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Assessment of Health-Oriented Layout and Perceived Density in High-Density Public Residential Areas: A Case Study of Shenzhen

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Abstract: Rapid urbanization has intensified public housing development and building density, posing significant challenges to residents' well-being and urban sustainability. With the population of the Greater Bay Area on the rise, enhancing the spatial quality of public housing is now essential. The study proposed a quantitative framework to evaluate the relationship between the residential design elements and perceived density in high-density public housing neighborhoods. It employed a virtual reality perception experiment to analyze the relationship between significant spatial indicators and perceived density by investigating 16 high-density residential layout models in 3 configurations: Tower-Enclosed, Balanced Slab-Enclosed, and Staggered Slab-Enclosed. The results indicate that: (1) greater building height intensifies perceived density, leading to sensations of overcrowding and discomfort; (2) an increased sky ratio mitigates perceived density, fostering a more open and pleasant environment; (3) recessed residential facades enhance residents' density perception; and (4) Staggered Slab-Enclosed Layout configurations receive the most favorable evaluations regarding perceived density. The authors attempt to go beyond current regulations to propose tailored solutions for Shenzhen's high-density context, improving spatial efficiency and residential comfort in future public housing designs. The finding provides scientific evidence to support urban planners and policymakers in developing more resilient and sustainable high-density neighborhoods.

Keywords: health perception; building layout; perceived density; public residential areas; virtual reality

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1. Introduction

Since the 1990s, urbanization in China has rapidly accelerated, leading to a significant population concentration in coastal areas, like the Pearl River Delta region, where scattered settlements have merged into megacities [1,2]. By the end of 2023, the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) encompassed 56,000 square kilometers and houses over 86.6 million people, making it the world's most densely populated bay area [3]. Rapid urbanization and overpopulation in GBA cities have led to high-density urban development, raising significant concerns about human health and quality of life. Shenzhen, the core city of the GBA, has the highest population density in China at 8800 people/km^2, presenting a significant challenge for urban development due to limited land for the growing population [4]. High-speed construction in Shenzhen over the past 40 years has raised the average plot ratio of residential development from 2.4 to over 5.0 [5,6]. Urban settlements, governed by current daylight standards and building density regulations, predominantly feature high-rise and super-high-rise structures. The Tower High-Rise and Super High-Rise settlements provide optimized plot ratios, streamlined construction processes, and high-quality living environments that maximize natural light and scenic views. However, the large-scale settlement pattern with low building coverage disrupts neighborhood continuity and limits inner street space, leading to congestion and oppression in the streets, ultimately reducing neighborhood interaction and vibrancy [7]. Moreover, greater building heights will significantly elevate fire safety risks and complicate retrofitting [8,9], hindering urban sustainable low-carbon development. Given these limitations, the Tower High-Rise and Super High-Rise settlement may not represent the most efficient approach for space utilization. In developed areas like New York, Tokyo, and Singapore, urban design typically features continuous building rows along streets in a block layout, resulting in high building coverage and low settlement heights [10]. The continuous row of buildings along the street creates a cohesive spatial experience within the neighborhood, simultaneously highlighting a variety of architectural styles and house types. Over the past decade, scholars have explored neighborhood settlement models for urban development in China [11], including "Housing Block" [12] and "Residential Block" [13], with prominent examples like the public housing in Qiaoxiang Village and Longrui Jiayuan in Shenzhen (Figure 1). These studies demonstrate that neighborhood settlement patterns effectively balance spatial efficiency and quality.

Figure 1. Typical cases of public housing in China.: (**a**) Aerial View of Qiaoxiang Village, Shenzhen (source: from the authors); (**b**) Site Plan of Qiaoxiang Village, Shenzhen (Map data: Google Earth, ©2020 Maxar Technologies); (**c**) Aerial View of Longrui Jiayuan, Shenzhen (source: from the authors); (**d**) Site Plan of Longrui Jia yuan, Shenzhen (Map data: ©2024 Google).

Research in environmental psychology indicates a strong link between building spatial form and the perceived density of occupants [14,15]. Reduced building heights and open outdoor spaces could lessen the feeling of crowding, while the higher building coverage and closer spacing may negatively affect residents' perception of density [16–19]. Currently, Block-Style Public Housing in China faces congestion and discomfort due to high plot ratio demands and the gap between actual and perceived building density. For instance, in the urban villages of Shenzhen, the average plot ratio is 2.56, with some plots exceeding 6.0, leading to narrow spacing between buildings that significantly diminishes residents' spatial experience [20,21]. Even with the same floor area ratio, different perceived densities are presented in different spatial layouts [22]. Hence, quantitative research examining the relationship between morphological characteristics of neighborhoods settlements and density perception is essential to improving residential quality of life in high-density areas and provides valuable insights for guiding future neighborhood design strategies. According to current policies in China, public housing is an essential aspect of urban residential supply [23]. While it benefits from public authority, it must also fulfil social obligations of spatial openness and resource sharing [24]. Public housing construction in Shenzhen follows the commercial development model, resulting in numerous high-rise structures that fail to enhance spatial experience and fulfil social responsibilities. By effectively addressing stringent daylight and building density regulations, public housing can adopt flexible design standards that facilitate the creation of innovative high-density neighborhoods, while enhancing and revitalizing urban public spaces [25].

This paper examines public housing in Shenzhen to outline an ideal model for high-density neighborhood settlements. The study proposed a quantitative framework to evaluate the relationship between the residential design elements and perceived density in high-density public housing neighborhoods. It employed a virtual reality perception experiment to analyze the relationship between significant spatial indicators and perceived density by investigating 16 high-density residential layout models in 3 selected configurations. Findings will guide strategies for sustainable, livable urban spaces by aligning perceived density with residential morphology, offering insights for policymakers to improve residential quality and urban resilience in rapidly growing cities. The hypothesis posits that particular morphological design elements in neighborhoods, like lower building heights, optimized spatial layouts, and well-configured public spaces, could affect perceived density, thereby enhancing spatial experiences. It aims to: (1) establish a quantitative framework to evaluate the relationship between the residential design configurations and perceived density in high-density public housing neighborhoods; (2) create an innovative assessment method using virtual reality technology to simulate residents' spatial experiences and evaluate density perception based on diverse building metrics; and (3) propose a design strategy that aligns perceived density with settlement morphology, providing tailored recommendations for creating high-density neighborhoods that balance livability, spatial efficiency, and urban resilience. The innovation lies in creating a comprehensive evaluation framework for high-density public housing settlements, which integrates virtual reality simulations with spatial analysis to assess perceived density. It goes beyond current regulations to propose tailored solutions for Shenzhen's high-density context, improving spatial efficiency and residential comfort in future public housing designs.

2. Data and Methods

2.1. Research Framework

This study adopts an inductive research approach to analyze the relationship between spatial form indicators and perceived density in three typical layouts of high-density block-style residential areas (Figure 2). The research strategy employed VR experiments, which offer precise and flexible variable control compared to field experiments and provide a more immersive experience than 2D images [26,27]. Based on 3 types of block-style residential area layout prototypes, this study develops 16 VR experimental models by relaxing the constraints of building coverage ratio and daylight regulations while maintaining uniform plot size and floor area ratio. Then, the authors identified three spatial form indicators—building height, sky exposure ratio, and recessed space in the selected models. Further, the study employed a quantitative method by conducting correlation analyses and ordinal logistic regression to evaluate the relationship between the spatial form indicators and residents' perceived density from questionnaires. The results attempt to offer design strategies and recommendations for optimizing standards and regulations in constructing high-density public housing that feels lower density.

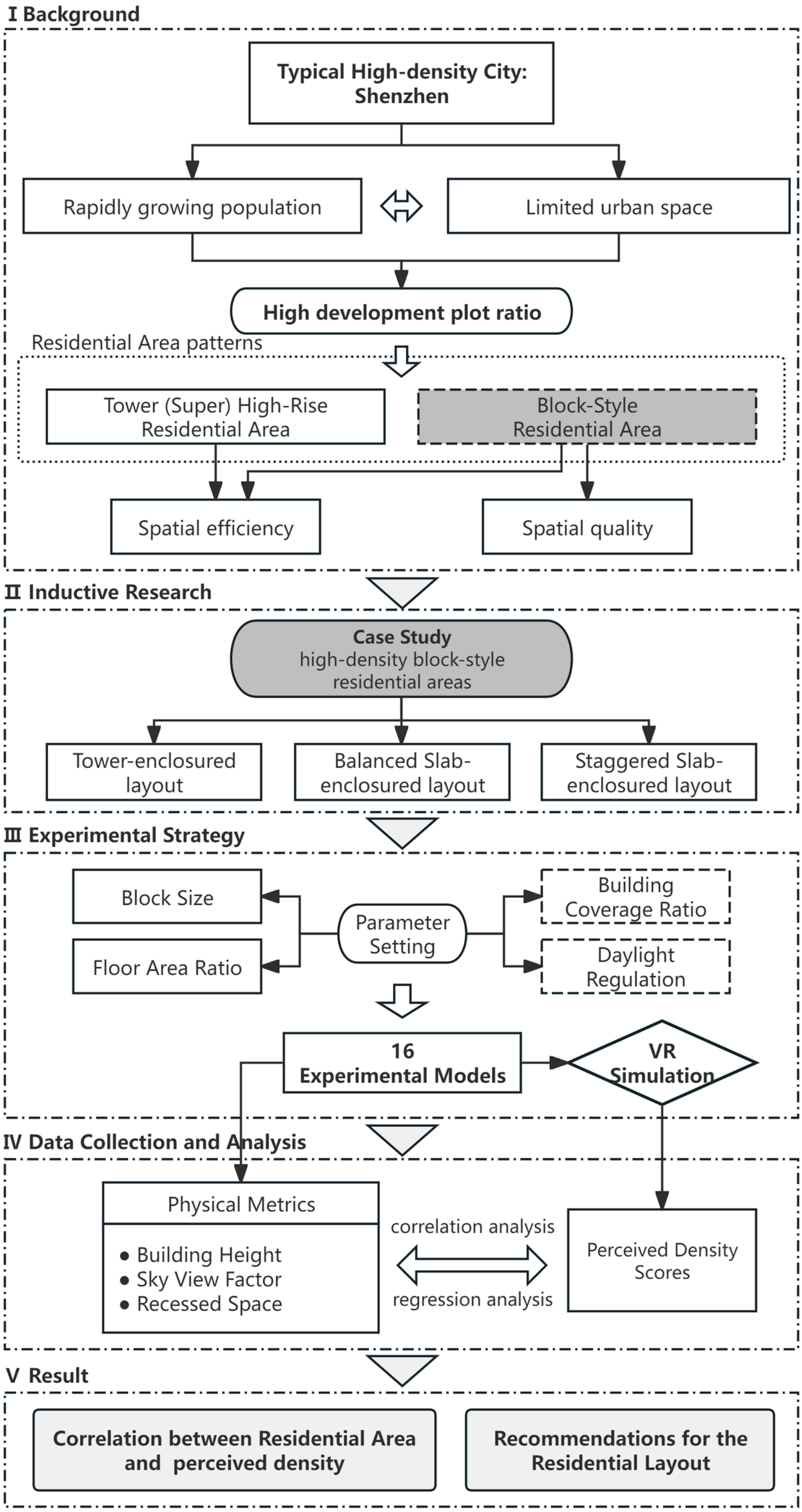

Figure 2. Research Framework.

2.2. Experimental Modelling

2.2.1. Representative Layout Typologies

Based on previous research, this study summarizes the morphological characteristics of high-density block-style residential areas domestically and internationally [5]. Three main layouts are distilled based on the building form and height combination, Tower-enclosed Layout, Balanced Slab-enclosed Layout, and Staggered Slab-enclosed Layout, as shown in Figure 3.

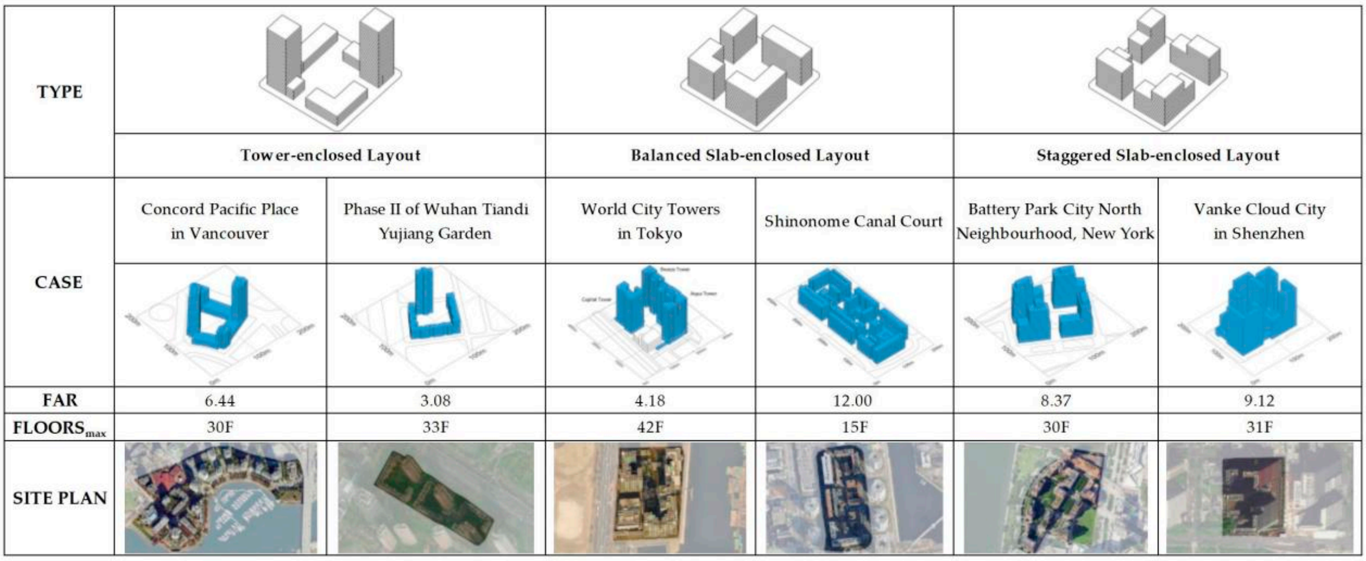

Figure 3. Classification of High-Density block-style residential area.

The Tower-enclosed layout consists of low-rise podium buildings along the street and high-rise to super-high-rise tower buildings. The podium buildings form continuous street frontage, while the tower portion above the podium ensures good sunlight exposure and scenic views for the residential units. Notable examples of this typology include Concord Pacific Place in Vancouver [28] and Wuhan Tiandi Site A [29].

The Balanced Slab-enclosed layout features uniform-height, high-rise residential buildings that line the street. To mitigate the effects of extensive, unbroken façades on the street and internal courtyards, building heights are regulated to between 10 and 20 stories, incorporating elevated or recessed sections at strategic points to improve ventilation and vistas. Notable examples include the Shinonome Canal Court [30] and the World City Towers in Tokyo, Japan [31].

The Staggered Slab-enclosed layout accommodates a higher floor area ratio (FAR), with the overall height generally exceeding 20 stories. By retracting upper floors, this design creates a varied facade with differing heights, maintaining a high degree of sky visibility and providing a diverse spatial experience. This approach also helps mitigate the sense of oppression often associated with high-rise enclosures. Typical examples include the Battery Park City North Neighborhood in New York [32] and Vanke Cloud City in Shenzhen [33].

2.2.2. Research Parameter Setting

- Block Size

Based on an analysis of block scales from exemplary block-type residential areas worldwide, scholars have concluded that the block size for high-density block-type residential areas in Shenzhen should be controlled within a range of 100–150 m, with an area between 1 to 2.5 hectares [34]. To facilitate the generalized analysis of the model, this study uniformly sets the block size to 120 m by 120 m, with a land area of 1.44 hectares.

- Floor Area Ratio (FAR)

Referring to the regulations on urban residential land density in the "Shenzhen Urban Planning Standards and Guidelines" (2021 Edition) and considering the current state of public housing development in Shenzhen, the floor area ratio (FAR) is set at 6.0.

- Building Coverage Ratio

Increasing building coverage at the same development intensity could significantly lower the overall height of residential buildings, fostering a more pleasant neighborhood scale [35]. In contrast to international standards, where building coverage ratio ranges from 30% to 50% [36,37], the urban design code in Shenzhen limits high-rise residential coverage ratio to 25%, which may impede the development of block-style residential areas. This experimental model aims to accommodate flexible adjustments of block-style forms by exceeding current local building coverage regulations.

- Daylight Regulation

Daylight regulation plays a crucial role in designing residential areas. In Shenzhen, strict regulations mandate a minimum effective sunlight duration of three hours on the Great Cold Day or one hour on the Winter Solstice in each residential unit [38]. These requirements have led to the prevalence of tower-enclosed residential areas, making it difficult to develop slab-enclosed communities. This study draws on sunlight exemption and worldwide compensation mechanisms, allowing for a moderate relaxation of daylight regulation in the residential block models during the generation process.

2.2.3. Generation Experiment

- Layout Generation

This study generated experimental models based on three typical high-density block layouts of residential areas selected in Section 2.2.1. Four representative apartment types were chosen from the Shenzhen public housing unit database: one-bedroom (35 m^2), two-bedroom (65 m^2), three-bedroom (80 m^2), and four-bedroom (100 m^2) (Figure 4a). The unit size refers to gross floor area rather than net internal area. Two residential building configurations, tower-type and slab-type, were generated by combining these apartment units (Figure 4b). The tower-type buildings are centered around a traffic core, with different-sized units enclosed to form a point layout. The overall dimensions of this building type are 30 m $\times$ 30 m, with recesses measuring 2.6 m $\times$ 7 m. The slab-type buildings are connected in parallel through corridors, divided into single-corridor and double-corridor types with depths of 11 m and 22 m, respectively. Additionally, different building forms are created based on the presence of recessed spaces. Tower-type and slab-type buildings encircle the site, creating 16 unique residential layouts that conform to Shenzhen's current apartment standards (Figure 4c).

- 3D Modelling

Based on the layout configurations, the three-dimensional models of experimental residential areas were generated using SketchUp Pro 2021 software (Figure 5). Each model has the same site size and Floor Area Ratio. Models are classified into two groups based on recessed spaces in the building floor plan: Group A—Recessed Type and Group B—Regular Type. Specifically, numbers 1 and 2 represent Tower-enclosed Layout, numbers 3 to 5 represent double-corridor Balanced Slab-enclosed Layout, numbers 6 and 7 represent single-corridor Balanced Slab-enclosed Layout, and number 8 represents a Staggered Slab-enclosed Layout.

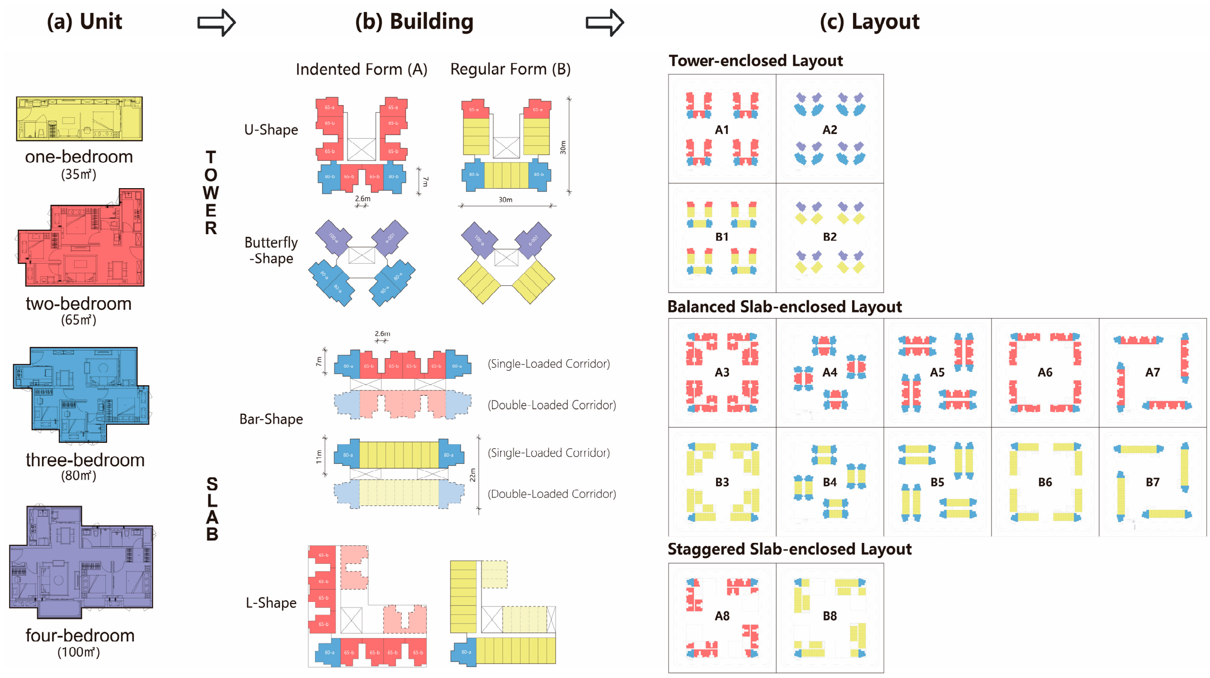

Figure 4. Logic of Experimental Model Construction.

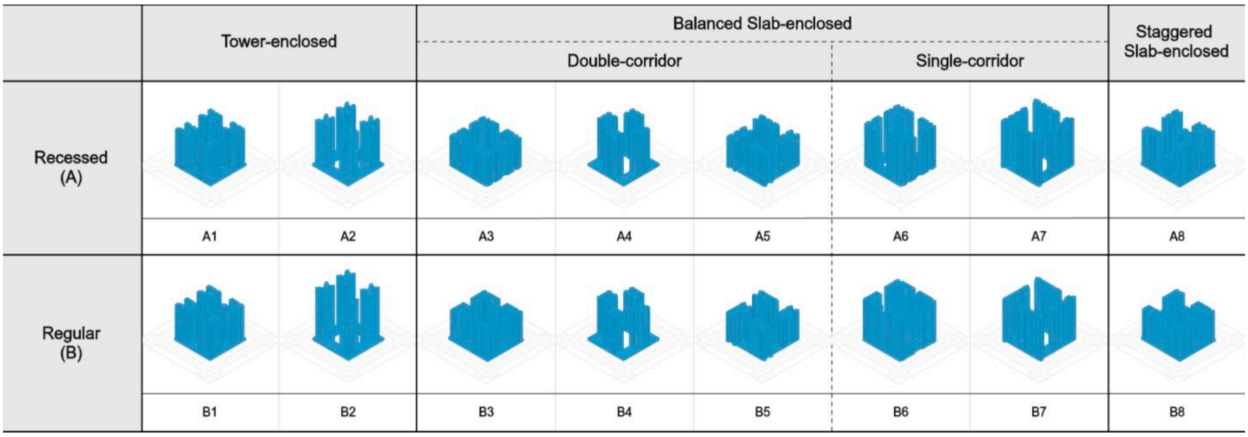

Figure 5. Experimental Models.

2.3. Virtual Reality Experiment

The Virtual Reality (VR) experiments aim to generate a 3D virtual environment through a head-mounted display, providing participants with an immersive sensory experience, which has been widely applied in visual perception research [39–41]. Compared to field experiments, VR experiments offer advantages in controllability and flexibility. Researchers can precisely control experimental variables and minimize interference from external factors.

In this experiment, virtual reality (VR) technology was employed to convert the experimental models into computer-generated virtual reality scenes (Figure 6). To avoid interference from external built environment settings, ground-level parking, facade materials, landscaping, and other factors on density perception, all residential area models in the experimental scenes were rendered with a uniform facade material, and the spatial environment was set to clear blue sky. Using these settings, eight groups of VR real-world models were rendered, and participants were recruited to study the relationship between the objective residential environment and subjective density perception.

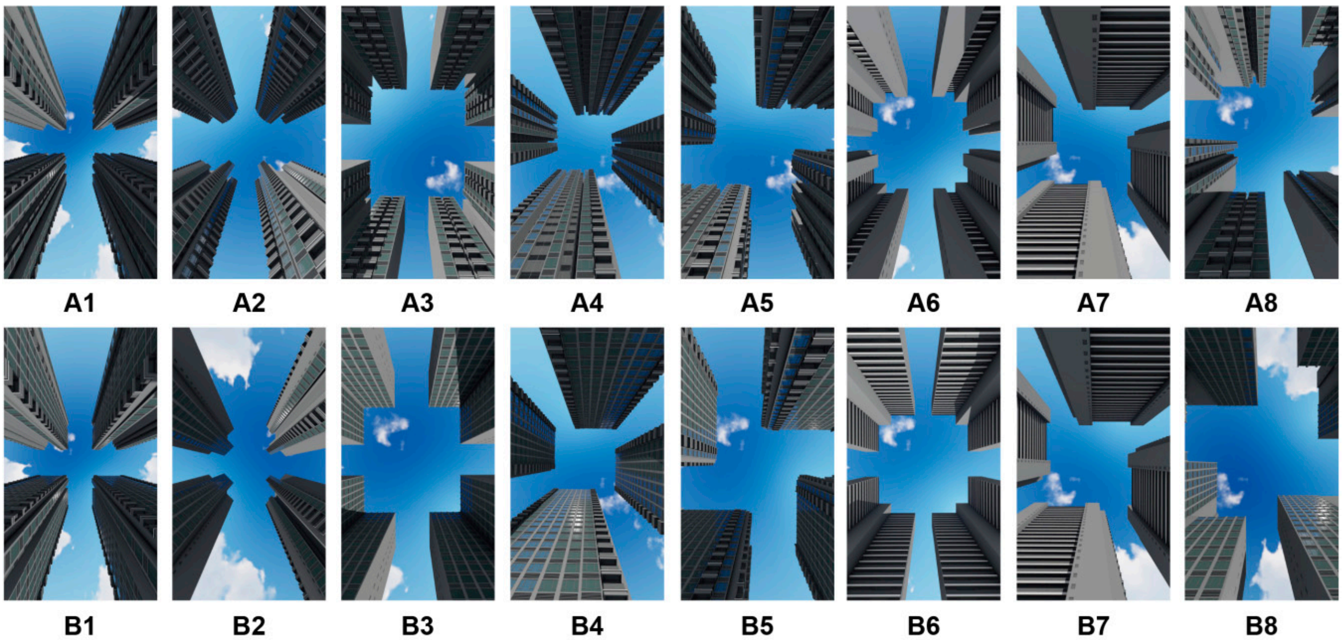

Figure 6. VR Scenes of the Experimental Models.

First, the authors employed a non-probability sampling method, specifically judgmental sampling, to recruit the experimental samples [42]. Then, the authors recruited individuals with architectural backgrounds and extensive experience in high-density built environments through school announcements and flyers to enhance the professionalism and reliability of the evaluation results. Given the relationship between research variables and sample size in statistics and the complexities of the VR experiment, a sample size of 60 has been chosen to ensure the experiment's credibility and feasibility [43]. The gender ratio among volunteers was balanced, with the majority aged 29 and below at 59%, followed by those aged 30 to 39 at 38%. This age distribution aligns with the demographic profile of the primary target group for public housing in Shenzhen, reinforcing the relevance and representativeness of the findings [44]. During recruitment, the authors explained the experimental procedure and virtual reality technology to help facilitate the process and to ensure accurate feedback from the participants.

This study adopts a cross-sectional approach, with the time horizon of data collection spanning three weeks from 11 December to 31 December 2023. Prior to the formal experiment, participants completed the essential information section of the questionnaire (Appendix A). Each session for a participant lasted approximately 20 min, allowing time for setup, immersion in the virtual environment, and completion of the density perception evaluation questionnaire. During the experimental phase, participants wore HTC VIVE Pro2 VR headsets to observe the spatial configurations of 16 residential area models (Figure 7). The perception path in the VR experiment began at the diagonal boundary of the open space of each residential area, with the route roaming toward the central region of the open space. Participants were allowed to freely look around and evaluate the differences in density perception brought about by the various spatial configurations (Figure 8). Afterwards, participants viewed each scene for about 30 s before sequentially completing the density perception evaluation in a questionnaire, which researchers collected and analyzed.

Figure 7. VR Scenes of the Experimental Models.

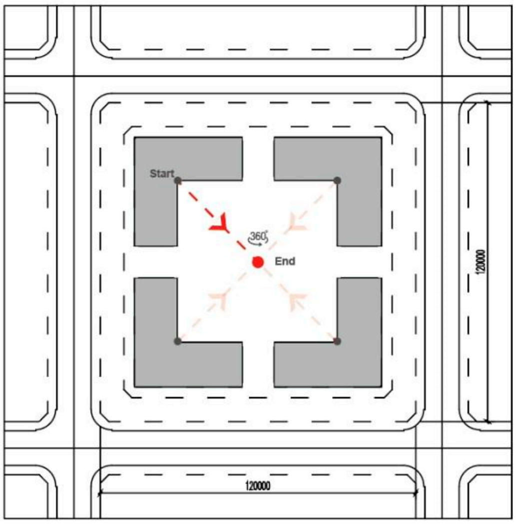

Figure 8. Perception Path.

3. Results

3.1. Descriptive Statistics

The questionnaire employed a Likert Scale to evaluate the volunteers' perceived density. Scores of 1 to 3 indicate positive perceptions, reflecting increasing levels of relaxation, soothing, and spaciousness. A score of 0 denotes a neutral state, while scores of −1 to −3 represent negative perceptions, indicating greater feelings of depression, tension, and crowding. To ensure the reliability and consistency of the perceived density evaluations, a reliability test was conducted, yielding a Cronbach's Alpha value of 0.705, indicating that the evaluation data from the 60 participants is relatively reliable [45].

Figure 9 and Table 1 provide a detailed overview of participants' evaluations of perceived density for the experimental models. The results reveal significant disparities in the perceived densities of various settlement layouts. The Staggered Slab-enclosed Layout (No. 8) received the highest median perceived density rating of 0.82, accompanied by overwhelmingly positive feedback. The Tower-enclosed Layout (No. 1–2) exhibited ratings ranging from 0.55 to 0.03, resulting in a median of 0.36. The Balanced Slab-enclosed Layout (No. 3–7) displayed a broad fluctuation in ratings, spanning from 0.77 to −1.28, with a median of −0.26. Notably, the Single-Corridor type (No. 7) model had a median rating below −1, indicating the most negative overall perception among participants.

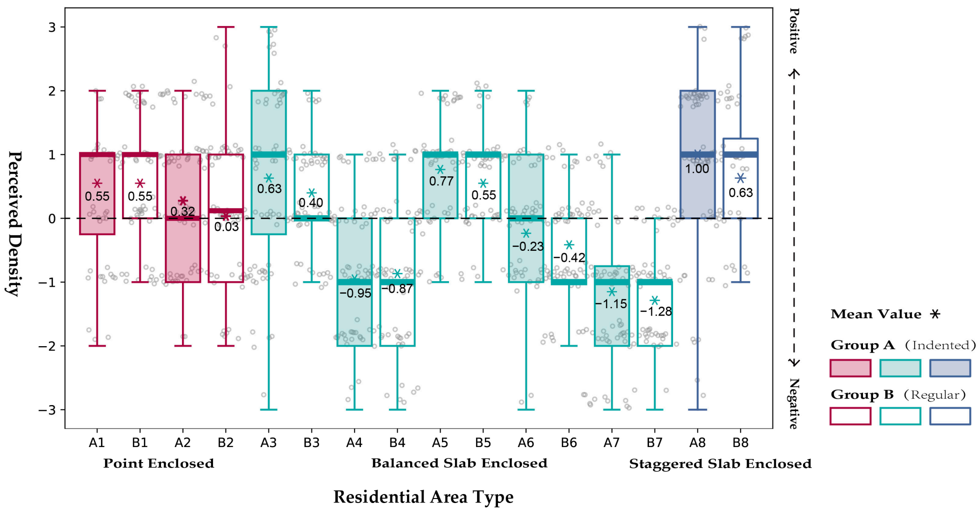

Figure 9. Scatter-Box plot of Perceived Density.

Table 1. Experimental Model Physical Metrics and Perceived Density Statistics.

Typology		Building Height	Building Coverage Ratio	Sky View Factor	Perceived Density
Tower-enclosed Layout	A1	84	20.44%	0.40	0.55
	B1	81	21.42%	0.36	0.55
	A2	102	16.44%	0.38	0.32
	B2	117	14.44%	0.52	0.03
	Group Mean Value	96	18.19%	0.42	0.36
Balanced Slab-enclosed Layout	A3	66	27.72%	0.38	0.63
	B3	66	27.72%	0.40	0.40
	A4	96	17.56%	0.31	−0.95
	B4	87	19.50%	0.31	−0.87
	A5	69	25.33%	0.41	0.77
	B5	66	27.28%	0.45	0.55
	A6	93	18.00%	0.37	−0.23
	B6	90	18.97%	0.29	−0.42
	A7	105	16.56%	0.33	−1.15
	B7	96	18.50%	0.35	−1.28
	Group Mean Value	83.4	21.71%	0.36	−0.26
Staggered Slab-enclosed Layout	A8	91	21.89%	0.42	1.00
	B8	69	26.75%	0.48	0.63
	Group Mean Value	80	24.32%	0.45	0.82

Table 1 presents critical built environment indicators from the experimental models, including building height, building coverage ratio, and sky view factors, which are analyzed in terms of perceived density. The building heights of the eight experimental groups vary significantly. On average, the Tower-enclosed Layout reach 96 m, the Balanced Slab-enclosed Layout is 83.4 m, and Staggered Slab-enclosed Layout is 80 m. The tallest is the Tower-enclosed Layout type B2 at 117 m, while the lowest is the Balanced Slab-enclosed Layout type A3 and B3 at 66 m. Regarding Building Coverage Ratio, Tower-enclosed Layout averages 18.19%, Balanced Slab-enclosed Layout 21.71%, and Staggered Slab-enclosed Layout 24.32%. The highest coverage (27.72%) is seen in types A3 and B3 of Staggered Slab-enclosed Layout, while the lowest is in Tower-enclosed Layout types A2 (16.44%) and B2 (14.44%). Regarding the Sky View Factor, the Tower-enclosed Layout average is 0.42, Balanced Slab-enclosed Layout 0.36, and Staggered Slab-enclosed Layout 0.45. The most open skies are in Tower-enclosed Layout B2 (0.52) and Staggered Slab-enclosed Layout B8 (0.48), while Staggered Slab-enclosed Layout B6 has the most compact skies at 0.29.

3.2. Regression Analysis

3.2.1. Ordinal Logistic Regression Model

Based on the characteristics of perceived density in terms of ordinality and discreteness, this paper employs the ordinal logistic regression analysis method to explore the correlation between physical spatial form indicators of residential areas and perceived density. Since the dependent variable (perceived density) is an ordinal categorical variable, the ordinal logistic regression model is more appropriate for the data characteristics of the survey results compared to the linear regression methods used in some studies.

This study employs the Cumulative Odds Model, assuming that the dependent variable has k levels, resulting in $k-1$ functions for the corresponding ordinal logistic regression analysis model. Let the probability of the dependent variable being at level $j(j=1,2,\ldots,k)$ be $P(\gamma = j \mid x)$. Then, the probability of the dependent variable being less than or equal to level $j(j=1,2,\ldots,k)$ is given by:

$$P(\gamma \leq j \mid x) = P(\gamma = 1 \mid x) + P(\gamma = 2 \mid x) + \ldots + P(\gamma = j \mid x), \quad (1)$$

Equation (1) can be referred to as the cumulative probability of below level $j(j=1,2,\ldots,k)$. By applying the logit transformation, it can be expressed as Equation (2):

$$\mathrm{log}it[P(\gamma \leq j \mid x)] = \ln\left[\frac{P(\gamma \leq j \mid x)}{1 - P(\gamma \leq j \mid x)}\right] = -\alpha_j + \beta_1 x_1 + \ldots + \beta_i x_i, \quad (2)$$

Equivalently expressed as Equation (3):

$$P(\gamma \leq j \mid x) = \frac{1}{1 + \exp(-\alpha_j + \beta_1 x_1 + \ldots + \beta_i x_i)}, \quad (3)$$

Subsequently, the probability of the dependent variable being at each specific level $j(j=1,2,\ldots,k)$ can be calculated as Equation (4):

$$\begin{aligned} P(\gamma = j \mid x) &= P(\gamma \leq j \mid x) - P(\gamma \leq j-1 \mid x) \\ &= \frac{1}{1+\exp(-\alpha_j+\beta_1 x_1+\ldots+\beta_i x_i)} - \frac{1}{1+\exp(-\alpha_{j-1}+\beta_1 x_1+\ldots+\beta_i x_i)} \end{aligned}, \quad (4)$$

Perceived density is categorized into seven levels with values of (PD = −3), (PD = −2), (PD = −1), (PD = 0), (PD = 1), (PD = 2), and (PD = 3). The corresponding ordinal logistic regression analysis model consists of six functions. The probabilities corresponding to each model are as Equation (5):

$$\begin{aligned} &P(PD = j \mid x) = \frac{1}{1+\exp(-\alpha_j+\beta_1 x_1+\ldots+\beta_i x_i)} - \frac{1}{1+\exp(-\alpha_{j-1}+\beta_1 x_1+\ldots+\beta_i x_i)} \\ &(j = 1,2,\ldots,7) \end{aligned}, \quad (5)$$

where

PD = j denotes the probability of perceived density at level j,
x_i represents the i-th independent variable,
α_j represents the intercept when the perceived density is at level j,
β_i is the regression coefficient.

3.2.2. Defining Variables

In this paper, the results of the perceived density questionnaire are used as the dependent variable, while the physical indicators from three aspects—maximum building height, sky view factor, and presence of recesses—are taken as independent variables. The coding information is detailed in Table 2. Standardizing the original variables with Z-score normalization is essential before further data analysis, as it ensures all variables are on the same scale due to differing units of measurement. To preliminarily assess the relationships between variables, a correlation analysis was conducted, with the results presented in

Table 3. The result indicates significant correlations between perceived density and the three physical indicators of the residential area. Specifically, it negatively correlates with building height and the recessed space, while it positively correlates with the sky view factor. The follow-up study further explained the degree of influence of each physical indicator on perceived density through ordinal logistic regression modelling. The models created in this study passed the model fitting ($p < 0.05$) and parallel line tests ($p > 0.05$), demonstrating statistical significance.

Table 2. Descriptive statistics for the variables.

Variables		Type	Description
Dependent	Perceived Density	Ordinal	"0" represented a neutral state; "1", "2", and "3" indicated three levels of increasing positive perceptions; "−1", "−2", "−3" represented three levels of increasing negative perceptions
Independent	Building Height	Continuous	the maximum height of residential buildings
	Sky View Factor		a dimensionless parameter used to quantify the portion of the sky visible from a specific point
	Recessed Space	Nominal	presence = 0; absence = 1

Table 3. Spearman correlation coefficient between perceived density and physical indicators of residential areas.

Variable		Building Height	Sky View Factor	Recessed Space
Perceived Density	Correlation Coefficient	−0.306 ***	0.382 ***	−0.065 *
	Sig. (2-tailed)	<0.001	<0.001	0.044

*** Correlation is significant at the 0.001 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

3.2.3. Model Results

The ordinal logistic regression results are provided by SPSS 27.0. The effects of independent variables on the dependent variable were analyzed with parameter estimation statistics. Parameter estimation in Table 4 explains the strength and statistical significance of the relationships between variables. β_i-value is a coefficient that expresses how the effect of variables on the dependent variable proportionally. e^{β_i}-value is used to interpret the effects of variable β_i-value, which provides insight into the strength and direction of the relationship between the independent and dependent variables. $e^{\beta_i} > 1$ indicates that an increase in the independent variable is associated with higher odds of being in a higher category, while $e^{\beta_i} < 1$ suggests that an increase is associated with lower odds of being in a higher category.

Table 4. Parameter estimation.

Variables	Building Height $_{Max}$	Sky View Factor	Recessed Space	
			Presence	Absence
Estimate (β_i)	−0.525 ***	0.604 ***	0.610 ***	0 [a]
Odds Ratio (e^{β_i})	0.299	4.018	4.074	0 [a]

Note: 1. *** Significant at the 0.001 level; 2. 0 [a] indicates reference.

The statistical tests found that the Building Height Max, Sky View Factor, and the Recessed Space all significantly impacted perceived density, which aligns with expectations. A significant negative correlation exists between the maximum building height and perceived density. For each standard deviation increase in building height, the likelihood of residents perceiving an improvement in density decreases by about 0.701 times. Thus, taller buildings are associated with a greater sense of crowding and oppression among residents. A strong positive correlation was identified between the sky view factor and recessed building facades with perceived density. For every standard deviation increase in sky view factor, the likelihood of residents perceiving improved density rises by 3.018 times. Likewise, recessed facades enhance perceived density by 3.074 times compared to regular facades. In essence, increased sky view factors in public spaces of residential areas or the conversion of regular facades into recessed designs significantly enhance residents' feelings of spaciousness and openness.

4. Discussion

4.1. The Correlation Between Residential Area and the Perceived Density

First, increasing building heights in residential areas negatively affects perceived density, intensifying residents' feelings of crowding and spatial oppression. A previous residential satisfaction survey in Hong Kong found that residents were dissatisfied with building height, which appears to negatively impact perceptions in densely populated areas [46]. Ye et al. [47] have identified that an evidence-based approach using virtual reality (VR) and wearable biosensors can effectively measure the spatial perception of ground conditions and inner spaces in high-rise buildings. Fisher-Gewirtzman [48] explores the impact of morphology on the perceived density of participants along pedestrian paths, highlighting that high-rise buildings significantly increase participants' perceptive density. Han et al. [49] conducted an empirical study in Seoul, South Korea, with the SegNet deep learning algorithm, which validly assesses the perceived psychological stress in the built environment of cities. Despite variations in urban morphology and socio-cultural contexts across different regions, which may influence the threshold at which residents perceive crowding due to building height, the negative impact of increased building height on perceived density appears to be a widespread phenomenon [50,51].

Second, the increased Sky View Factor (SVF) enhances perceived density, fostering a sense of openness and comfort. The correlation between SVF and perceived density has been confirmed by numerous scholars [52–54]. Incorporating SVF as an evaluation criterion in urban planning can help coordinate urban layout, enhance the built environment, and appropriately manage construction height and density [55]. Wen, Kenworthy, and Marinova [17] highlight that crowding is shaped by perceived density and human needs, making it essential to understand these factors for tackling the challenges of high-density urban areas. El-Didy et al. [16] proposed that low- and mid-rise buildings are effective for maintaining SVF and revitalizing street activity to reduce crowding. On the other hand, it is crucial to recognize that excessive sky openness in subtropical regions can substantially increase solar radiation and ambient temperatures, which adversely impacts the thermal comfort of urban settlements and the perceived well-being of residents [56,57]. This heightened exposure to solar radiation can exacerbate heat stress and reduce the overall livability of these environments. Thus, an optimal threshold for sky openness serves as a critical regulatory mechanism in balancing perceived density with other environmental qualities. This dynamic warrants further in-depth research to better understand its implications for urban design and environmental sustainability.

Third, the recessed space of residential facades can positively impact residents' perceived density. Wang et al. [58] examined the relationship between color elements and visual perception and comfort by analyzing the color matching of residential building façades in terms of hue, lightness, and saturation, which identified visual comfort gradually decreased with an increase in color saturation. Grounded in Visual Complexity Theory, Hashemi Kashani and Pazhouhanfar [59] explored the link between a building façade's physical attributes and public visual preferences across ten levels, which demonstrated that side recesses and ornamentation were the most significant factors influencing perceived visual complexity. The experimental results in our research show that facades with recessed spaces could promote residents' visual perception of outdoor areas. The reason may be due to the visual richness that recesses add, which helps reduce the perceived mass of the building and alleviate feelings of spatial oppression [60]. However, recessed designs may also expand the building's floor plan or height, complicating the balance between these effects on perceived density, a topic that deserves further exploration.

4.2. Recommendations for the Residential Layout

The Staggered Slab-enclosed Layout is the most recommended residential model for high-density cities, as it receives favorable evaluations for perceived density. Its enclosed design minimizes building height, enhancing the sense of enclosure, while the stepped upper sections promote openness to the sky. By arranging buildings in a staggered manner, this layout effectively increases the residents' field of vision and improves natural lighting, reducing the sense of enclosure. This design feature plays a crucial role in lowering the psychological perception of density [17]. Additionally, the Staggered Slab-enclosed Layout significantly reduces residents' subjective experience of crowding, offering a feasible solution for improving residential quality in high-density urban environments [61]. Although some units may not meet the full sunlight requirements, research indicates that this deficiency can be mitigated by incorporating other design elements, such as increased green spaces and public activity areas, thereby enhancing the overall attractiveness of the living environment [62].

Tower-enclosed Layout exhibits the second highest average perceived density. The results highlight that although the building height is relatively high, this layout provides a wide visual field and better ventilation, which helps alleviate the oppressive feeling of density. This finding aligns with previous research, which indicates that appropriate sky openness in high-rise environments can effectively reduce the perception of crowding [63]. Moreover, the Tower-enclosed Layout increases the distance between buildings, further enhancing the sense of openness in the living environment, which is consistent with earlier studies on the effects of building enclosure and open space design that suggest that open spatial layouts help mitigate negative psychological responses in high-density environments [59]. Further research is necessary to better manage perceived density as building heights rise. One possible solution is to integrate more green spaces and public areas to improve residents' satisfaction with their living environment [37].

The average perceived density rating for the Balanced Slab-enclosed Layout was the lowest. In particular, the dual-corridor layout (No. 3 and No. 5) effectively reduced the negative impact of height on perceived density by keeping building heights below 70 m, leading to positive evaluations. However, other balanced slab configurations received negative ratings due to their dense spatial organization, which created a more enclosed experience and somewhat diminished residents' comfort in public spaces. This discrepancy in evaluations may be attributed to the spatial qualities of the different layouts. The dual-corridor layout, by maintaining moderate building heights and ensuring sufficient spacing between structures, enhances visual openness and allows for better air circulation and natural light, factors that positively contribute to residents' perceptions of density and comfort [17]. In contrast, the more enclosed configurations, despite being space-efficient, limit the amount of visual and physical openness, which can exacerbate the sense of crowding [59]. Further exploration into optimizing building height and spatial arrangement may provide better strategies for improving perceived density without compromising the overall spatial efficiency of high-density residential areas.

Hence, to implement the Staggered Slab-enclosed Layout, it is essential to optimize the existing Tower Super High-Rise design and relevant architectural standards during the design process: (1) In the planning stage, advocate for better building arrangement efficiency and spatial experience by adopting an appropriate plot size (100–150 m) and implementing a contiguous building layout along the street; (2) Further increase the current requirement for a 25% building coverage ratio in Shenzhen to create favorable conditions for high coverage ratio enclosure layouts; (3) Adjust the current mandatory requirement that each unit meets daylighting regulation, introducing some unit types that may lack direct sunlight but offer good views or lower rental prices, thereby providing diverse value in unit products.

5. Conclusions and Limitations

This study examines high-intensity public housing development in Shenzhen, utilizing high-density block-style residential models from both domestic and international contexts. By employing virtual reality technology and statistical methods, it investigates how spatial forms influence perceived density in these areas. The research assesses the relationship between optimal residential designs and key spatial elements, proposing strategies and guidelines for future high-density public housing layouts. This paper draws the following main conclusions:

First, establish a quantitative framework to evaluate the relationship between the residential design configurations and perceived density in high-density public housing neighborhoods. The evaluation system analyzed 3 residential layout typologies with 16 models, highlighting a significant correlation between building morphology and perceived density. It is noticed that the Staggered Slab-enclosed Layout is the most recommended residential model, while the average perceived density rating for the Balanced Slab-enclosed Layout was the lowest.

Second, create an innovative assessment method using virtual reality technology to simulate residents' spatial experiences and evaluate density perception based on diverse building metrics. The results identified that: (1) greater building height intensifies perceived density, leading to sensations of overcrowding and discomfort; (2) an increased sky ratio mitigates perceived density, fostering a more open and pleasant environment; (3) recessed residential facades enhance residents' density perception.

Third, propose a design strategy that aligns perceived density with settlement morphology, providing tailored recommendations for creating high-density neighborhoods that balance livability, spatial efficiency, and urban resilience. During the planning stage, it is recommended to enhance building arrangement efficiency and spatial experience by selecting a suitable plot size (100–150 m) and creating a contiguous building layout along the street. Additionally, consider increasing Shenzhen's current 25% building coverage ratio to promote diversity and vibrancy in block-style residential layouts. Adapt to the mandatory residential daylighting code by offering compensatory unit types with improved views or reduced rental prices, thus increasing the value of a diverse public housing products.

This study focuses on the public spaces within residential areas, which may lack continuity and completeness in spatial scenes, potentially deviating from actual perceived density. Factors like the location and quantity of personnel, parking, and greenery can also influence perceived density to some extent. Future research should broaden the indicators influencing perceived density to include elements such as building color, landscaping, and acoustic, light, and thermal conditions, clarifying a reasonable scope of design standards. Moreover, the research scope could also extend to street spaces and high-rise residential spaces from an aerial perspective. With the increasing prevalence of personal wearable VR devices, future studies could implement online surveys in VR environments, enabling greater participation in perception surveys, thereby increasing the sample size and enhancing the measurement accuracy.

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

Appendix A

Questionnaire on Perceived Density in High-Density Public Residential Area Based on VR Experiments
Part I: Background

1. Gender: ☐ Male ☐ Female
2. Age Range: ☐ 18–29 ☐ 30–39 ☐ 40–49 ☐ 50 and above
   (Notes: reference from the local public housing policy)
3. Type of your Residence:
   ☐ Public Housing ☐ Commercial Housing ☐ Self-built House ☐ Other:

Part II: VR Experiment

4. Please rate the perceived density of the following 16 residential area scenarios as follows:
   (Range from −3 to 3)

Type	Crowded			Neutral		Spacious	
	−3	**−2**	**−1**	**0**	**1**	**2**	**3**
A-1							
B-1							
A-2							
B-2							
A-3							
B-3							
A-4							
B-4							
A-5							
B-5							
A-6							
B-6							
A-7							
B-7							
A-8							
B-8							

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