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A Study on the Innovative Integration of Age-Friendly Elements in Architectural Design and Their Impact on the Living Environment

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Abstract In response to the urgent demand for living environments caused by population aging, this paper explores a collaborative optimization strategy combining architectural design space optimization and smart home technology. A network indicator system for architectural space was constructed, the fitness of network structure nodes was calculated, and a space optimization model based on the microhabitat genetic algorithm was established. The design of the aging-friendly smart home system incorporates Zigbee technology, featuring a low-power network topology and protocol stack, and deploys a fall detection model for elderly individuals living alone based on the YOLOv5 object detection model. The spatial optimization model improved spatial utilization efficiency and fitness to 78% and 96%, respectively. The smart home system achieved a 96.8% accuracy rate in fall detection for the elderly, and user satisfaction evaluations saw varying degrees of improvement across six dimensions. This approach not only meets the monitoring and assistance needs of elderly individuals living alone while enhancing their comfort but also provides a scientific solution for the renovation of living environments in an aging society.

Index Terms microhabitat genetic algorithm, architectural design space optimization, Zigbee technology, Yolov5 algorithm

I. Introduction

According to statistics, by the early 21st century, the global population of individuals aged 60 and above had reached 620 million, accounting for approximately 10% of the world's total population. This clearly indicates that population aging has become an inevitable trend in human societal development, and the resulting challenges of elderly care have now escalated into critical issues that nations must address with urgency [1]-[3]. Population aging is a global challenge that all nations must confront. Addressing the housing needs of urban elderly populations and creating a senior-friendly living environment are complex challenges that must be resolved in the future development of national economies and urban planning and construction.

The issue of elderly care in the current living environment is a top priority for the state. On the one hand, due to the decline in physical functions, the elderly have a significantly reduced range of outdoor activities and typically center their outings around their residences, engaging in leisure and recreational activities in green spaces, squares, and building entrances within their residential areas. As a result, the external living environment has become the primary activity space for the elderly [4]-[7]. On the other hand, in most major cities, buildings constructed from the 1980s to the early 21st century primarily consist of multi-story residential structures without elevators. Such residential building designs fail to meet the needs of the elderly, resulting in a significant mismatch between the physical, mental, and psychological needs of urban elderly residents and their living environment [8]-[10]. Seo [11] pointed out that the development of high-rise buildings has distanced the elderly from the ground-level areas of the community, leading to feelings of alienation and a lack of belonging, which is detrimental to social interaction. Additionally, traditional residential environments have serious deficiencies in stair height, door width, emergency call systems, fall prevention design, and thermal comfort, exposing safety hazards for the elderly [12], [13]. Ismail et al.[14] found that preferences for age-friendly housing design prioritize the bathroom, bedroom, kitchen, flooring, living room, and staircase. Therefore, incorporating age-friendly elements into housing design is necessary.

The integration of age-friendly design elements can effectively enhance the self-care abilities of the elderly, creating an accessible and convenient living environment for them. This enables them to independently perform various daily activities, reduce their reliance on others, boost their confidence and sense of well-being, and live more safely and comfortably in familiar surroundings. Additionally, it alleviates the caregiving burden on their children, allowing them to work and live with greater peace of mind [15]-[18]. Zhou et al. [19] noted that age-friendly architectural design can help alleviate anxiety and fear in elderly schizophrenia patients, positively impacting symptom improvement and reducing the utilization of medical resources. Tanutama et al. [20] developed a fall detection and emergency warning system for bathrooms in residential settings, using sensors to detect elderly movements. The system employs PIR detectors to monitor movement patterns, with warning indicators activating when no movement is detected, and signals transmitted to home care providers. Tseng et al. [21] designed a care management and guidance safety system for dementia patients, utilizing ultra-wideband positioning technology to provide location tracking, send location reports, and plan routes for patients and their caregivers. Amaripadath et al. [22] used EnergyPlus software and genetic algorithms to optimize thermal comfort design for elderly-friendly residential facilities during extreme summer conditions, aiming to provide age-appropriate thermal comfort.

Traditional residential buildings often have deficiencies in terms of aging-friendly design, such as unreasonable spatial layout, insufficient comfort, and lack of emergency response capabilities. This paper proposes an improvement strategy that combines spatial optimization with intelligent home technology. In terms of architectural space optimization design, a small-scale genetic algorithm is proposed to reconstruct the architectural space network. In the field of smart home technology, an aging-friendly smart home system for fall prevention is developed based on Zigbee technology and the YOLOv5 model, ensuring the safety of the elderly. Through experiments such as spatial adaptability simulation and user satisfaction testing, the feasibility of the proposed work is validated.

II. Application of age-friendly design in architectural spaces

II. A. Optimizing spatial layout

A reasonable spatial layout in architectural design can not only enhance the quality of life for the elderly but also improve the safety of daily living. Therefore, when designing spaces for aging-friendly renovations, it is essential to focus on the physiological and psychological needs of the elderly and optimize the spatial structure layout accordingly. (1) Increase the flexibility of spatial structures to allow the elderly to freely adjust architectural layouts according to their needs. For example, in aging-friendly kitchen renovations, install adjustable-height countertops. (2) Emphasize barrier-free design by eliminating floor level differences, widening corridors to expand the elderly's activity space, and adjusting switch heights to enhance operational convenience. (3) Select colors and materials based on the visual characteristics of the elderly to make the indoor space more warm and inviting. Specifically, when renovating space layouts for the elderly, consider incorporating colors with higher saturation and brightness, such as yellow, into the design. By creating a bright and vibrant indoor environment, the elderly can maintain a sense of joy and well-being. Additionally, materials that meet the daily living needs of the elderly should be selected in conjunction with the artistic effects of the space design. For example, high-friction floor materials can be chosen to meet the elderly's need for balance while walking. By selecting eco-friendly materials to design indoor furniture, the elderly's demand for a healthy living space can be met.

II. B. Smart Home Systems

In the design of aging-friendly architectural spaces, it is essential to prioritize the design and practical application of smart home systems. First, in terms of residential safety, integrate technologies such as artificial intelligence, localized data processing, and sensors to create an intelligent, interconnected security system. The key is to install various types of sensors in appropriate locations, particularly those responsible for real-time data collection and monitoring. For example, install smart door magnets at the entrance to monitor and identify the status of the door in real time. In kitchens and bathrooms, smart water leakage sensors, smart gas alarms, and smart smoke detectors should be installed to monitor gas leaks (including natural gas and liquefied petroleum gas) and smoke concentration in real time, automatically triggering audio-visual alarms upon detecting abnormalities. Additionally, a real-time feedback mechanism for monitoring data is established via a wireless network, enabling different types of monitoring data to be centralized and fed back to the user end. Furthermore, the security system features real-time warning functionality. When the system detects abnormal conditions, it automatically triggers an alarm procedure and synchronizes warning information to the user end, allowing family members to promptly address any dangers the elderly may encounter. Moreover, an emergency response mechanism is established using intelligent devices, enabling the elderly to initiate an emergency call for assistance with a single button press when faced with urgent situations.

III. Architectural design space optimization methods

III. A. Construction of Architectural Design Space Network and Indicator Analysis

The construction of an architectural design spatial network is a critical step in optimizing architectural design spaces. A well-designed architectural design spatial network structure should possess the characteristics of diversity, multi-level, and systematization to meet the needs of different elderly populations and provide more comprehensive and considerate services. Among these, diversity is a fundamental requirement for the architectural design spatial network structure. When constructing the network structure, different types of spaces must be considered. These spaces should have distinct functions and characteristics to accommodate the needs of different elderly individuals. Multi-level structure is an important feature of the architectural design spatial network structure. Spaces at different levels should complement and support one another, forming an organic whole. Systematization is a necessary condition for the architectural design spatial network structure. All nodes within the network should be interconnected and coordinated, forming an organic whole. This requires the establishment of a comprehensive operational mechanism and management system to ensure the effective utilization and optimal allocation of various resources. By adhering to the aforementioned principles, a comprehensive architectural design spatial system can be established to better meet the needs of the elderly and enhance their quality of life.

In the architectural design spatial network structure of this paper, living service nodes, commercial space nodes, and group green space nodes are used as the foundation for reasonable construction.

When constructing the architectural design spatial network structure, the above three types of nodes need to be reasonably laid out and integrated to meet the health, leisure, and living needs of the elderly. On this basis, to ensure the scientific rationality of the constructed network structure, it is necessary to analyze the interrelationships between different nodes. The specific analysis process is as follows:

$$\begin{cases} P = \dfrac{2L}{N(N-1)} \\ Q = \dfrac{1}{2m}\sum_{i,j}[A_{ij} - \dfrac{k_i k_j}{2m}]\delta(c_i, c_j) \end{cases} \tag{1}$$

In Equation (1): P represents the closeness between different network nodes, L represents the number of connections between different network nodes, N represents the number of network nodes, Q represents the modularity of the network structure, m represents the number of individual network nodes, k_i, k_j represents the fusion degree of different network nodes, $\delta()$ represents the formula for calculating the modularity of the network structure, c_i, c_i represents the parameter value of the network structure, and A_{ij} represents the stability of the network nodes. By calculating the closeness and modularity of network nodes using Equation (1), we compare the values of these two metrics to assess the connectivity of the current network structure and evaluate its partitioning effectiveness. If both values are too small, it indicates that the current network structure's partitioning effectiveness is poor, and it needs to be re-partitioned according to the established rules. With this, the design of constructing the spatial network structure of architectural design and analyzing related metrics is complete.

III. B. Building design space optimization model based on microhabitat genetic algorithm

Using the architectural design space network structure constructed above as a foundation, an architectural design space optimization model is generated under the influence of the microhabitat genetic algorithm [23]. As an optimization algorithm, the microhabitat genetic algorithm possesses strong search capabilities. In this study, its application in the construction process of the architectural design space optimization model enhances the optimization efficiency of the model. When constructing the optimization model, it is necessary to first define the optimization objectives and then proceed with model construction. The results of the optimization model construction are shown in Figure 1.

In the aforementioned architectural design space optimization model, the optimization objectives are first clearly defined, followed by the determination of appropriate optimization variables. Under the influence of the small habitat genetic algorithm, a set of architectural design space design schemes is first randomly generated and used as the initial population. The fitness functions of different design schemes are then calculated. Based on the fitness values, more outstanding individuals are selected for processing, and crossover operations are performed on them to generate new individuals. Mutation is then applied to increase population diversity, followed by population update.

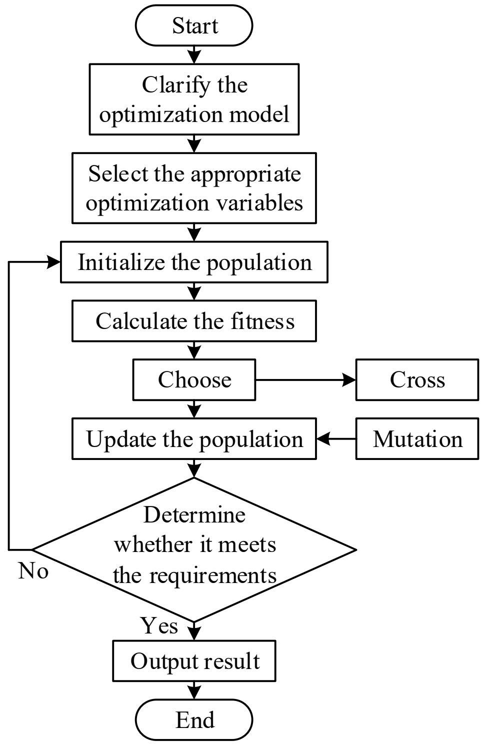


Figure 1: Space optimization model based on niche genetic algorithm

After completing the above operations, determine whether it meets the standards. If it does, directly output the optimization results; if not, the population needs to be reinitialized. In the optimization model constructed above, the formula for calculating the fitness of individuals is as follows:

$$F(x)=\frac{1}{f(x)+\varepsilon} \tag{2}$$

In Equation (2): $F(x)$ represents the fitness value of an individual, $f(x)$ represents the objective function, and ε represents a constant that is infinitely close to 0. The corresponding fitness value is calculated using Equation (2), which is used as the basis for constructing the optimization model, laying the foundation for the subsequent output of architectural design space optimization strategies. At this point, the design of the architectural design space optimization model based on the microhabitat genetic algorithm is complete.

IV. Design of smart home systems suitable for the elderly

IV. A. Overall Architecture of Age-Friendly Smart Home Systems

By simulating real-life home scenarios, six terminal nodes are distributed at specific locations indoors: a temperature and humidity node in the bedroom, a combustible gas node in the kitchen, a light intensity node in the living room, a human infrared intrusion detection node and an RFID access control node at the door. These nodes are responsible for collecting indoor environmental data and performing subsequent linked control tasks. These nodes also form a Zigbee wireless sensor network with the coordinator node. The coordinator node uses serial communication to upload indoor environmental parameters to the PC end. The PC end primarily uses the predefined serialport class in Qt to initialize the serial port, receive, and display the corresponding indoor environmental data; Additionally, a health information database for the elderly is created, which not only includes basic information such as name, home address, and contact number but also stores critical information such as medical history and allergy medications. The interface runs a fall detection model based on Yolov5[24] and utilizes an external high-resolution camera to monitor falls among elderly individuals living alone. Once the fall monitoring mode is activated and a fall event is detected, the PC-end system will send an emergency assistance SMS to the designated recipient's phone via the SMS network platform, taking into account user feedback and actual circumstances, and following the pre-set alarm priority, to save the elderly person the most valuable golden rescue time. The overall architecture of the system described in this paper is shown in Figure 2.

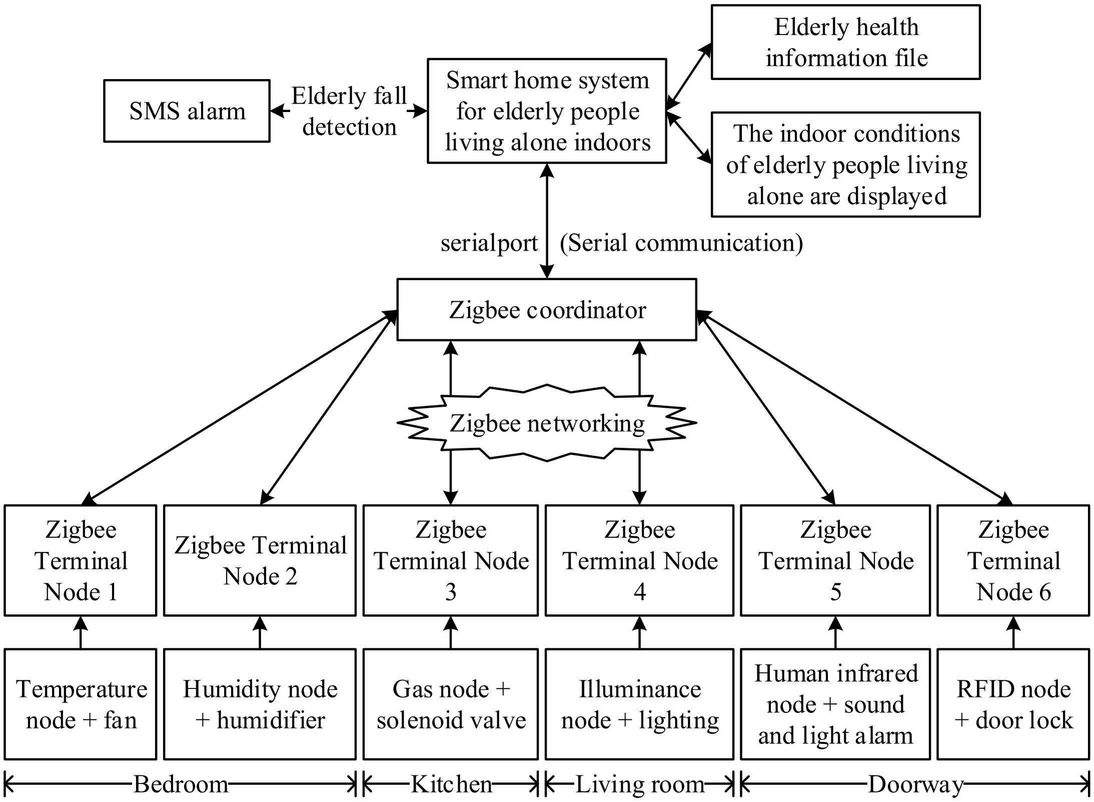


Figure 2: Overall System Architecture

IV. B. Zigbee Technology

IV. B. 1) Zigbee Technology Features

Some of the advantages of Zigbee technology [25] are as follows:

(1) Low power consumption: Battery life can last up to six months to two years, which is an advantage that other wireless communication devices do not have.

(2) Low data rate: Zigbee's data transmission rate ranges from 20 to 250 kbit/s, fully meeting the requirements for low-speed data transmission.

(3) Low latency: Switching from sleep mode to active mode typically takes only 15 ms, and nodes can access the wireless network in approximately 30 ms, ensuring rapid response times.

(4) High security: Zigbee incorporates the AES-128 encryption algorithm and offers three security modes to choose from, ensuring effective network security.

IV. B. 2) Zigbee Node Device Types

Zigbee networks are based on the IEEE 802.15.4 standard, and physical devices can be divided into two types: full-function devices (FFD) and reduced-function devices (RFD). According to the Zigbee Alliance standard, different standards have been established logically, thereby dividing node devices into the following three types: coordinators, routers, and end devices, which belong to FFD, FFD, and RFD devices, respectively.

IV. B. 3) Zigbee Network Topology Structure

Zigbee can be divided into three types based on network structure: star network, tree network, and mesh network. Mesh networks are generally more commonly used.

IV. B. 4) Zigbee Protocol Stack

The Zigbee protocol stack is the unified standard for Zigbee technology, which strictly defines the communication specifications required for wireless data transmission at close range and low data rates. It primarily consists of two main components: first, the physical layer (PHY) and medium access control layer (MAC) established based on the IEEE 802.15. 4 standard, and the second is defined by the Zigbee Alliance at the network layer (NWK), application support sublayer (APS), and application layer (APL). The complete Zigbee protocol stack architecture is shown in Figure 3 below.

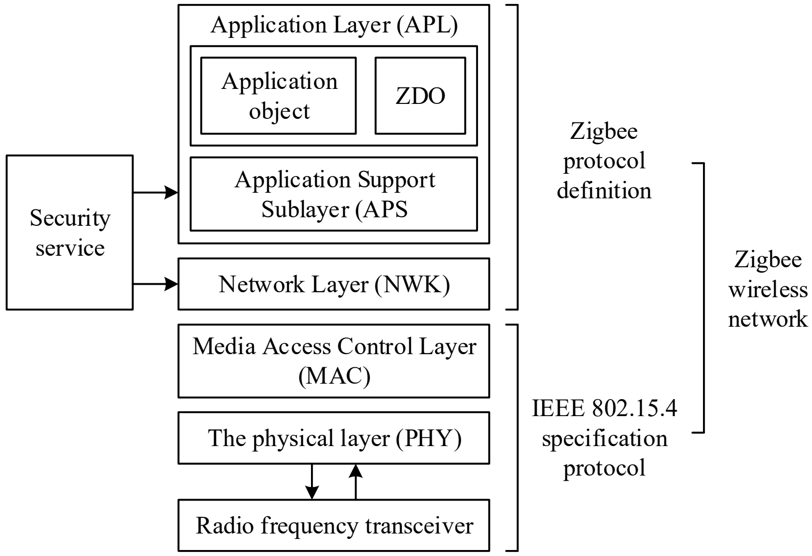


Figure 3: Zigbee Protocol Stack Framework Structure

IV. C. Design and implementation of fall detection functionality for elderly people living alone

Currently, methods for detecting people in images can generally be divided into two categories: one category involves obtaining explicit knowledge such as the height-to-width ratio and center of gravity shift of human kinematics as the fundamental basis for behavioral judgment. However, this approach is prone to limitations such as camera position shifts and low resolution, which can result in a certain probability of failing to clearly identify human body features, thereby significantly reducing the effectiveness of person tracking. The other category involves deep learning-based object detection algorithms, with the YOLOv5 algorithm being one of the most mature and representative examples currently available.

Yolo5 is a series of object detection architectures and models pre-trained on the COCO dataset. It is an extension of the Yolo series. The network structure of this algorithm mainly consists of four parts: input, backbone, neck, and prediction. The input stage uses Mo-saic for data augmentation; the backbone primarily includes Focus slice processing and Cross-Stage Parity (CSP) structure, which serves the function of slice downsampling; the neck adopts a fusion approach combining Feature Pyramid Network (FPN) and Path Aggregation Network (PAN); the prediction output stage consists of a classification loss function and a regression loss function, used to evaluate detection performance.

In addition to the inherent advantages of its model structure, the PyTorch framework used by YoloV5 is user-friendly and features readable code; it offers fast model training and prediction speeds; and it can directly perform inference on images and videos. YoloV5, a one-stage object detection algorithm, can automatically identify, detect, and classify the features required for target recognition, and convert raw input information into more abstract, higher-dimensional features through a CNN network. Therefore, this paper ultimately adopted the YoloV5-based object detection algorithm as the core algorithm for conducting research on elderly fall detection in this study.

After detecting the corresponding target, additional parameters are required to evaluate the effectiveness of the detection. Specifically: TP refers to cases where both the predicted and actual results are positive samples; TN refers to cases where both the predicted and actual results are negative samples; FN refers to cases where the predicted result is negative, but the actual result is positive; FP refers to samples that are classified as positive but are actually negative; AP denotes average precision; mAP denotes the average of AP across all categories; precision (P) denotes the proportion of actual positive samples in the predicted samples relative to the total number of positive samples. The closer this result is to 1, the higher the precision, as per formula (3):

$$P = \frac{TP}{TP + FP} \tag{3}$$

The recall rate (R) represents the proportion of actual positive samples in the predicted samples to all predicted samples, corresponding to formula (4):

$$R = \frac{TP}{TP + FN} \tag{4}$$

Accuracy (ACC) refers to the proportion of positive samples in the predicted samples relative to the total number of samples, corresponding to formula (5):

$$ACC = \frac{TP + TN}{TP + FP + TN + FN} \tag{5}$$

In summary, the basic concept of the indoor elderly fall detection solution based on the Yolov5 algorithm described in this paper is shown in Figure 4.

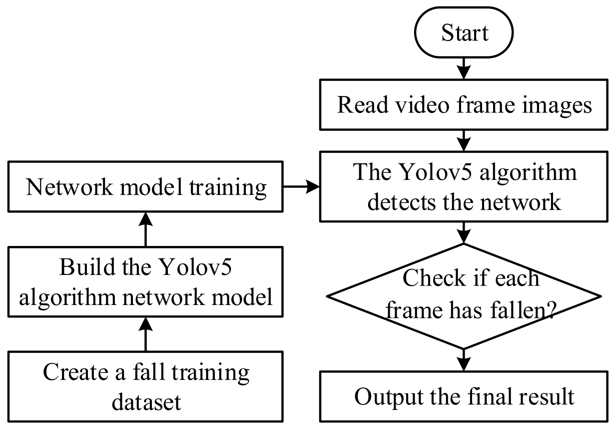


Figure 4: Indoor Elderly fall detection Scheme Based on Yolov5 algorithm

V. Analysis of architectural design space optimization and its impact on the living environment

The selected experimental subjects include 12 indoor architectural spaces. To meet the diverse needs of the elderly, the architectural spaces are divided into different functional zones. Based on the selected experimental subjects, a comparative experiment was conducted using two architectural space optimization design methods: Method 1—PSO-LSSVM-based architectural space optimization design and Method 2—Dynamo-based generative design for intelligent architectural space optimization. Given the multiple objectives of architectural space optimization design and the limited scope of the experiment, the evaluation criteria for the results of elderly-friendly architectural space optimization design were selected as spatial utilization efficiency, spatial adaptability, and noise impact scores. Based on the test data, these evaluation criteria were calculated and analyzed.

V. A. Analysis of Space Utilization Efficiency

This paper proposes a method, and after applying Comparison Method 1 and Comparison Method 2, the utilization efficiency of aging-friendly building spaces is shown in Figure 5 and Table 1. Before optimization, the utilization efficiency of building spaces was 40%. After applying the proposed method, Comparison Method 1, and Comparison Method 2, the utilization efficiency of aging-friendly building spaces was significantly improved. Through data comparison, it can be seen that after applying the proposed method, the utilization efficiency of building spaces increased by up to 38%, reaching 78%, thereby making more efficient use of building spaces.

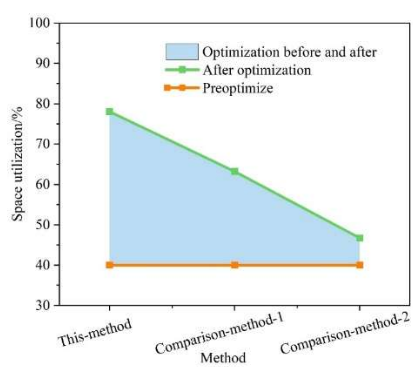


Figure 5: Space utilization efficiency comparison

Table 1: The efficiency of the aging building space

Space efficiency	This method	Comparison method 1	Comparison method 2
Preoptimize/%	40	40	40
After optimization/%	78	65	48

V. B. Spatial fitness analysis

Taking architectural spaces A, B, C, D, E, and F as the research subjects, the corresponding spatial adaptability values were calculated based on the test data, as shown in Table 2.

The spatial adaptability values range from 0 to 1, with higher values indicating better functional performance of the architectural space. The spatial adaptability values obtained using the method proposed in this paper are all greater than those obtained using Comparison Method 1 and Comparison Method 2, with the maximum value reaching 0.96. This indicates that the proposed method results in better functional performance of aging-friendly architectural spaces.

Table 2: Spatial fitness data

Interior space	Application method	Space fitness
A	This method	0.94
	Contrast method 1	0.58
	Contrast method 2	0.44
B	This method	0.87
	Contrast method 1	0.13
	Contrast method 2	0.35
C	This method	0.89
	Contrast method 1	0.46
	Contrast method 2	0.48
D	This method	0.91
	Contrast method 1	0.35
	Contrast method 2	0.74
E	This method	0.96
	Contrast method 1	0.53
	Contrast method 2	0.54
F	This method	0.85
	Contrast method 1	0.31
	Contrast method 2	0.55

V. C. Noise Impact Score Analysis

This section focuses on building spaces G, H, I, J, K, and L as the research subjects. Based on the test data, the corresponding noise impact scores for these spaces are calculated, as shown in Table 3. The noise impact score ranges from 0 to 1, with lower values indicating a smaller impact of noise on users. As shown in the data in Table 3, the noise impact scores obtained using the method proposed in this paper are all lower than those of Comparison Method 1 and Comparison Method 2, with the minimum value being 0.08. This indicates that after applying the proposed method, the acoustic environment of the building spaces is improved, significantly reducing spatial noise in the living environment for the elderly. This enhances the comfort of their living environment and has certain benefits for their physical health.

The proposed method effectively improves the usage efficiency and adaptability of building spaces while reducing noise impact scores, achieving better spatial optimization design outcomes. It provides elderly individuals with a better indoor building environment and offers support for related research, demonstrating the successful integration of innovative aging-friendly elements in this study.

Table 3: Noise impact score data

Interior space	Application method	Space fitness
A	This method	0.11
	Contrast method 1	0.55

	Contrast method 2	0.64
B	This method	0.089
	Contrast method 1	0.77
	Contrast method 2	0.85
C	This method	0.21
	Contrast method 1	0.94
	Contrast method 2	0.88
D	This method	0.18
	Contrast method 1	0.44
	Contrast method 2	0.65
E	This method	0.08
	Contrast method 1	0.46
	Contrast method 2	0.49
F	This method	0.22
	Contrast method 1	0.77
	Contrast method 2	0.68

VI. Testing of smart home applications for the elderly

VI. A. YOLOv5 Model Performance Comparison Test

The purpose of this section is to compare the YOLOv5 model with other excellent object detection algorithms and fall detection algorithms based on other methods.

To demonstrate the advantages of the YOLOv5 model in fall detection, this paper conducts comparative experiments between YOLOv5 and other state-of-the-art object detection models. All experiments were conducted on the VOC 2007 and VOC 2012 public datasets, with comparisons made primarily across three aspects: model size, mAP, and detection speed (FPS). The comparison results are shown in Table 4. Compared to SSD, YOLOv5 has a model size that is only 13.43% of SSD's, an mAP improvement of 16.44% over SSD, and an inference speed that is 2.64 times faster than SSD. Compared to Mask_RCNN, YOLOv5's model size is only 4.58% of Mask_RCNN's, its mAP is 16.44% higher than Mask_RCNN's, and its inference speed is 3.22 times faster. Compared to the similar YOLOv4, YOLOv5's model size is only 14.1% of YOLOv4's, and both mAP and inference speed have improved to varying degrees.

Table 4: Yolov5 is compared to the target detection algorithm

Model	Weight/MB	map/%	FPS
SSD	105	81.5	22
Mask_RCNN	308	75.8	18
YOLOv1	245	74.5	25
YOLOv2	205	78.9	36
YOLOv3	158	81.2	39
YOLOv4	100	83.6	42
YOLOv5	14.1	94.9	58

The changes in the loss functions of the final models YOLOv5, YOLOv4 and SSD during the training process are shown in Figure 6. It can be seen from the figure that the loss function of the YOLOv5 model converishes the fastest, with the loss value eventually convergent to 0.0018. YOLOv4 and SSD converge almost simultaneously, and the final convergent loss values are all greater than 0.01. The changes of relevant evaluation metrics (Precision, Recall, mAP) of the YOLOv5 model during the training process are shown in Figure 7. Graphs a to d represent the changes of Precision, Recall, mAP@0.5 and mAP@0.5:0.95 metrics, respectively.

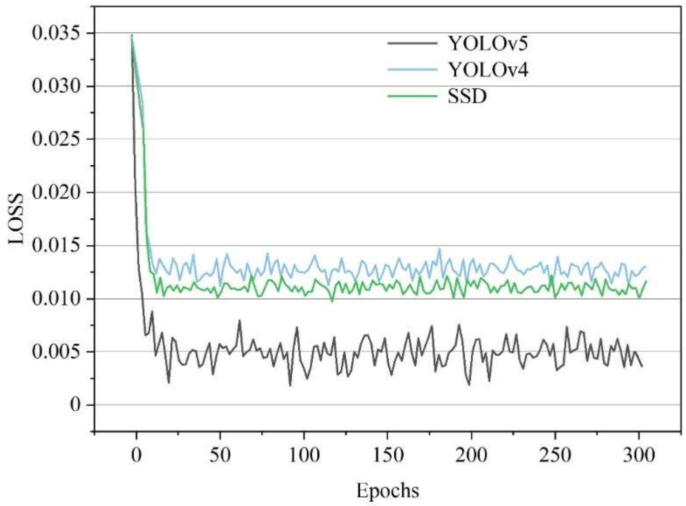
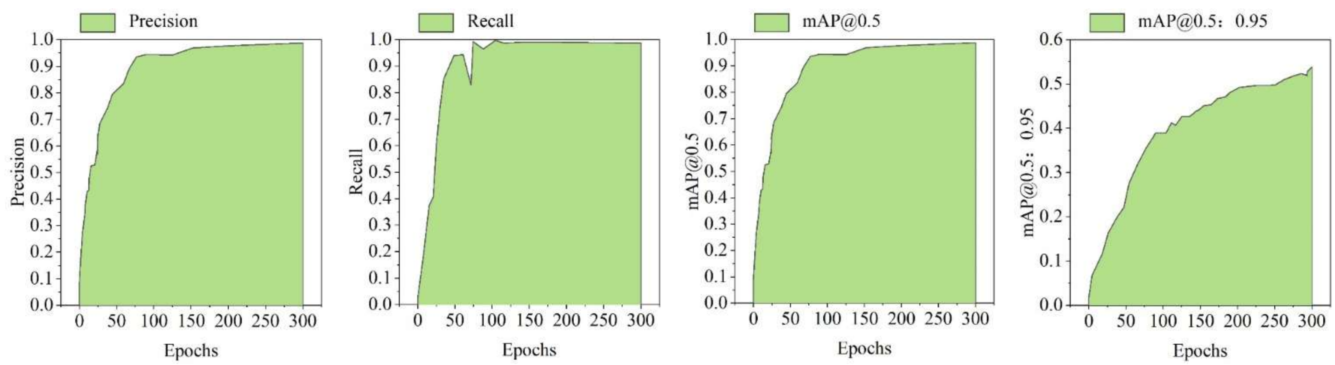


Figure 6: Loss contrast diagram



(a) Precision (b) Recall (c)mAP@0.5 (d)mAP@0.5:0.95

Figure 7: Yolov5 changes the indicators in the training process

VI. B. Fall Detection Results

This paper integrates the dataset processed by the video keyframe selection algorithm with newly added data to create a comprehensive dataset as the training set, named the L-F dataset. To validate the practicality of this algorithm, this paper also constructs a validation dataset containing multiple videos, named the human posture dataset. These videos capture the daily behaviors of elderly individuals in indoor environments while alone, including actions such as standing, sitting, and falling. This experiment evaluates the detection performance of the algorithm based on the ACC metric, with the results shown in Table 5.

The experimental results show that the accuracy rates for standing and falling postures are relatively high, with the accuracy rate for falling reaching 0.968. However, the accuracy rates for sitting and squatting are relatively low. This is because the features of standing and falling postures are more distinct, while the features of sitting and squatting are more similar, leading to some confusion. Additionally, some of the bending features in the dataset may be slightly similar to squatting. In the validation of the P-P dataset, although the accuracy of these five postures decreased, the results showed that this decrease was still within an acceptable range. The experimental results not only support the effectiveness of this algorithm but also demonstrate the applicability of the algorithm proposed in this paper in architectural design.

Table 5: Results of falls detection

Old posture	L-F data set(Acc)	P-P data set(Acc)
Standing	0.895	0.875
Sit	0.758	0.728
Stooping	0.849	0.799

Squat down	0.778	0.736
Fall down	0.968	0.911

VI. C. Usability testing for elderly users

In June 2023 and February 2024, a total of 30 elderly individuals participated in user testing. The age range of the elderly users was between 55 and 70 years old. A comparative experiment was conducted to evaluate the usability of the smart home system guided by this system versus a conventional home system among the 30 elderly users. The experimental process and objectives were explained to the participants, and their consent was obtained. After the experiment, each participant received a carton of milk and a box of eggs as compensation.

The results of the Likert scale are shown in Table 6. By comparing the scores of the two home systems, it can be observed that elderly users rated the usefulness, ease of use, and satisfaction with the two home systems differently, with the elderly-friendly smart home system scoring higher than the conventional home system, and there was a significant difference in the degree of preference for use.

Table 6: The 5 level of the old user's Richter scale results

Evaluation	Smart home system			Household household system		
	Median	Mean value	Standard deviation	Median	Mean value	Standard deviation
Perceptual usefulness	4	4.279	0.644	4	3.926	0.65
Perceptual ease of use	5	4.564	0.751	4	4.223	0.832
Usage satisfaction	5	4.678	0.601	4	4.215	0.806
Use tendency	5	4.443	0.944	3	3.211	1.019

The experimental time was sorted and ranked according to duration, with the results shown in Figure 8. The trend shown in the figure indicates that the time spent on home operations controlled by this system is shorter than that of traditional home operations. Among these, operating a coffee machine takes longer than using a vacuum cleaner, and the difference between the two methods is relatively small when using a vacuum cleaner. This suggests that the smart home system offers higher operational efficiency, particularly in more complex operational scenarios.

Most participants held a positive attitude toward smart home devices, finding the experience novel. Some elderly participants believed that using more high-tech products is an inevitable part of societal development, and while there may be initial discomfort, most of them view exposure to smarter products as unavoidable, as it can enhance quality of life and improve the convenience of living environments.

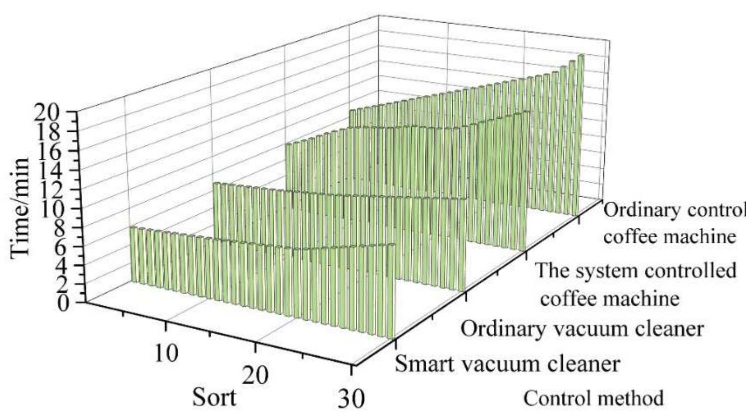


Figure 8: Use this paper to compare the time of the household

VI. D. Evaluation of the Impact of Smart Home Systems on the Living Environment

Briefly introduce the functions and uses of smart home design to the participants, and invite each elderly user to use their own mobile phones to experience the smart home interface without time restrictions. Afterward, participants are required to complete a post-experience user satisfaction survey questionnaire, designed using a 7-point Likert scale. After data collection, a repeated measures ANOVA was conducted to assess the impact of the living environment on user satisfaction. The dimensions A, B, C, D, E, and F in the figure represent environmental comfort, convenience of daily life, energy management efficiency, safety protection capabilities, system usability, and health assistance, respectively. The results showed a significant difference in user satisfaction before and after using the smart home system, with F(1,14) = 9.184, p = 0.008. The data analysis results are shown in Figure 9, which indicates that users' overall satisfaction and scores across all dimensions of the living environment have significantly improved after using the smart home system, demonstrating its feasibility.

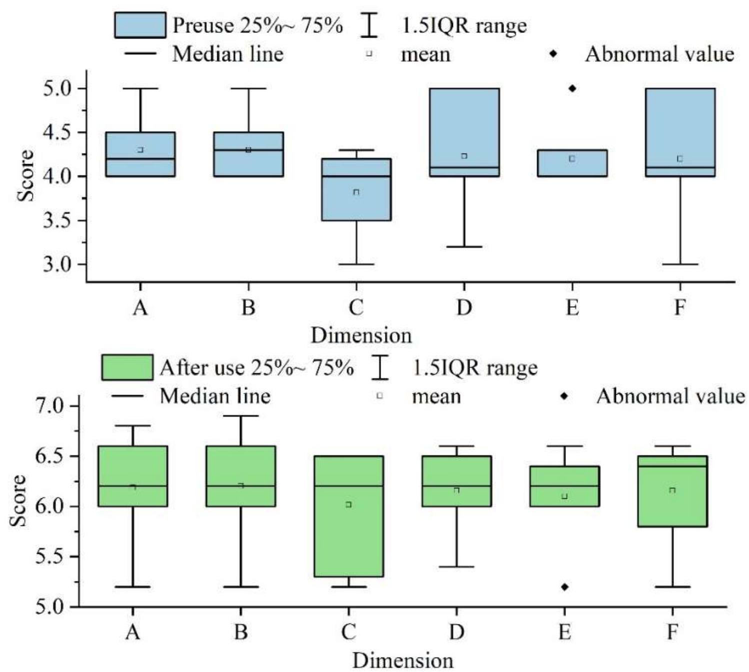


Figure 9: Data analysis results

VII. Conclusion

This study applied the microhabitat genetic algorithm to optimize building spaces for aging-friendly design and innovated smart home technology, designing an aging-friendly smart home system and exploring its multidimensional impact on the living environment.

The microhabitat genetic algorithm-based spatial optimization model effectively improved the usage efficiency and adaptability of living spaces, with the maximum improvement in usage efficiency reaching 38% and the maximum adaptability value reaching 0.96. Through layout optimization, noise interference in the living environment was significantly reduced, creating a more comfortable and safe living environment for the elderly.

The elderly-friendly smart home system based on Zigbee technology and the YOLOv5 model achieves high-precision detection of elderly falls, with an accuracy rate of 0.968. The YOLOv5 model also demonstrated excellent robustness in multi-indicator testing.

Usability tests for elderly users and tests on the impact of the smart home system on the living environment confirmed that users experienced significant improvements in environmental comfort, convenience of daily life, energy management efficiency, safety protection capabilities, system usability, and health assistance. The p-value before and after use was 0.008, indicating that the innovative integration of aging-friendly elements in this study directly optimized the functionality of the living environment and the psychological safety of the elderly.

The scale and geographical scope of the study samples in this paper need to be further expanded to explore the deeper applications of multimodal technology in the field of aging-friendly design.

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References

[1] Roser, M. (2019). The global population pyramid: How global demography has changed and what we can expect for the 21st century. Our world in data.
[2] Asadzadeh, M., Maher, A., Jafari, M., Mohammadzadeh, K. A., & Hosseini, S. M. (2022). A review study of the providing elderly care services in different countries. Journal of Family Medicine and Primary Care, 11(2), 458-465.

[3] Luo, Y., Su, B., & Zheng, X. (2021). Trends and challenges for population and health during population aging—China, 2015–2050. China CDC weekly, 3(28), 593.

[4] Guo, N., Xia, F., & Yu, S. (2024). Enhancing Elderly Well-Being: Exploring Interactions between Neighborhood-Built Environment and Outdoor Activities in Old Urban Area. Buildings, 14(9), 2845.

[5] Lu, Y. (2023). A Study on the Impact of Perceived Built Environment on Elderly Communication Activities in Old Communities. Open Access Library Journal, 10(6), 1-15.

[6] Ruengtam, P. (2017). Factor analysis of built environment design and management of residential communities for enhancing the wellbeing of elderly people. Procedia Engineering, 180, 966-974.

[7] Wu, Z. J., Song, Y., Wang, H. L., Zhang, F., Li, F. H., & Wang, Z. Y. (2019). Influence of the built environment of Nanjing's Urban Community on the leisure physical activity of the elderly: An empirical study. BMC public health, 19, 1-11.

[8] Cho, M., Ha, T. M., Lim, Z. M. T., & Chong, K. H. (2018). "Small places" of ageing in a high-rise housing neighbourhood. Journal of Aging Studies, 47, 57-65.

[9] Ji, Q., Yin, M., Li, Y., & Zhou, X. (2023). Exploring the influence path of high-rise residential environment on the mental health of the elderly. Sustainable Cities and Society, 98, 104808.

[10] Kumar, A., Khare, R., Sankat, S., & Madhavi, P. (2023). Fire safety assessment for older adults in high-rise residential buildings in India: A comprehensive study. International journal of building pathology and adaptation, 41(3), 625-646.

[11] Seo, H. B. (2022). Examining the Relationship Elderly Community Care and Urban High-Rise Residential Development-Based on Theory, Research Literature, and In-Depth Interviews. Journal of the Architectural Institute of Korea, 38(1), 3-13.

[12] Mauritzson, E., McKee, K. J., Elf, M., & Borg, J. (2023). Older adults' experiences, worries and preventive measures regarding home hazards: A survey on home safety in Sweden. International journal of environmental research and public health, 20(2), 1458.

[13] Gutman, S. A., Amarantos, K., Berg, J., Aponte, M., Gordillo, D., Rice, C., ... & Schluger, Z. (2018). Home safety fall and accident risk among prematurely aging, formerly homeless adults. The American Journal of Occupational Therapy, 72(4), 7204195030p1-7204195030p9.

[14] Ismail, H., Nordin, M. S. A., & Abidin, A. W. Z. (2020). The Elderly-friendly housing design features preferences by generations in Malaysia. Environment-Behaviour Proceedings Journal, 5(15), 141-148.

[15] Yamada, K., Murotani, K., Mano, M., Lim, Y., & Yoshimatsu, J. (2023). Age-friendly approach is necessary to prevent depopulation: Resident architectural designers and constructors' evaluation of the age-friendliness of Japanese municipalities. International Journal of Environmental Research and Public Health, 20(17), 6626.

[16] Luciano, A., Pascale, F., Polverino, F., & Pooley, A. (2020). Measuring age-friendly housing: A framework. Sustainability, 12(3), 848.

[17] Jiang, Y. S., Shi, H., Kang, Y. T., Shen, J., Li, J., Cui, J., ... & Zhang, J. (2023). Impact of age-friendly living environment and intrinsic capacity on functional ability in older adults: a cross-sectional study. BMC geriatrics, 23(1), 374.

[18] Chau, H. W., & Jamei, E. (2021). Age-friendly built environment. Encyclopedia, 1(3), 781-791.

[19] Zhou, B., Shen*, Z., Li, J., & Hao, Y. (2025). 108 THE IMPACT OF AGING FRIENDLY DESIGN OF RESIDENTIAL BUILDINGS FOR THE ELDERLY ON THE SYMPTOMS OF ELDERLY PATIENTS WITH SCHIZOPHRENIA. Schizophrenia Bulletin, 51(Supplement_1), S59-S59.

[20] Tanutama, L., Wijaya, H., & Ardianti, D. (2021, July). Elderly fall detection and warning system. In IOP Conference Series: Earth and Environmental Science (Vol. 794, No. 1, p. 012131). IOP Publishing.

[21] Tseng, W. S. W., Wong, W. K., Shih, C. C., & Su, Y. S. (2020). Building a care management and guidance security system for assisting patients with cognitive impairment. Sustainability, 12(24), 10516.

[22] Amaripadath, D., Prasad, D., Safi, T. O., & Attia, S. (2024). Design optimization of an assisted living facility to improve summer thermal comfort in warming climates. Journal of Building Engineering, 93, 109814.

[23] Han Soo Seo,Chan Bae Park,Seong Hwi Kim,Gang Lei,Youguang Guo & Hyung Woo Lee. (2024). Utilizing MicroGenetic Algorithm for Optimal Design of Permanent-Magnet-Assisted WFSM for Traction Machines. Applied Sciences,14(12),5150-5150.

[24] Bipin Nair B J,Niranjan,Saketh P & Shobha Rani N. (2025). WAYVision: A hybrid deep learning approach for recognizing handwritten Kannada Braille using wavelet transformation and attention based YOLOv5. MethodsX,15,103440-103440.

[25] Shaoru Chen,Hui Zhi,Hongmei Zhang,Jie Wang & Xin Li. (2024). Application of Integrated Medical Care "Cloud-Based Virtual Ward" Management Model on Postoperative Analgesia: Based on Zigbee Technology.. Pain management nursing : official journal of the American Society of Pain Management Nurses,26(1),23-29.