First of all, the overall planning and coordination of the research should be considered: the overall layout and functional zoning should be considered to ensure the coordinated development of all parts to avoid local optimization and poor overall effect. Second, optimization goals should take a long-term view: ensuring sustainable development, rather than focusing only on short-term benefits. Finally, systematic thinking should be adhere to the following: economic, social, environmental, and other factors should be considered comprehensively, and the one-sidedness of a single perspective should be avoided.

3. Limitations in expertise for digital technologies

Due to limitations in personal expertise and experience, there are shortcomings in the research on graph theory algorithms, simulation modeling, and other digital technologies. While some aspects have been addressed, a lack of in-depth insights poses challenges in providing a comprehensive discussion of other greedy algorithms and related technologies. As Krustral algorithm is only used in this study to analyze specific cases, it is lacking applicability. For example, for the shortest path calculation of dense graphs, the efficiency of Krustral algorithm will be reduced. If it is not used in combination with other algorithms, the computational efficiency may decrease when the function distribution of public space is very uneven, and it cannot meet the requirements of short-term parallelization.

Despite the intention to cover a broader range, the coverage falls short due to limited expertise. In the future, it is hoped that the optimization analysis can be carried out through further learning and application of new mathematical technical tools, so as to cover the defects of this part. The learning of other algorithms and hybrid algorithms should be included and applied to other different types of projects.

5. Conclusions

As cities develop, the efficient utilization of space has gained increasing importance. The layout of public spaces within high-rise residential buildings often tends to be fragmented and dominated by single functional types, leading to insufficient environmental sharing. Consequently, there is a significant need and demand for the optimization of public spaces in these projects.

Combining practical experience with theoretical knowledge, residential projects must adopt a whole life cycle perspective to ensure the consistency of the entire project. Taking the high-rise residential project in Shanghai as an example, the primary spatial optimization issues to address include the unreasonable allocation of public space activities, insufficient spatial connectivity, and low space utilization efficiency and functional accessibility. The most critical aspect is enhancing citizens' life experiences. Based on the case study, developing people-oriented optimization strategies can make similar projects more beneficial and effective.

By effectively building the optimization model through Kruskal's algorithm and using Anylogic simulation for verification and further optimization, the study demonstrates significant improvements in spatial structure, activity functions, and access paths. The results from Kruskal's algorithm and Anylogic simulation clearly show enhanced spatial organization, better utilization of activity spaces, and improved accessibility, addressing the previously identified issues and enhancing residents' life experiences. These improvements include more comprehensive activity functions, public spaces that meet the diverse needs of residents, and increased overall efficiency and vitality of public spaces.

The selected case study, based on a real project, validates the practical applicability of the analytical results. The use of digital methods, widely applied across various fields, proves beneficial for the optimization of public spaces, providing a solid foundation for future upgrades. Integrating advanced digital methods into construction not only improves efficiency but also ensures more accurate and holistic planning. In addition, it is worth noting that the enhancement in community vitality is closely linked to environmental sharing. By sharing environmental resources and public spaces, communication and cooperation among community members are fostered, thereby enhancing community cohesion and a sense of belonging, ultimately improving the overall quality of community life [39]. The culture and spirit of a community are rooted in the interactions between its citizens, and public spaces are essential venues for these interactions. Providing more opportunities for people to share the same environment fosters a sense of inclusion, which is a critical factor in effective community governance.

Furthermore, with the rapid innovation in digital appliances, the development of smart cities is becoming mainstream. Proper public space allocation forms a solid foundation for achieving smart city initiatives. From a digital perspective, not only the scientific methods and techniques applied in this study but also other methods that can contribute to creating intelligent, inclusive, and accessible communities that can be further explored and extended [40]. This approach ensures that public spaces are designed to support smart city infrastructure, enhancing the overall functionality and livability of urban environments. Our primary goal is to tackle issues related to the poor configuration and connectivity of public spaces, as well as the underutilization of peripheral activity areas. Understanding the crucial impact that the layout of public spaces has on residents' living experiences, the importance of addressing these issues in the early stages of design needs to be emphasized. By incorporating scientifically based digital technology solutions, the goal is to develop smart, inclusive, and accessible communities that effectively meet the diverse needs of residents.

Author Contributions: Conceptualization, J.L. and Y.H.; methodology, Y.H. and J.L.; software, Y.H.; writing—original draft preparation, Y.H. and D.T.; writing—review and editing, J.L. and Q.L.; supervision, D.T. and Q.L.; funding acquisition, D.T.; J.L. and Y.H., contributed equally to this manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research is supported by the National Social Science Foundation of China (20BGL300).

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

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

References

1. Shu, P.; Wang, L.; Song, L. A Strategic Study on the Residential Planning and Housing Stories in Large Cities. *City Plan. Rev.* **2002**, *26*, 32–38.
2. Qi, K. Community and Residence. *Mod. Urban Res.* **2012**, *27*, 103–104.
3. Wang, Y.; Wang, Q.; Ye, Q. *Research on the Development of Super High-Rise Residential Buildings*; China Architecture and Building Press: Beijing, China, 2012.
4. Lv, Y.; Cao, X.; Li, J.; Zhang, J. Research on the Mode of Community Public Space Shared by the Elderly and Children. *Archit. J.* **2021**, *28*, 80–85.
5. Stokes, B.; Bar, F.; Baumann, K.; Caldwell, B. Neighborhood Planning of Technology: Physical Meets Digital City from the Bottom-Up with Aging Payphones. *J. Community Inform.* **2014**, *10*, 1–19. [CrossRef]
6. Yu, Q. Some Thoughts on the High-Quality Construction of Future Communities. *Zhejiang Econ.* **2021**, *37*, 48–49.
7. Wang, G. Future Community Construction Empowers High-Quality Urban Development. *Constr. Sci. Technol.* **2023**, *22*, 1.
8. Xu, N. Review of Urban Space Researches from Multidisciplinary Perspective. *Landsc. Archit.* **2021**, *28*, 52–57. [CrossRef]
9. Xing, R. *Confucius' Courtyard: Architecture, Philosophy and the Good Life in China*; Bloomsbury Publishing: London, UK, 2021.
10. Abass, Z.; Tucker, R. White Picket Fences & Other Features of the Suburban Physical Environment: Correlates of Neighbourhood Attachment in 3 Australian Low-Density Suburbs. *Landsc. Urban Plan.* **2018**, *170*, 231–240.
11. Guo, Q. Publicity Dilemma in Digital Exchange Space and Its Enhancing Strayegy. *Stud. Social. Chin. Charact.* **2022**, *28*, 80–87.
12. Li, G. The Quality Research to Residence With High FAR:Wuhan Examble. *Planners* **2014**, *30*, 91–95.
13. Van Dellen, E.; Sommer, I.E.; Bohlken, M.M.; Tewarie, P.; Draaisma, L.; Zalesky, A.; Di Biase, M.; Brown, J.A.; Douw, L.; Otte, W.M.; et al. Minimum Spanning Tree Analysis of the Human Connectome. *Hum. Brain Mapp.* **2018**, *39*, 2455–2471. [CrossRef] [PubMed]
14. Hua, Y. Discussion on E-Commerce Logistics Distribution Scheme Based on Kruskal Theory. *J. Commer. Econ.* **2017**, *36*, 81–82.
15. Huang, H.; Savkin, A.V.; Huang, C. Reliable Path Planning for Drone Delivery Using a Stochastic Time-Dependent Public Transportation Network. *IEEE Trans. Intell. Transp. Syst.* **2020**, *22*, 4941–4950. [CrossRef]
16. Wang, Q.; He, Y. Transportation Planning Method Based on Improved Kruskal Algorithm. *J. Comput. Appl.* **2021**, *41*, 149–152.
17. Lai, Y. Study on Contingency Plan for Sudden Peaks in Passenger Demand in Urban Rail Transit Using Simulation. Master's Thesis, Beijing Jiaotong University, Beijing, China, 2017.
18. Fruin, J.J. *Pedestrian Planning and Design*; Springer: New York, NY, USA, 1971.
19. Wang, L.; Zhang, B.; Zheng, Z.; Wang, Y. Simulation Study of Crowd Evacuation in Stadiums Based on Social Force Model. *Archit. J.* **2022**, *69*, 239–245.
20. Lin, Z.; Liu, Z.; Fang, Z.; Liu, J.; Zhang, P.; Jiang, R. Review of Pedestrian and Traffic Evacuation Simulation Software. *China Saf. Sci. J.* **2022**, *32*, 100–110. [CrossRef]
21. Yu, B.; Ren, J. Research on Optimisation of High-Speed Railway Station Transfer Efficiency Based on Any Logic Simulation While Considering Tianjin West Railway Station as an Example. *South Archit.* **2021**, *28*, 94–99.
22. Zhu, W.; He, H. Analysis of High-Speed Railway Passenger Queuing Based on Anylogic Simulation. *Urban Mass Transit* **2020**, *23*, 133–137+141. [CrossRef]
23. Feng, S. System Dynamics Model for Battery Recycling of Electric Vehicles in Anylogic Simulation. *IJIMS* **2018**, *5*, 405. [CrossRef]
24. Ding, B.; Peng, J.; Xu, G.; Zhou, C. Optimizing and Evaluating the Equipment Layout of Rail Transit Station Hall Based on AnyLogic. *J. Railw. Sci. Eng.* **2020**, *17*, 1578–1585. [CrossRef]
25. Tang, J.; Hu, Y.; Wang, Y. Research on Evacuation Guidance Strategy in Large Space Buildings Based on Anylogic. *Fire Sci. Technol.* **2021**, *40*, 1594–1598.
26. Chen, B.; Cai, Y.; Yao, Y.; Peng, X.; Li, A. Method for Forecasting and Evaluation Public Space Utilization Efficiency of Intercity Underground Stations. *Chin. J. Undergr. Space Eng.* **2021**, *17*, 22–33+54.
27. Wang, D.; Zhou, T. Optimal Design of Residential District Edge Space Based on Edge Effect Throry: Taking Guangyi Street Residential Area in Chongqing as an Example. *J. Hum. Settl. West China* **2024**, *39*, 129–135. [CrossRef]
28. Wu, W.; Sun, R. Theories and Methods for Accessibility Evalluation of Urban Public Service Facilities. *City Plan. Rev.* **2024**, *48*, 65–70.
29. Broutin, N.; Devroye, L.; McLeish, E. Note on the Structure of Kruskal's Algorithm. *Algorithmica* **2010**, *56*, 141–159. [CrossRef]
30. Shang, W.; Wu, Z.; Zheng, W.; Zeng, Y.; Lv, S. Study on the Correlation Between Street Attractiveness and the Rate of Change of Walking Speed in Modern Cities. *Archit. J.* **2021**, *68*, 99–105.
31. Zhang, M.; Zhang, X.; Wang, H. Impact Analysis of City Scale on Trip Distance of Urban Residents. *Manag. Sci. Eng.* **2015**, *4*, 92. [CrossRef]

32. Li, X.; Zhao, S. Research on Construction for Sustainable Housing Based on the Whole Life Cycle. In *Green Building Technologies and Materials*; Wu, X.K., Xie, H., Eds.; Trans Tech Publications Ltd.: Stafa-Zurich, Switzerland, 2011; Volume 224, pp. 164–169.
33. Li, D.; Cui, P.; Lu, Y. Development of an Automated Estimator of Life-Cycle Carbon Emissions for Residential Buildings: A Case Study in Nanjing, China. *Habitat Int.* **2016**, *57*, 154–163. [CrossRef]
34. Grakhov, V.P.; Kuznecov, A.L.; Kislyakova, Y.G.; Simakova, U.F.; Knyazeva, Y.O. Implementation of Digital Project Management for Construction and Operation of Energy-Efficient Residential Buildings. *Sci. Tech.* **2021**, *20*, 66–74. [CrossRef]
35. Kan, Z.; Kwan, M.-P.; Wong, M.S.; Huang, J.; Liu, D. Identifying the Space-Time Patterns of COVID-19 Risk and Their Associations with Different Built Environment Features in Hong Kong. *Sci. Total Environ.* **2021**, *772*, 145379. [CrossRef]
36. Duygan, M.; Fischer, M.; Paerli, R.; Ingold, K. Where Do Smart Cities Grow? The Spatial and Socio-Economic Configurations of Smart City Development. *Sust. Cities Soc.* **2022**, *77*, 103578. [CrossRef]
37. Qingdao Wisdom Cloud Valley Intelligent Technology Co. *Smart City Virtual Reality Public Service Platform*; Qingdao Wisdom Cloud Valley Intelligent Technology Co.: Jinan, China, 2019.
38. Kadaei, S.; Nezam, Z.; González-Lezcano, R.A.; Shokrpour, S.; Mohammadtaheri, A.; Doraj, P.; Akar, U. A New Approach to Determine the Reverse Logistics-Related Issues of Smart Buildings Focusing on Sustainable Architecture. *Front. Environ. Sci.* **2023**, *10*, 1079522. [CrossRef]
39. Yao, M.; Zeng, E.; Lin, Z. Research on Urban Renewal and Revitalization Strategies Based on the Concepts of "Phases" and "Interfaces": A Case Study of Urban Renewal and Revitalization in Macau's Rua de São João Baptista District. *Chin. Landsc. Archit.* **2016**, *32*, 48–52.
40. Chaiyasoonthorn, W.; Khalid, B.; Chaveesuk, S. Success of Smart Cities Development with Community's Acceptance of New Technologies: Thailand Perspective. In Proceedings of the 9th International Conference on Information Communication and Management, Prague, Czech Republic, 23–26 August 2019; ACM: Prague, Czech Republic, 2019; pp. 106–111.