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Satisfaction with Nighttime Outdoor Activity Environment Among Elderly Residents in Old Gated Communities

Fang Wen *, Liang Peng, Bo Zhang *, Yan Zhang and Yuyang Zhang *

Department of Architecture, School of Architecture and Art, North China University of Technology, Beijing 100144, China; pengliang-leo@ncut.edu.cn (L.P.); zhangyan@mail.ncut.edu.cn (Y.Z.)
* Correspondence: fangwen@ncut.edu.cn (F.W.); abaodoc@ncut.edu.cn (B.Z.); yuyond@ncut.edu.cn (Y.Z.)

Abstract: China, like many other countries around the world, faces a rapidly aging population. "Aging in place" is the most popular choice for older people in China, with more than 90% of urban older people living in the same residential areas they did in middle age. Nighttime outdoor activity (NOA) is popular among the elderly and has a positive impact on both their physical and mental health. However, the conditions of nighttime activity places in old gated communities often do not meet the activity needs of the elderly, and there are problems such as low lighting and poor accessibility. This study focuses on typical old gated communities in a large city and analyzes data on three dimensions of independent variables: the lighting of activity places, the built environment of old gated communities, and the attributes of the elderly residents themselves. Taking "satisfaction with the environment for NOAs", "the biggest environmental problem with NOAs", and "locations that need improved lighting" as dependent variables, we used machine learning to calculate the contributions of various influencing factors on the dependent variables. It was found that the most important factors that influence satisfaction with the NOA environments are lighting levels, with the built environment or elderly residents' attributes being less important. The most important factor that influences older people's judgment of "locations that need improved lighting" is the perception of safety related to lighting in NOAs, followed by the perception of uniform lighting and green areas in their gated community. This study provides a reference for the renovation of age-friendly community environments as well as the overall enhancement of the nighttime activity environments in old gated communities.

Keywords: old gated community; nighttime outdoor activity (NOA); activity environments; outdoor lighting; elderly residents; environmental satisfaction; influencing factors

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1. Introduction

Populations across the globe are facing serious aging problems [1]. Researchers predict that by 2080, there will be more people aged 65 and over than children under 18 [2], and by 2054, older people could make up a third or more of the population in 16 countries and territories where the population has already peaked [3]. China is no exception to this global trend. Fortunately, decades of research has shown that living in familiar environments for as long as possible promotes both physical health and life satisfaction in older adults [4–6], and as a result, the concept of "aging in place" has led to an increasing number of older people in China choosing to live in communities and home environments rather than in institutions [7,8]. Research indicates that residential outdoor environments are the primary outdoor activity space that the elderly use on a daily basis [9], and familiar neighborhood

environments also make them more inclined toward social interaction activities within their communities [10]. Sufficient outdoor activities and interaction can promote the health of older people [11] and can also have a positive effect on their well-being in later life [12,13].

Outdoor activities at night are particularly important. For example, during regular working days in China, "office workers" and "school-goers" are only available in the community in the evening [14], and older people can interact with multigenerational residents and engage in relatively rich social lives [15], which in turn affects their physical and mental health [16]. Additionally, the effect of thermal comfort on outdoor activities is very significant for the elderly [17]. In summer, when the sun is too strong during the day and the air is hot, the night becomes a good time for older adults to engage in all manners of outdoor activities [18,19]. Indeed, activities at night can be beneficial to the health of older adults [20]; nonstrenuous walking, for example, helps the elderly fall asleep quickly [21].

Safe and comfortable activity places are thus very important for nighttime outdoor activities (NOAs) for older people [22], and lighting is obviously a crucial environmental condition. Bright lighting can illuminate places and prevent people from falling as well as other accidents during activities [23]. In addition, good environmental lighting makes people feel safer and encourages them to go out [24]. However, elderly individuals experience a decline in their ability to adapt to light and dark changes and recover from glare due to visual degradation [25,26], which results in reduced visual efficiency at night. Coupled with a decline in motor function, the difficulty of walking and engaging in activities at night increases, and the probability of falling under poorly lit conditions is much higher than during the day [20]. Therefore, elderly residents are more dependent on and have higher demands for nighttime outdoor lighting conditions than other residents [27], and there are differentiated and individualized lighting needs for different behavioral activities as well [28], both of which require high-quality lighting on roads and in activity spaces in residential areas at night.

Old gated communities are a specific type of residential area in China, with the characteristics of being "double old" [29]. First, due to the relatively early period during which they were constructed, in which there was little or no formal planning, they have problems such as old buildings and insufficient outdoor space [30]. Second, aging issues tend to be more severe in these communities, especially in large cities, with large populations of older people living in them [31]. Data from the Ministry of Housing and Urban-Rural Development show that there are 170,000 old gated communities reported to be in need of renovation across the country, involving over a hundred million residents [32]. There are low illuminance levels and poor uniformity of illuminance in many old gated communities, with many ground obstacles on roads and in activity spaces, and there are frequently problems with vehicles and items blocking the way, which pose certain risks to the elderly during NOAs [23]. At present, with the government taking the lead, the environmental renovation of old gated communities provides an opportunity to develop them into age-friendly residential areas.

Unfortunately, there is a dearth of research pertaining to the satisfaction of the elderly with NOA environments in residential areas. Existing studies have focused on the perception of lighting and safety at night for the elderly in outdoor settings such as pavements and parks [27,33,34], but overall, the field of lighting lacks targeted research for the elderly. Some studies have addressed the impact of residential lighting on the health of the elderly, such as the relationship between light pollution and sleep and disease [35,36]. However, there is a scarcity of lighting research that takes into account the outdoor behavior of the elderly at night, such as their perception of lighting during NOAs. Research on the satisfaction of elderly residents with outdoor public spaces in old gated communities has

already highlighted the importance of the built environment, including factors such as site grade difference, accessibility, green features, and outdoor lighting [37]. Therefore, whether the built environment also significantly influences the satisfaction of the elderly with the environment for NOAs is a question worthy of investigation. Additionally, previous studies have indicated a strong correlation between the frequency and richness of outdoor activities and environmental satisfaction [38]. Consequently, the characteristics of elderly people's NOAs are also likely to influence their satisfaction with the activity environments significantly.

In summary, this study addresses the gap in research regarding the lighting perception and environmental satisfaction of elderly residents during their NOAs in residential areas by focusing on older gated communities in Beijing, China. It examines the impact of built environmental elements, such as nighttime outdoor lighting, and elements of activity characteristics of elderly residents on their satisfaction with their community nighttime outdoor environments. Data collection was conducted through comprehensive investigation methods, including illuminance index measurements, behavioral observations, and questionnaire surveys. The subsequent analysis methods employed machine learning, in which we utilized a random forest model to conduct a comprehensive analysis of multi-dimensional indicators. This analysis aimed to identify the nighttime activities of elderly residents and the most critical factors that influence their environmental satisfaction. The goal is to provide a research reference for future improvements in outdoor environmental lighting conditions and to offer insights for the renewal of age-friendly environments in older gated communities.

2. Materials and Methods

2.1. Study Area

2.1.1. Selection of Old Gated Community Types

Based on existing studies, old gated communities in Beijing's urban areas are classified by their building layout, including determinant, enclosed, semi-enclosed, detached line, detached tower, and detached L-shaped [39,40]. For this study, we focused on old gated communities with multi-story residential buildings, which account for the majority of such communities in the city. Considering the characteristics of the lighting layout, four common types of old gated communities were selected (Table 1).

Table 1. The four types of old gated communities and their characteristics.

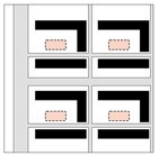
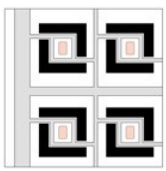
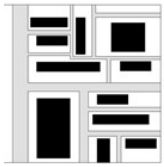
Type	Schematic	Layout	Environmental Features	Lighting Features
Semi-enclosed		The buildings do not form a complete enclosure.	Mostly a combination of L-shaped, U-shaped, and I-shaped detached buildings, generally with a high concentration of open space for activities.	The layout of the lighting fixtures in activity spaces is very different from the road lighting.
Enclosed		The layout presents several enclosed small groups of buildings.	Each group of small buildings has a centripetal character, with roads accessible from the four sides or corners of the group. The roads and buildings divide the group into more uniform activity areas.	Residents tend to engage in activities within the building groups, but lighting planning remains deficient due to the construction era.

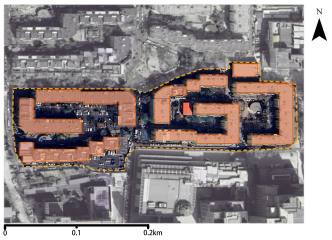
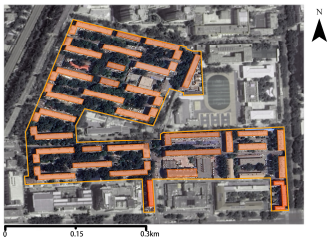
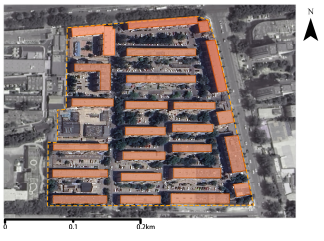
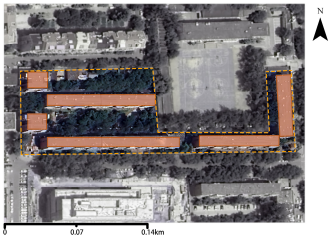
Table 1. *Cont.*

Type	Schematic	Layout	Environmental Features	Lighting Features
Determinant		All the buildings are arranged in rows.	The buildings are arranged evenly. Due to the lack of planning for centralized activity spaces during construction, residents use the open areas alongside the interior roads between the buildings.	Outdoor lighting is laid out in a regular pattern, with only neatly arranged streetlights on both sides of the interior road.
Detached		Historically, all single buildings were built separately and later brought together as a community for management purposes.	Residents have limited space for activities and conduct activities on interior roads.	The internal roads were laid prior to the urban roads of the old city, with lighting fixtures being old streetlamps that were later supplemented with lighting in spatial nodes.

2.1.2. Selection of Old Gated Communities

One typical community for each of the four types was selected from among those that had adequate space and had undergone at least some amount of renewal (Table 2).

Table 2. Basic information on the four gated communities in the study area.

Layout	Name of Sample	Code Name	Number of Households	Aging Rate (%)	Construction Dates	Maps
Semi-enclosed	Nanluyuan in Xicheng District	A	1055	31.0	1992–1995	
Enclosed	Guangminglou in Dongcheng District	B	1568	33.3	1950	
Determinant	Hengyitiao in Fengtai District	C	1538	35.4	1980	
Detached	Jingtaixili in Dongcheng District	D	426	33.3	1981–1986	

The four communities are located in the central area of Beijing, within 6.5 km of the downtown landmark, where there is a high density of residents (Figure 1). All four communities have property management tasked with ensuring a clean and safe environment.

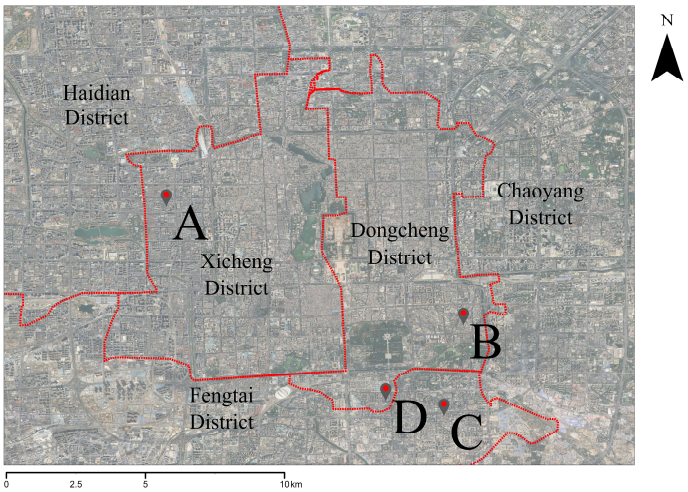


Figure 1. Locations of the four gated communities in Beijing, including their location relative to the downtown landmark.

2.2. Pre-Survey Research

2.2.1. Behavioral Observation and Lighting Index Measurements

We carried out pre-survey data collection in order to understand the NOAs of the elderly in the activity spaces of each of the four communities as well as their general relationship with lighting levels and the utilization of the sites. The most frequently used activity places within each community were selected for observation. On the nights of 7 and 8 June 2023, two observers conducted observation tasks onsite. Starting from 20:30 to 21:30, the observers recorded the behavior of the elderly at 10-minute intervals.

Two researchers conducted illuminance index measurements in the selected activity places on the evenings of 12, 13, 14, and 15 June 2023, between 20:30 and 22:00. For the measurement of both horizontal and vertical illuminance, the central point method was employed, and the average illuminance values and uniformity of illuminance were also calculated (Chinese Standard: Measurement methods for lighting GB/T5700-2008) [41].

2.2.2. Finding A: Generally Poor Lighting in Activity Locations

Based on the abovementioned data (Table 3), community B had the best lighting conditions in its activity locations; however, many of the lights also created glare. Community A exhibited the worst conditions as there was no lighting in the activity spaces, and the lighting on the roads was also in bad condition and obstructed by trees. Community C had added a few lights in activity areas during renovations, resulting in a stark contrast between the brightness of the new lights and the dimness of the existing ones. Similarly, community D had also added new lights in its activity areas, but the presence of numerous trees led to light obstruction.

The common characteristics of the nighttime activity environments in the four communities are as follows: the outdoor activity places were small, with some being spontaneously chosen by residents over the decades or designated by management departments, and the original lighting conditions were not intended for activity use. Roads were the second choice of location for many elderly residents to engage in activities, and plants in or around the activity spaces blocked the lighting (Figure 2).

Table 3. Illuminance index values in the activity places of four communities.

Community	Average Horizontal Illuminance, $E_{h,av}$ (lx)	Minimum Horizontal Illuminance, $E_{h,min}$ (lx)	Minimum Vertical Illuminance, $E_{v,min}$ (lx)	Uniformity of Illuminance, U_E
A	0.68	0.46	0.4	0.68
B	21.3	3.2	1.86	0.15
C	8.88	0.09	0.66	0.01
D	2.59	0.51	1.21	0.2

Figure 2. Lighting conditions of activity places in four old gated communities: (**a**) community A, (**b**) community B, (**c**) community C, and (**d**) community D.

2.2.3. Finding B: Elderly Residents Tend to Stay in Places with Better Lighting Conditions

During the observation period, there were no older people engaging in activities in the activity place of community D, although the elderly residents at the other locations varied between staying and walking through the other three activity spaces (Figure 3). In community A, the number of residents staying in the activity place decreased to zero over time, but the number of active residents increased over time in community C. Community B had the highest number of elderly residents staying in the activity place. Statistical analysis of the places where elderly residents stayed three or more times during the observed period yielded six such areas in community B and three in community C, with an average illuminance level of 21.1 lx across all nine areas. The number of older people passing through without staying in community D was significantly higher than that in the other three; however, this was possibly due to the smaller, narrow, and elongated site that had a pronounced lack of facilities for activities.

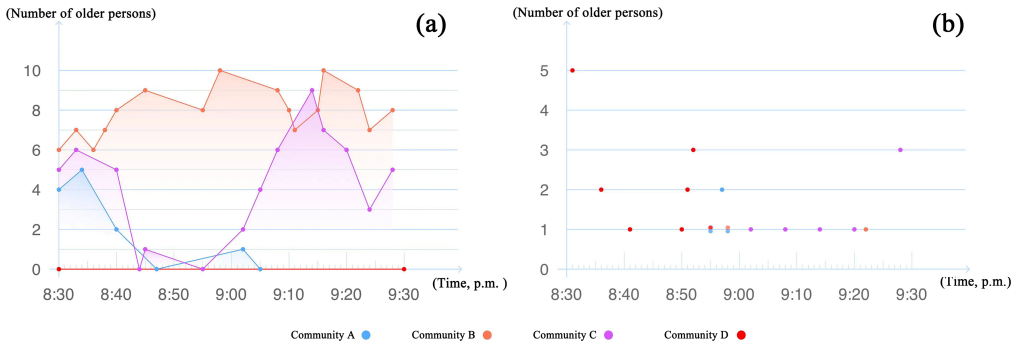


Figure 3. Elderly residents' habits of staying in (**a**) and walking through (**b**) activity spaces at night in the four gated communities.

2.2.4. Finding C: Low Utilization Rates of Activity Places by Elderly Residents at Night Are Not Only Related to Lighting Conditions

Our observations indicated that the number of older residents who use the activity places was quite small compared to the large population of residents in the communities. In community A, the elderly primarily engaged in childcare, and in community B, they mainly participated in activities such as playing chess and chatting. In community C, in addition to chatting, sitting alone, and childcare, there were also individuals who used fitness equipment. Under the condition of low overall illuminance levels, the selection of areas in activity places by older people was actually highly random (Figure 4a). When the uniformity of illuminance was uneven in one activity place, the elderly tended to stay in areas with better lighting conditions (Figure 4b). Their choices were also related to the layout of the site, especially in areas equipped with fitness equipment or rest benches, where lighting may not be a crucial factor (Figure 4c). However, the presence of equipment and adequate lighting in a place did not necessarily mean that the elderly would use it (Figure 4d).

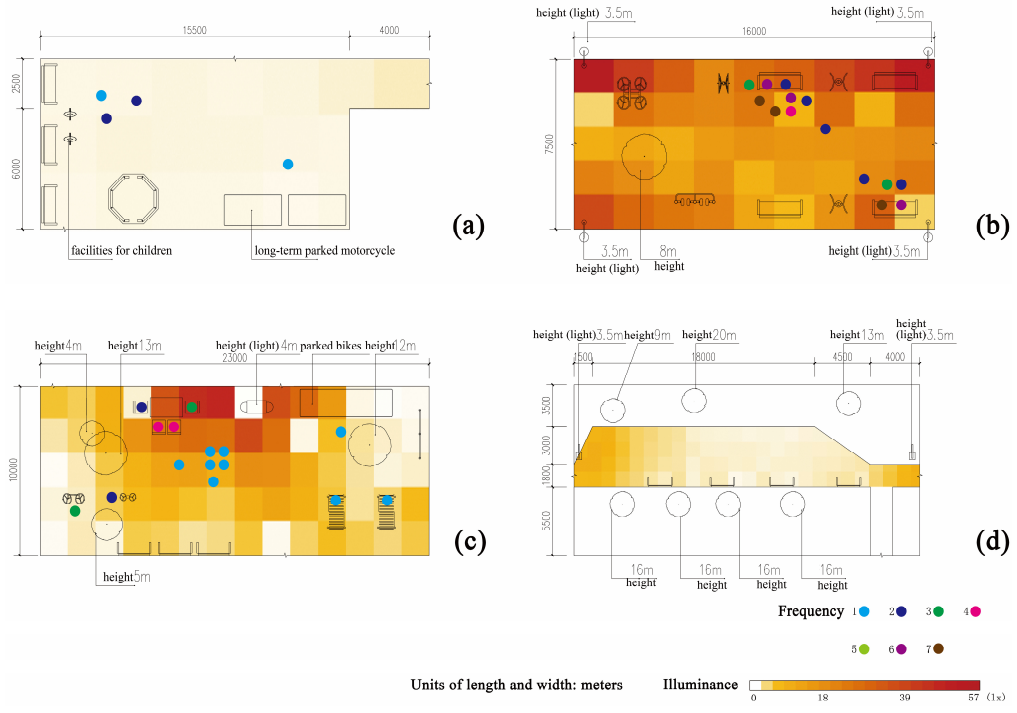


Figure 4. Combined heat map of illuminance in activity places for location characteristics of older users' stays at activity places: (**a**) community A, (**b**) community B, (**c**) community C, and (**d**) community D. The frequency represents the number of people present at that location at different times.

In summary, the factors that influence the NOAs of elderly residents extend beyond lighting conditions and are also related to the size of the activity places, the surrounding greenery, and other conditions. Furthermore, the utilization of outdoor activity places by the elderly is not only associated with nighttime lighting and the suitability of the site but is also linked to their demands for activities, which in turn are influenced by the layout of outdoor equipment. Based on these findings from our pre-survey research, we established specific indicators for dependent and independent variables.

2.3. Research Framework and Calculation

According to the research framework illustrated in Figure 5, this study systematically explored the impact of lighting levels, characteristics of elderly residents, and built environment features on elderly residents' satisfaction with environments for NOAs and their demand for lighting improvements. Regarding lighting level, we incorporated both index measurement and subjective perception indicators into this study. The former was obtained through onsite illuminance measurements, and the latter was collected through questionnaires. In terms of the elderly's characteristics, we considered residents' activity patterns and their own attributes, which are all measured via questionnaires. Built environmental features encompassed both onsite measured data and indicators calculated through a geographic information system (GIS). In the end, the dependent variables included "satisfaction with the environment for NOAs", "the biggest environmental problem with NOAs", and "locations that need improved lighting". A random forest machine learning model was used to calculate the importance of each potential influencing factor for each of the three dependent variables.

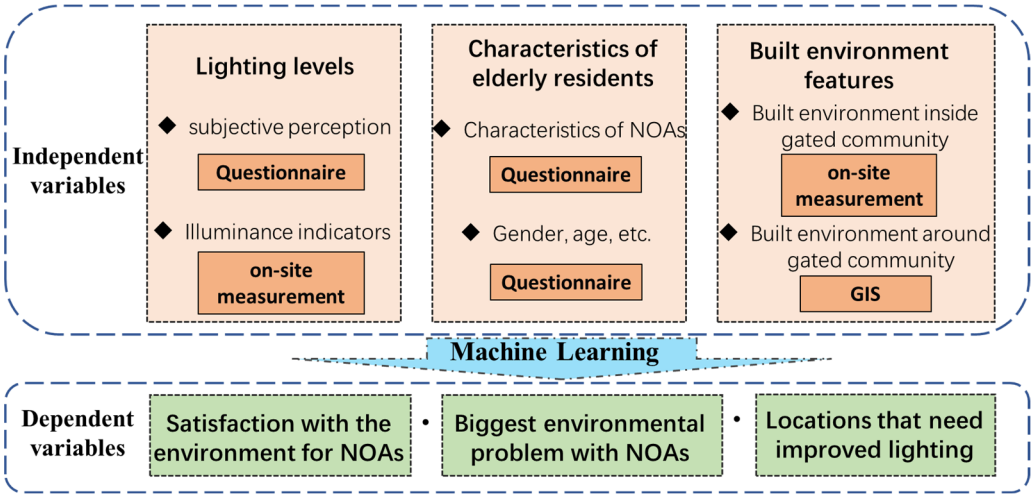


Figure 5. Research framework.

2.4. Dependent Variables

Data for the three dependent variables were obtained through questionnaires. We aimed to understand what influences older residents' "satisfaction with the environment for NOAs". A 5-point Likert scale was thus employed for evaluation, with 1 indicating the lowest level of satisfaction and 5 indicating the highest. Subsequently, through interviews conducted with elderly residents engaged in NOAs across multiple communities during the preliminary research, the main issues affecting their NOAs were categorized into five types, namely, "Small space, can't work out"; "Uneven ground, afraid of falling"; "Unregulated parking, many obstacles"; "Can't see clearly, the light is insufficient"; and "Few acquaintances, lack of communication", in addition to an "Other" option. This approach sought to identify which types of nighttime environmental issues were most troubling for

the elderly while also providing further understanding of the factors that influence their judgments. Finally, since lighting is the most critical factor in any nighttime environment, the perspectives of elderly residents regarding locations within the community that require improved lighting conditions are particularly important. Based on preliminary investigations, we identified several crucial spatial nodes with poor lighting conditions, including roads inside gated communities, entrances of gated communities, small gardens, building unit entrances, and garbage stations and activity places, in addition to an "Other" option.

2.5. Independent Variables

The independent variables were categorized into three dimensions: lighting level indicators, elderly residents' own characteristics, and built environmental features.

2.5.1. Lighting Level Indicators

The most critical factor that can influence the NOAs of elderly residents is lighting conditions. This study therefore combined subjective perceptional measurements with illuminance index measurements to relate the perception of the lighting with the lighting environment in order to clarify the relationship between the two.

(1) Indicators of subjective perceptions and data

In addition to research on visual tasks under different outdoor lighting conditions [27], "perceptual research" or "public perception" occupies a large portion of existing outdoor lighting studies. These generally include two parts: measurements of lighting and perception indicators, which both aim to obtain users' subjective feelings under specific lighting conditions. These aspects help to determine how different lighting indicators affect people's perceptions and to identify issues with lighting environments [42]. Many studies currently explore the visual comfort and perception of safety related to lighting during nighttime travel [43–45], such as Portnov's finding that increasing illuminance and its uniformity has a positive impact on people's perception of security [44]. Some scholars have researched the impact of different lighting environments on people's emotions as well, such as how different combinations of illuminance and color temperature evoke various positive and negative emotions [46]. Lighting perception research has also shown that nighttime lighting is an important factor that affects people's psychological aspect during nighttime travel, indirectly influencing satisfaction with NOAs [47].

In this study, a questionnaire was used to measure the perception of the elderly during NOAs in old gated communities. Building on previous research, it involved four categories of perception: perception of safety, visual comfort, perception of uniform lighting, and perception of light glare [33]. The first three perceptions were measured using a 5-point Likert scale, with 1 being the lowest score and 5 being the highest, with higher scores representing more satisfaction with the choice. Available choices for the perception of light glare were "many places with glare", "in 1–2 places with glare", and "no place with glare".

(2) Illuminance indices and data

Illuminance values are an essential representation of lighting conditions. Considering that activity places are the primary spaces for the elderly's activities, we used four types of indicators to characterize the lighting levels of activity places in each of the four communities: average horizontal illuminance, minimum horizontal illuminance, minimum vertical illuminance, and uniformity of illuminance. The measurement methods were the same as those used in our preliminary research on illuminance, the central point method from "Measurement methods for lighting (GB/T5700-2008)" [41].

2.5.2. Characteristics of Elderly Residents

The satisfaction of elderly residents with NOAs is not only related to the lighting environment but also to the characteristics of their NOAs themselves. Research has demonstrated that residents have varying demands for environmental conditions based on different types of activities and durations of activities; so, whether the environment can support their activities influences their satisfaction. Environmental support includes both physical space and the social support derived from the activities themselves [48], and previous studies have indicated a strong correlation between the frequency and richness of outdoor activities in parks and environmental satisfaction [38]. Thus, the characteristics of NOAs among elderly residents in residential communities impact their assessments of environmental satisfaction.

A questionnaire was employed to measure the behaviors of the elderly during NOAs, including companionship during NOAs, the frequency of NOAs, the duration of NOAs, NOA types, the most common NOA, NOA locations, and the reason for NOA location selection. The questionnaire also included three key variables for the elderly: age, gender, and the duration of residence in the gated community. A longer duration of residence is likely to reflect a resident's familiarity with the environment, but it may also be influenced by personal psychological factors and locale attachment [49]. The aspects above, along with the four perception questions, were placed together in the same questionnaire. On the nights of 26, 27, 28, and 29 June 2023, two surveyors distributed a total of 100 questionnaires across the four communities and collected 96 completed questionnaires, all of which were valid. The elderly who filled out the questionnaires were all informed and consented to the anonymous collection of their information. The font of the questionnaire was designed to be large enough for elderly respondents to answer independently. Additionally, when some elderly individuals had difficulty reading in dim lighting conditions, the surveyors conducted one-on-one interviews by asking each question individually and recording the responses.

2.5.3. Built Environment Indicators

Taking into account the influence of greenery within communities and the size of activity places of elderly residents' NOAs, we also incorporated other built environmental indicators, in addition to lighting level indicators, such as the area of all activity places, housing prices, floor area ratio, green space ratio, number of households in the gated community, road density, green space ratio, and density of bus stops within a 500 m buffer zone. Data collection was accomplished using field investigations, GIS calculations, and information retrieved from relevant websites (Table 4).

Table 4. Indicators of the built environment and their data sources.

Indicators of the Gated Community	Calculation Method	Data Sources
Housing prices	/	Lianjia.com https://bj.lianjia.com/ershoufang/ (accessed on 5 June 2023).
Number of households	/	Lianjia.com
Area of the gated community	Area of the occupied plot inside the boundary wall	Amap https://lbs.amap.com/?ref=https://console.amap.com/dev/index (accessed on 5 June 2023).
Total building area	/	Lianjia.com

Table 4. *Cont.*

Indicators of the Gated Community	Calculation Method	Data Sources
Floor–area ratio	Total building area divided by the footprint area of the gated community	Lianjia.com and Amap
Green area of the gated community	Total green area in the gated community	Amap
Green area ratio of the gated community	Total green area divided by the area of the gated community	Amap
Area of buffer zone	Area within the 500 m buffer zone around the gated community	Amap
Road density around the gated community	Sum of the lengths of all the roads within the 500 m buffer zone of the subdivision divided by the area of the buffer zone	Amap
Density of bus stops around the gated community	The total area of the 500 m buffer zone divided by the total number of bus stops in the buffer zone	Amap
Green area of the buffer zone	Sum of green areas in the buffer zone	Amap
Green area ratio of the buffer zone	Area of green spaces in the buffer zone divided by the area of the buffer zone	Amap
Area of all activity places in the gated community	The sum of the activity areas within the community	Field investigation
Area of all roads in the gated community	The sum of the areas of the roads within the community	Field investigation

2.6. Calculation Methods

Initially, we analyzed the results of the questionnaire using statistical methods to interpret the basic information of the elderly, the characteristics of their NOAs, and their perception of lighting. Subsequently, we employed a random forest classification model to analyze the influencing factors. Specifically, the parameters for the random forest model were set as follows: the number of decision trees (*n*_estimators) was set to 50, and the random seed (random_state) was designated as 42 in order to ensure the reproducibility of the results. During the model training process, we first standardized the dataset to mitigate the scale differences between features, thereby enhancing the model's convergence rate and predictive performance. In terms of dataset partitioning, we utilized cross-validation to determine the optimal ratio of the training set to the test set. Through grid search, we identified the most favorable ratio of the training set to the test set as 70:30 (70% of the data were allocated for model training and 30% for model testing). Under this configuration, the model was able to predict unseen data while ensuring a sufficient amount of training data. This approach not only ensured the model's generalizability but also introduced SHAP values to elucidate the model's decision-making process. The SHAP values quantify the contribution of each feature to the model's output. The plotting of a SHAP summary plot therefore assists in identifying which features have the most significant impact on the model's predictive outcomes by visually demonstrating the overall importance of each feature.

3. Results

3.1. Questionnaire on NOA Characteristics and Perception of Lighting

The questionnaire results indicate (n = 96) that among the respondents, elderly males constituted 57.3% and females made up 42.7%. Most of the elderly were in the young-old group (n = 82), with 12.5% aged between 70 and 79 and only two individuals aged 80 or above. This suggests that most of the elderly individuals engaging in NOAs are likely

to be younger. Additionally, most residents had lived at their current locations for over 20 years (n = 67, i.e., 69.8%). This indicates that elderly residents are likely to have witnessed environmental changes within their communities over the years.

In terms of NOA characteristics, the elderly residents predominantly engaged in activities alone (n = 71, i.e., 74%). Over the last three months of the study period (spring and the transition to early summer), most elderly individuals seemed to go out every night (n = 80, i.e., 83.3%), followed by those who chose to go out 3 to 5 nights a week (n = 15), with only one individual going out 1 to 2 nights per week. The ratio of the duration of NOAs of less than one hour to NOAs for over an hour was approximately 2:1. Furthermore, the most common types of activities were walking and chatting, followed by childcare. When several activity places were available, the primary motivation for choosing a location was convenience, in terms of distance, indicating that activity space layouts and the uniformity of their layouts within the community affected the number of users. Additionally, crowds and lighting conditions also influenced elderly residents' choice of locations.

In terms of lighting perception, more than a third felt comfortable, almost a third felt a moderate level of comfort, and almost 20% felt uncomfortable. The perceptions of safety were polarized; however, there was the same number of responses for "safe" and "unsafe", suggesting a stronger subjective element in lighting. The results on the perception of lighting uniformity also show polarization, similar to the sense of safety, with around 20% of individuals adopting a neutral stance. In terms of glare, 20% felt that the lighting was too harsh. Overall, we conclude that there are obvious shortcomings in terms of lighting safety and uniformity, with some problems with comfort and glare. Moreover, a large number of individuals selected the neutral option for lighting perception, which should not be ignored.

3.2. Important Factors for Satisfaction with NOA Locations

In response to questions about their satisfaction with NOA locations, nearly half of the elderly residents expressed satisfaction, although over 20% indicated dissatisfaction or extreme dissatisfaction. Approximately one-fourth of the elderly provided a neutral response. These figures indicate that there are issues with the NOA environments that prevent the majority of elderly residents from feeling satisfied.

From the SHAP-enabled random forest regression model (R^2 = 0.9, Figure 6), it is evident that the most important influencing factors that impact older people's decision of satisfaction with the NOA environments are their perception of safety and visual comfort related to lighting in NOAs, which are both subjective perceptions of lighting conditions. The top five most significant factors also include the minimum vertical illuminance and minimum horizontal illuminance of activity places, as well as the size of the green area of the gated community. Other important factors were the green space ratio of the gated community, the perception of uniform lighting during NOAs, the duration of NOAs, gender, and the perception of glare. Factors beyond these top 10 had relatively low importance. It is thus clear that subjective perceptions of lighting have the most significant impact on satisfaction with the environment, followed by illuminance indices; all lighting level-related factors constitute six of the top ten most significant factors, meaning that lighting is very important indeed.

The green area and greening rate of the gated community were the most significant built environment factors, whereas the density of bus stops and roads was less influential. The importance of activity duration was more obvious among the activity characteristics of the elderly themselves, but activity types and locations did not enter the top 10 in terms of importance. Overall, this shows that both the influence of the built environment

and the elderly's nighttime behavior characteristics on their satisfaction with their NOA environments are not as important as that of lighting.

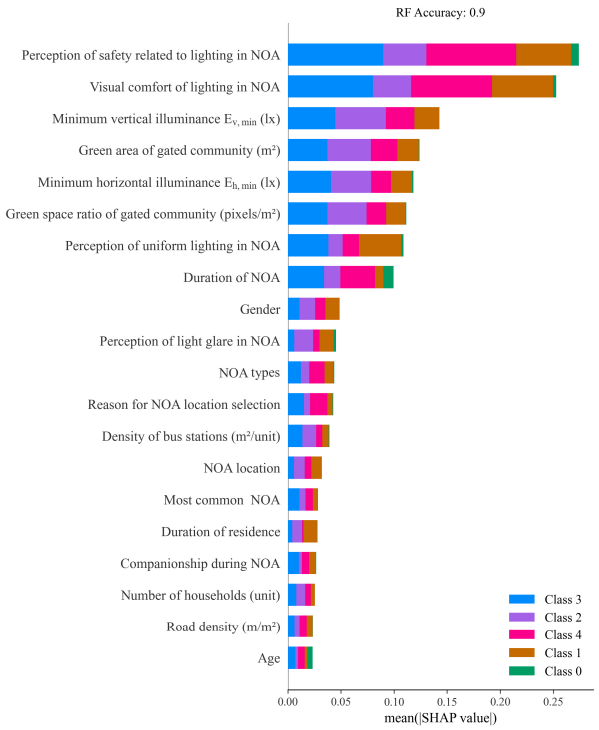


Figure 6. Importance of influencing factors for older people's satisfaction with the NOA environments.

3.3. Key Factors That Affect Elderly Residents' Judgment of the Biggest Environmental Problem in NOAs

The questionnaire responses indicate that elderly residents perceive the biggest environmental problem in NOAs as "small space", followed by "uneven ground", "messy parking", and "insufficient lighting". These factors are closely related to the environmental characteristics of historic old cities. Small places, uneven ground, and insufficient lighting are inherent environmental issues that require improvements during environmental renovation work; unregulated parking and many obstacles are management issues that also demand adequate attention from the government. From the SHAP-enabled random forest regression model (R^2 = 0.59, Figure 7), the top three most important factors that affect elderly residents' judgment of the biggest environmental problems in NOA locations were NOA types, the reason for NOA location selection, and the uniformity of illuminance. The top 10 influential factors also include age, gender, and the duration of residence in the community, as well as lighting level indicators, such as the perception of safety and minimum vertical illuminance, and built environmental characteristics, such as the green area of the buffer zone. It is thus evident that the characteristics of the elderly themselves are significant factors that influence their determination of the biggest environmental problems with NOAs as the top 10 most influential factors included 6 of these, with the characteristics of their NOAs having an even more substantial impact. The features of lighting levels were relatively less important, and the impact of the built environment was even lower. This differs from the results regarding "satisfaction with the environment for NOAs", where lighting level characteristics were the most important and the elderly's own attributes were the least significant.

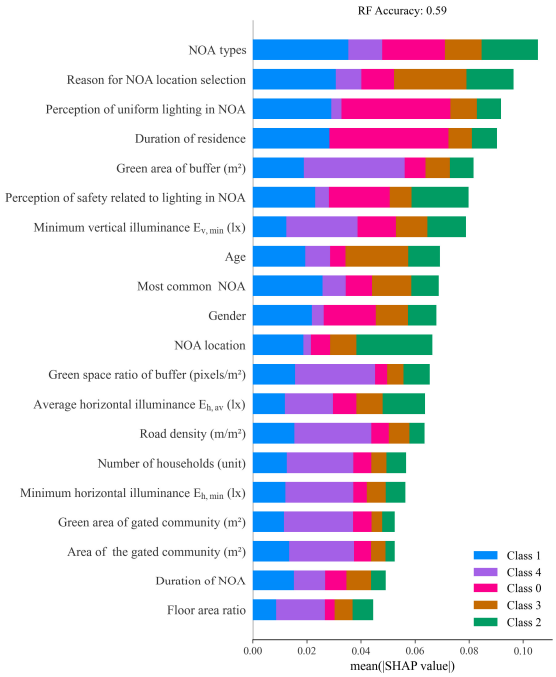


Figure 7. The importance of factors that affect elderly residents' judgment of the biggest environmental problems in NOAs.

3.4. Elderly Residents' Views on "Locations That Need Improved Lighting"

In the survey regarding the locations where elderly residents believe improvements in lighting conditions were needed (a multiple-choice question), the most frequently selected option was activity place, with over half of the elderly residents choosing this option, followed by roads inside their gated community and building unit entrances, with nearly half of the elderly selecting both. This result indicates that activity places are crucial environmental zones for NOA participation and that lighting layout is extremely important. Additionally, the lighting conditions of roads inside the gated community and building unit entrances also received ample attention from elderly residents, and the current lighting in these three types of locations frequently does not meet the needs of over half of elderly residents. Some elderly residents also indicated a need for improved lighting in small gardens, garbage stations, and entrances of gated communities, indicating that the lighting in important spatial nodes within the community was unsatisfactory.

A SHAP-enabled random forest regression model was used to calculate the importance of factors for the choice of each of the six locations in the question ($R^2 \geq 0.75$, Figure 8), and it showed that the most important factors were the perception of lighting safety, the perception of lighting uniformity, the type of activity, and the green area of the buffer zone, among which the perception of lighting safety was the most important influencer of the selection of roads, activity places, and building unit entrances as locations for lighting improvement. All of these belong to the subjective perception factors related to lighting and also indicate that the characteristic factors of illuminance have an important influence on the selection of locations where older people believe that lighting needs to be improved. The characteristics of the older people themselves (activity characteristics) and those of the built environment (buffer zone landscaping) were less important.

Statistical analysis revealed that among the top three and top five influencing factors for all location choices, the most frequent factors were the perception of safety and green areas in gated communities, respectively, belonging to categories of the subjective perception of lighting and the built environment. Expanding this analysis to the top ten factors, in addition to these two, the minimum horizontal illuminance and NOA types also had a

higher frequency of responses in the questionnaire. This shows that the illuminance level significantly influences the elderly's subjective judgment of whether to improve lighting at certain locations within the community. The influence of the built environment indicators was slightly weaker, and the influence of the elderly's own attributes was the lowest, which is similar to the results we obtained for satisfaction with the available environment for NOAs.

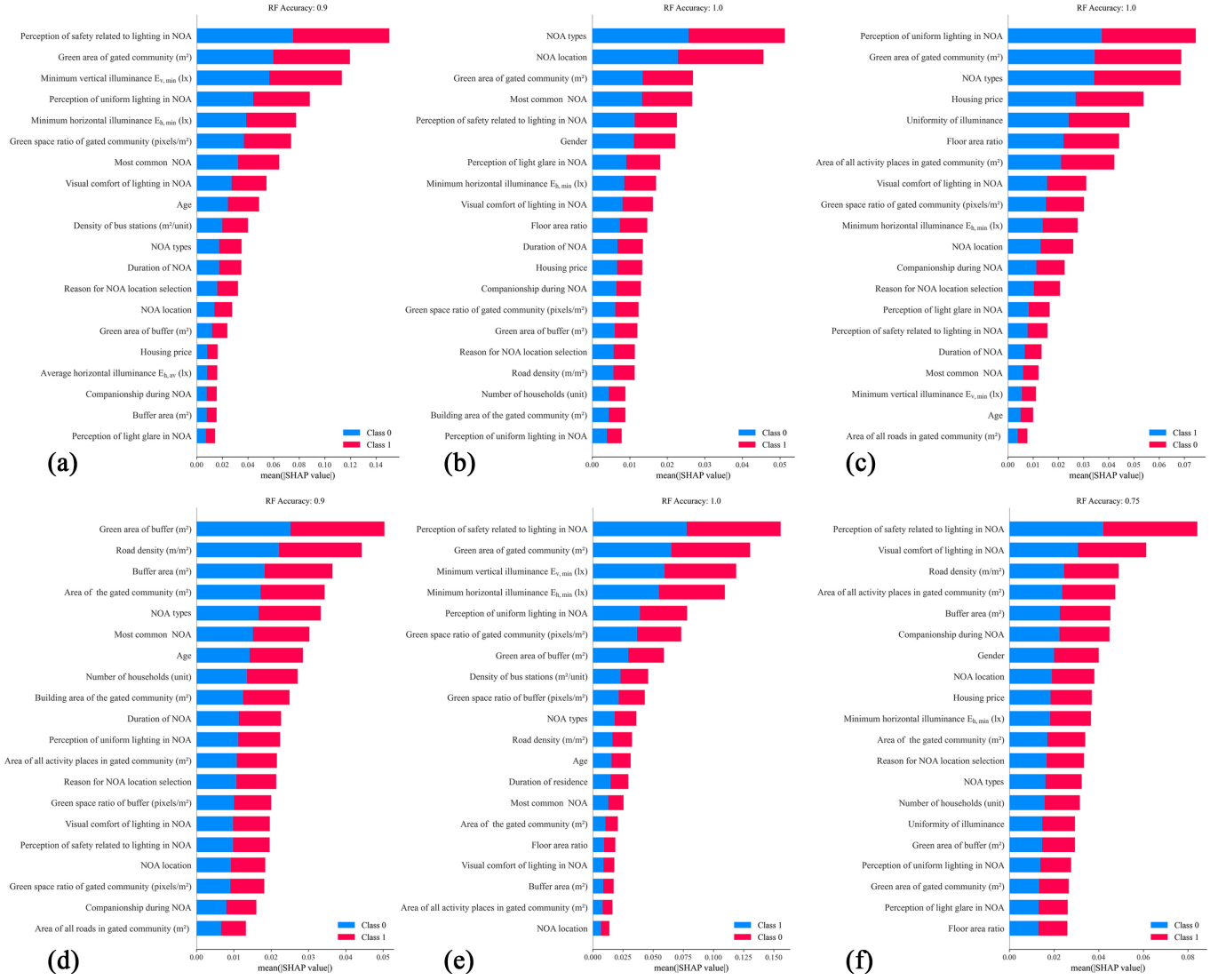


Figure 8. The importance of influencing factors for older people's choice of location for lighting improvement: (**a**) roads inside gated communities, (**b**) entrances of gated communities, (**c**) small gardens, (**d**) building unit entrances, (**e**) garbage stations, and (**f**) activity places.

4. Discussion

4.1. Current Lighting Environments in Old Gated Communities Are Insufficient for the Diverse and High-Frequency NOAs of Elderly Residents

The questionnaire results reflect the characteristics of elderly residents in old gated communities who engage in NOAs (Cronbach's alpha = 0.846 and KMO = 0.861). These elderly residents were primarily healthy and active seniors, with a significant proportion of respondents being young-old people and only 2.1% aged 80 and above. As elderly individuals experience physical decline, they are less able to participate in various NOAs, which is consistent with previous gerontological research on patterns of aging [50].

Our survey also indicates that elderly residents in older gated communities generally have a longer duration of residence, which underscores the high aging rate of the "double old" characteristics of these communities [29]. Elderly residents have a strong sense of belonging in their neighborhoods and a high tolerance for the physical environment, and although the buildings and outdoor facilities have become old, they still tend to exhibit relatively high levels of satisfaction due to their emotional attachments that have been developed over the years [51,52].

In terms of nighttime behavior characteristics, the frequency of NOA participation and companionship during NOAs, NOA types, and NOA locations deserve attention and discussion. The results of response frequency showed that over 80% of elderly residents engaged in outdoor activities every evening during seasons with favorable weather. The results also indicate that most of the time, elderly individuals went out alone for NOAs, which implies that in the event of a fall or other accidents, they may not receive immediate assistance. Therefore, steps should be taken to make NOA environments safer for elderly individuals who are out alone [53].

The most frequent and popular NOAs among the elderly are walking and chatting, with walking being an activity that extends to a wider area within the community and demanding higher standards for overall accessibility and lighting conditions. Not only should adequate lighting be ensured in various types of places, such as roads and activity places, but light uniformity must also be maintained across different spaces to avoid potentially dangerous accidents in the transitions from light to dark conditions or vice versa [54,55]. Previous domestic studies focused on lighting for residential roads but lacked clear standards for activity places, and international studies have not provided any detailed reference standards for activity spaces either (CIE 136-2000) [56]. Furthermore, no study has yet focused on the lighting perceptions of residents during their movements from one place to another.

NOA locations mainly consist of activity places and main roads, probably due to these locations' good lighting conditions, the relatively spacious sites, and the concentration of people in these areas. The primary motivation for elderly residents to choose an activity location is convenience in terms of distance when there are many activity places within a given community. However, it also reflects that the spatial scale of old gated communities is generally appropriate [31], with the distance elderly residents need to travel to reach activity places typically being within an acceptable range [57,58].

Elderly residents' perceptions of lighting in activity places during NOAs also show certain patterns. For example, the number of people who expressed dissatisfaction and extreme dissatisfaction was not small, with the proportion of such responses ranging from 20% to 40% for all factors, except visual comfort, indicating that there are many elderly residents who were dissatisfied with the lighting conditions. For many of the various indicators in the questionnaire, a considerable number of people held a neutral attitude; however, this may have been due to their indifference to lighting perceptions or their attachment and emotions towards their communities, making them reluctant to give negative opinions about their environments [52].

4.2. Lighting Conditions Are the Most Critical Determinant of the Elderly's Satisfaction with NOA Environments

Our results indicate that lighting levels have a significant impact on the elderly's satisfaction with NOA locations, particularly their subjective perceptions of lighting, all of which rank in the top 10. Therefore, if the goal is to enhance this satisfaction, the primary focus should be on improving the lighting conditions of activity places and even in communities overall. The perception of safety and visual comfort are two important indicators of age-friendly lighting [33]. Improving illuminance levels is crucial for allowing

elderly residents to see the outdoors clearly and better perform their visual tasks [27,59], enhancing their sense of safety. When they can identify uneven ground and spaces with obstacles to avoid falls, as well as vehicles and people, their control over the safety of their activity environment is greatly improved [60,61]. However, lights should be reasonably arranged to increase the uniformity of lighting so as to avoid patches of light and dark conditions or strong contrasts between them [62]. Enhancing the visual comfort of elderly residents and strengthening their perception can enable them to carry out activities more safely and efficiently [28].

Based on our survey results regarding the elderly's judgment of "locations that need improved lighting", the top three locations where improvements were deemed necessary were activity places, roads inside gated communities, and building unit entrances, with the perception of safety being the most important factor that influenced the judgments of these three locations. Moreover, these three types of spaces are all important locations on the main activity routes of elderly residents at night; so, their lighting conditions should be prioritized for renovation. To enhance the sense of safety felt by elderly residents, measures such as increasing environmental brightness and eliminating lighting dead zones can be implemented [61,63]. Additionally, since most building code specifications have different standards for lighting in residential roads and activity areas (CIE136-2000, CIE115-2010, and the standard for the lighting design of urban roads in China) [56,64,65], the strong contrast between dim road spaces and bright activity areas may cause visual discomfort; so, transitional lighting in these three spaces should be installed during the renovation process [54].

The lighting issue in small gardens reported by many residents is due to plants blocking the lights, which can lead to feelings of insecurity while walking [66]. One method of dealing with this is simply to prune plants in a timely manner. A more practical and reasonable approach, however, is to add ground lights to illuminate the path beneath pedestrians' feet [66,67]. In addition, good lighting at the entrance of gated communities and garbage stations is very important for elderly residents entering and leaving their communities at night and for those disposing of garbage. The renovations of the lights in these areas should first meet the basic functional lighting needs of the elderly residents and then follow the same guidelines as those for activity places.

In summary, lighting conditions are key to safe NOAs for elderly residents and are an important factor that affects these residents' satisfaction with their NOA environments. Improving lighting conditions are therefore an effective means to promote outdoor activities among the elderly [68]. In the future, specific renovation measures for outdoor lighting design in residential areas with different characteristics should be explored based on the differentiated needs of elderly groups in different types of communities.

4.3. Environmental Issues That Affect Elderly Residents' NOAs Deserve Attention in Renewal Plans for Old Gated Communities

Although the most important factor that affects the satisfaction of elderly residents with NOAs is lighting, the biggest environmental problems subjectively identified by elderly residents were not lighting-related but rather the small size of activity places, uneven ground, and unregulated parking, which are longstanding issues [37]. Due to the lack of planning during construction and current land use restrictions in the old city areas where old gated communities are typically located [69], current community activity places cannot be expanded to meet the needs of elderly residents for many activities, both during the day and at night. Uneven ground is related to the lack of reasonable barrier-free modifications, and the presence of uneven ground in renovated communities is a symptom of the poor level of barrier-free construction [70,71].

"Messy parking" has always been a difficult issue in the governance of large cities. Due to the very tight parking spaces in old gated communities and the large number of private cars, it is inevitable that vehicles occupy activity spaces, and there is an urgent need for effective parking solutions [72,73]. Additionally, small activity places can affect the normal course of NOAs for elderly residents, not only easily leading to collisions with furniture, for example, but also reducing their willingness to use the spaces due to concerns about overcrowding. Uneven ground and unregulated parking can threaten the safety of elderly residents while walking due to the risks of falling, bumping into objects or people, or being hit by vehicles [74].

The most important factors that influence elderly residents' subjective judgments of the biggest environmental issues were not lighting conditions but rather the residents' own activity characteristics, such as NOA types and reasons for NOA location selection, which is consistent with previous studies on the different space needs for various types of activities among elderly residents [75,76]. Different types of activity can lead to different perceptions of environmental adaptability. For instance, walking requires the continuity of barrier-free spaces, but sitting for a rest or a chat does not need much environmental support, especially regarding the size of the space, its lighting conditions, or its barrier-free environment. Therefore, when improving the lighting, it is necessary to refine it to the specific activity demands of a given place. In addition, the basic attributes of elderly residents also have a significant impact on their judgment, such as their age, which may affect their adaptability to the environment, and the duration of residence, which may affect their objectivity of judgment [51,77].

In summary, in order to address the issues with NOA environments for elderly people, renovations of physical spaces and improvements in lighting conditions need to be carried out simultaneously. Not only should activity places be enlarged and age-oriented retrofitting and barrier-free design be implemented but parking problems should also be solved.

4.4. Other Factors Should Also Be Included in Future Research

In the context of lighting conditions, our findings indicate that subjective perceptions have a greater impact than objective indicators due to the diverse sources of subjective feelings. In practice, subjective perceptions of lighting are the result of a combination of factors such as the brightness and color temperature of the light, the form of lighting fixtures, and the height of the light sources [78,79]. They can even be related to the openness of the field of view and landscape characteristics within it [80,81]. Therefore, in lighting modifications, attention should be paid to other indicators beyond illuminance, and it is necessary to summarize all the various types of influencing factors. Instead of blindly following the recommended values for illuminance and glare according to standard guidelines, the user experience should be appropriately considered and the differentiated needs of elderly resident groups in different residential areas should be explored [43,79].

Among built environmental indicators, the most significant influencing factor in this study was green space attributes in the gated communities, including green area and green space ratio. However, this is a "double-edged sword". Although good greening is needed to enhance the attractiveness of outdoor activity spaces [82,83], it can lead to the obstruction of light at night [84]. Thus, it becomes necessary to measure the scale of greening within activity places in order to find a good balance between pleasing greenery and light obstruction [85].

Preliminary behavioral observations also reflect other influencing factors, such as the shape of activity places and the layout of the facilities within. Our observations reveal that not all activity places with lights necessarily attract elderly residents' activities. The

question of whether the elderly stay is related to places suitable for their stay. Narrow and long-shaped sites are not conducive to stay for the elderly and are, for the most part, merely traversed; the presence of rest seats and fitness equipment in a place also affects whether it is used for activities, with the former playing a more significant role [85–87].

In addition, excluding weather conditions, even when the size of an activity space is appropriate, the lighting is suitable, and the facilities are well arranged, there may still be no older people using it. The occurrence of such situations may be related to the lifestyle, social habits, and neighborhood relationships of the elderly residents within a gated community [88]. For example, the preference for daytime activities or the habit of going outside for organized group activities (square dancing, for example) can lead to the desolation of nighttime activity places [89]. The "acquaintance society" of the old gated community prompts a shift by the passing or moving away of the elderly, leading to indifferent neighborhood relationships [90]. All of these potential factors that may affect NOAs still require further research [91].

4.5. Limitations

This study has certain limitations. First, although four old gated communities with relatively typical spatial structures and layouts were selected, they do not necessarily represent all old gated communities, and the districts where they are located covered only three out of the six central urban districts in Beijing. Future research should therefore expand the scope of residential area samples, diversify the sample types, and increase sample sizes to validate the conclusions of this study. Additionally, the survey for this study was conducted during the transition from spring to summer, which does not cover all the seasons suitable for elderly activities. Future research should thus be repeated in the suitable weather conditions of spring, autumn, and the transition from summer to autumn in an effort to obtain more comprehensive research conclusions. Finally, this study did not sufficiently consider the micro-scale factors of the built environment, such as the quantity and layout of facilities in activity places. Factors such as the social habits of elderly residents and neighborhood support have not been summarized, and the independent variables characterizing the elderly residents themselves were not exhaustive. These aspects should be considered in subsequent studies.

5. Conclusions

Previous studies on nighttime outdoor behavior and their environments have largely focused on pedestrian lighting safety perception, visual comfort, and lighting efficiency but lack analysis of the environment for nighttime activities within residential outdoor areas that are specific to the elderly. In China, old gated communities constitute a significant proportion of the central urban areas of large cities, and due to their "double old" characteristics, they have more environmental issues as well as higher numbers of elderly residents compared to new residential areas. In this study, we selected four typical old gated communities in the central urban area of Beijing and collected information about their available NOA areas through onsite investigation, behavioral observation, and questionnaire distribution. The characteristics of lighting levels, the attributes of the elderly themselves, and the characteristics of the built environment of the communities served as three dimensions of independent variables, with their data being obtained through field measurements, questionnaires, and GIS calculations. "Satisfaction with the environment for NOAs", "the biggest environmental problem with NOAs", and "locations that need improved lighting" were used as three dependent variables, with their data being obtained via questionnaires. Using both statistical and machine learning methods, we analyzed the NOAs of the elderly and the most critical factors affecting the dependent variables

and found that although elderly residents in old gated communities frequently engage in NOAs, the lighting in their activity spaces does not fully meet their needs. Other problems included issues with the size of activity spaces and uneven ground.

This study reveals that the important factors for the elderly's satisfaction with NOA environments were lighting level indicators, and the most significant factors that affected elderly residents' judgment of the biggest problems with NOA spaces were nighttime activity characteristic indicators related to the elderly's own attributes. The most critical factor that influenced the judgment of locations that needed lighting improvement was the perception of safety; the impact of built environment indicators was relatively low, and only greening in the community was of real concern. These results highlight the importance of improving outdoor lighting conditions, and we recommend that this be the primary task of the environmental renovation of old gated communities. Historical issues such as small activity spaces need appropriate modernization, and management issues such as uneven ground and unregulated parking need to be addressed urgently. Other factors, such as the elderly's social habits or neighborhood relationships, also have a certain impact on their NOAs and should be studied as independent variables in the future. In summary, this study serves as a reference for improving outdoor lighting conditions in old gated communities and offers insights for enhancing the nighttime vitality of residential areas with a large number of elderly people.

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Informed Consent Statement: Older adults who filled out the questionnaire were all informed and consented to the anonymous collection of their information.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

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