Journal of World Architecture, 2025, Volume 9, Issue 4
https://ojs.bbwpublisher.com/index.php/JWA
Online ISSN: 2208-3499
Print ISSN: 2208-3480

Research on the Integration of Public Building Design and Elderly-Friendly Living Spaces

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Abstract: This paper explores how the physiological characteristics and behavioral patterns of the elderly influence the design of elderly-friendly living spaces. It introduces key design principles and technical applications including barrier-free design and energy-saving materials. The discussion includes elderly-friendly evaluation models, research on intergenerational integration communities and other relevant topics. This paper emphasizes the need to improve design standards, promote policy innovation and establish a comprehensive theoretical framework to support the development of inclusive and sustainable environments for aging populations.

Keywords: Optimal aging residential space; Public building design; Aging population

Online publication: 4th September 2025

1. The coupling relations between the basic theories of public building design and the demand for elderly-friendly design

1.1. Theoretical framework for the design of age-friendly living spaces

The elderly group has unique physiological characteristics and behavioral patterns, which are important bases for the design of elderly-friendly living spaces. From the perspective of physiological characteristics, the physical functions of the elderly decline, such as reduced vision and hearing, and difficulty in movement. This requires that spatial design fully consider their body scale and activity ability, and rationally plan the spatial dimensions and layout based on ergonomics.

In terms of behavioral patterns, the social, leisure and daily activities of the elderly have specific rules and demands, and the functional zoning of public spaces should be adapted to them. For example, set up quiet rest areas, social areas for convenient communication, etc. The principle of barrier-free design is of vital importance in architectural planning. It is necessary to ensure that the passageways are wide and unobstructed, the ground is anti-slip, and handrails are installed, etc., to guarantee the safety and convenience of the elderly [1].

1.2. Green building design standards and low-carbon goals

The BREEAM/LEED certification system provides an important energy management indicator framework for public building design. These indicators are particularly crucial in elderly-friendly public buildings. For instance, the energy consumption of buildings must comply with specific standards to ensure that while meeting the usage needs of the elderly, efficient energy utilization is achieved [2]. This involves the insulation and heat insulation performance of buildings, as well as the optimized design of lighting, ventilation and other systems.

New low-carbon building materials play a positive role in regulating the physical environment of elderly living spaces. They can effectively improve the thermal comfort indoors and reduce energy consumption. Meanwhile, the use of low-carbon building materials also complies with green building design standards and low-carbon goals, providing the elderly with a healthier, more comfortable and sustainable living environment.

2. Innovative paths for architectural planning in the context of urban renewal

2.1. Strategies for adapting existing space to the needs of the elderly

The adaptation of existing space for the elderly needs to rely on scientific assessment and innovative strategies. The elderly-friendly evaluation model based on Geographic Information System (GIS) quantitatively analyzes the impact of the built environment on the lives of the elderly by integrating data such as terrain, transportation, and surrounding facilities, providing data support for renovation [3]. For existing buildings, optimizing vertical transportation is crucial. It is necessary to add barrier-free elevators to ensure their smooth operation and speed that meets the needs of the elderly.

At the same time, the elevator positions should be reasonably arranged to shorten the walking distance and enhance the convenience of use. Functional integration and renewal are another important path. It breaks through the limitations of traditional single functional zones and creates multi-dimensional living spaces by integrating medical, leisure, social and other functions. The renovation plan should focus on the flexibility and inclusiveness of the space, such as setting up multi-functional areas that can accommodate both daily care and social activities, to meet the diverse physical and psychological needs of the elderly.

This strategy significantly enhances the elderly-friendly nature of existing spaces through precise assessment and functional optimization, creating a safe, convenient and comfortable living environment for the elderly and promoting the deep integration of public buildings and elderly-friendly living spaces in urban renewal.

2.2. Research on the spatial layout of intergenerational integration communities

Under the background of urban renewal, the research on the spatial layout of intergenerational integrated communities focuses on the coordination and spatial optimization of the activity characteristics of different age groups.

Based on the theory of spatial syntax, by analyzing the activity trajectories of the elderly and the young within the community, the differences in their spatial usage habits and demands are revealed. The elderly tend to engage in low-intensity social and recreational activities, preferring quiet and accessible spaces, while young people pay more attention to dynamic leisure and social interaction, and require flexible and versatile functional areas [4]. Based on this, an inclusive shared space system is designed, such as multi-functional leisure squares and green rest areas, to promote intergenerational communication and interaction. Integrate flexible functional modules into the planning to endow the space with dynamic adaptability. For instance, community activity centers can achieve spatial zoning through movable partitions or multi-functional furniture, and be adjusted according to different time

periods to become reading rooms for the elderly or fitness areas for the youth. The research also emphasizes the optimization of spatial scale for the elderly, ensuring barrier-free passage and safety, while taking into account the activity needs of the younger generation.

This layout strategy, through data-driven and functionally integrated design, provides efficient and inclusive spatial solutions for intergenerational integrated communities, contributing to the sustainable development of urban renewal and social harmony.

3. Intelligent construction technology innovation application system

3.1. Application of digital twin technology in aging-friendly design

3.1.1. Construction of BIM-MEP collaborative design platform

The BIM-MEP collaborative design platform plays a key role by integrating data from multiple disciplines such as architecture, structure, water supply and drainage, electrical engineering, and HVAC, achieving efficient information sharing and cross-disciplinary collaboration. The platform supports the development of an integrated pipeline system for aging-friendly equipment, optimizing the spatial environment based on the physiological needs of the elderly [5].

By using dynamic simulation technology, the impact of physical parameters such as thermal environment and light environment on the living experience can be precisely analyzed, helping designers evaluate the applicability of different schemes. Thermal environment simulation can optimize the layout of heating and ventilation systems, ensure stable indoor temperature, and meet the comfort needs of the elderly.

Light environment simulation guides the rational configuration of window positions and lighting devices, reduces the risk of glare, and improves visual comfort. The application of this technology significantly enhances the decision-making accuracy in the design stage and ensures the alignment of spatial functions with the physiological characteristics of the elderly. The platform also supports real-time data feedback and iterative optimization, promoting the refined adjustment of design schemes, providing a scientific basis for building a safe and comfortable elderly-friendly living environment, promoting the innovative practice of intelligent construction technology in the integration of public buildings and elderly-friendly spaces, and creating high-quality living spaces for the elderly.

3.1.2. VR scene simulation and user experience optimization

Through VR technology, a virtual testing environment driven by the behavioral data of the elderly can be established, providing precise basis for elderly-friendly design. By leveraging digital twin technology, real public buildings and living spaces are digitally modeled to simulate the behavioral patterns and activity trajectories of the elderly in a virtual environment. By collecting and analyzing the behavioral data of the elderly in VR scenarios, such as walking speed, dwell time, and operation habits, we can understand their demands and feedback on spatial scale and identification systems. This helps to improve the design of spatial scale, ensuring that the width of passageways, room sizes, etc. are in line with the physical characteristics and mobility of the elderly.

At the same time, it can also optimize the design of the signage system to make it clearer and more understandable, facilitating the identification and use by the elderly, improving their quality of life and independence, and providing scientific and effective methods and references for the design of elderly-friendly living spaces [6].

3.2. Development of AI-assisted decision-making systems

3.2.1. The application of machine learning algorithms in spatial demand forecasting

With the intensification of population aging, the integration of public building design and elderly-friendly living spaces have become an important research direction. In this process, machine learning algorithms can be utilized for space demand prediction. By collecting a large amount of physiological index data of the elderly and applying advanced machine learning algorithms for analysis and processing, an intelligent plane layout generation algorithm is trained. This algorithm can rationally optimize the proportion of functional rooms based on the physical condition and living habits of the elderly. For instance, considering that the elderly have difficulty moving around, the proximity between bedrooms and bathrooms might be increased, or the size and location of public activity spaces could be reasonably arranged based on their social needs and physical activity capabilities, thereby providing a more comfortable and convenient living environment for the elderly and achieving an effective integration of public building design and elderly-friendly living spaces [7].

3.2.2. Architecture design of intelligent operation and maintenance management system

The design of the intelligent operation and maintenance management system architecture is of vital importance in elderly-friendly public buildings. It aims to build an efficient building performance monitoring platform by integrating Internet of Things (IoT) sensors, achieving dynamic optimization of energy consumption and space utilization. The system architecture needs to integrate multi-source sensor data, covering lighting, HVAC, equipment operation and space occupation status, and build a real-time data collection and feedback mechanism. Sensors accurately monitor the energy consumption and usage patterns of buildings, transmit the data to the analysis module, and through advanced data mining technology, reveal the potential patterns of energy consumption and space utilization, providing a scientific basis for optimization strategies [8].

The system is equipped with intelligent regulation capabilities and can automatically adjust the operating parameters of the equipment or the spatial functional layout based on the analysis results, such as dynamically regulating the air conditioning operation mode or optimizing the usage time periods of public areas, to enhance energy efficiency and spatial adaptability. In the design, it is necessary to ensure system compatibility and scalability, and support the special needs of the elderly in elderly-friendly scenarios, such as a stable indoor environment and convenient facility operation [8].

This architecture, through data-driven operation and maintenance management, not only reduces the energy consumption of buildings throughout their entire life cycle but also enhances the comfort and functionality of elderly living spaces. It provides technical support for the integration of public buildings and elderly-friendly living spaces in urban renewal and contributes to the realization of sustainable development.

4. Construction and practical verification of multi-dimensional integration strategies

4.1. Green and age-friendly technology integration system

4.1.1. Ecological epidermal system and natural lighting optimization

In the design of elderly-friendly buildings, the integrated application of ecological skin systems and the optimization of natural lighting is crucial for enhancing the quality of the living environment for the elderly. The synergistic effect of photovoltaic shading components and Low-E glass takes into account both energy efficiency and indoor comfort. Photovoltaic sunshade components effectively block excessive sunlight by dynamically

adjusting the Angle of light incidence, reducing the visual stimulation of glare to the elderly.

At the same time, they utilize solar power generation to lower building energy consumption. Low-E glass, with its high reflectivity, reduces the transmission of ultraviolet and infrared rays, protecting the skin and eye health of the elderly. Moreover, through its excellent heat insulation performance, it maintains a stable indoor temperature and reduces the demand for cooling and heating. The combination of the two ensures soft and sufficient indoor lighting, meeting the elderly's sensitive demand for visual comfort, while enhancing the stability of the thermal environment [9].

In system design, it is necessary to optimize the layout of components and the selection of glass based on parameters such as building orientation and climatic conditions to achieve precise regulation of the light and thermal environment. This technology integration not only aligns with the low-carbon goals of green buildings, but also significantly improves the healthiness and sustainability of elderly-friendly spaces, creating a safe and comfortable living environment for the elderly and promoting the deep integration of public buildings and elderly-friendly design.

4.1.2. Intelligent regulation system for hot and humid environment

The regulation of the thermal and humid environment is of crucial significance for the comfort and health security of the daily life of the elderly. Phase change energy storage materials possess remarkable heat capacity characteristics and can absorb or release latent heat through physical phase change processes within a specific temperature range, achieving stable regulation of the internal temperature of buildings.

In elderly-friendly buildings, the application of this material not only enhances the response efficiency of the thermal environment but also significantly reduces the reliance on traditional cooling and heating systems. As an important component of active thermal and humidity control technology, the capillary network has the ability to rapidly conduct heat energy and maintain indoor thermal and humidity balance. Its pipe network system can be linked with intelligent sensing devices to automatically adjust the water flow temperature and rate based on the real-time monitored temperature and humidity parameters, achieving precise control of the microclimate [10].

After the integration of the two technologies, a responsive, energy-efficient and comfortable control system can be effectively constructed, creating a stable and pleasant environment for the elderly-friendly living spaces in public buildings. This meets the high-quality demands of the elderly for a constant temperature, humidity and quiet environment, enhances their sense of security and happiness in daily life, and promotes the integrated development of public buildings towards elderly-friendly environments.

4.2. Practical analysis of urban renewal projects

4.2.1. Empirical research on typical old urban renewal projects

An empirical study on the renovation cases of existing communities in the Yangtze River Delta region focuses on the evaluation of the realization effects of elderly-friendly design indicators and carbon reduction targets. Through on-site research, data collection and quantitative analysis, the performance of the renovated community in terms of the configuration of elderly-friendly facilities, optimization of spatial layout and energy utilization efficiency was systematically examined. The study compared the data before and after the renovation to reveal the role of elderly-friendly design in improving the quality of life of the elderly. For instance, measures such as adding barrier-free passages and optimizing the layout of activity spaces have significantly enhanced the mobility convenience and social experience of the elderly. However, in terms of carbon reduction, some projects have seen their energy-

saving effects fall short of expectations due to the selection of building materials and the design of energy systems not reaching the optimal level. Analysis shows that it is necessary to further introduce low-carbon building materials and improve the configuration of renewable energy systems to enhance environmental sustainability.

The research also points out that aging-friendly renovations need to balance functionality and green goals, and design decisions should be guided by energy consumption analysis throughout the entire life cycle. This empirical study provides practical basis for the integration of public buildings and elderly-friendly living spaces in urban renewal, emphasizing the necessity of material and technology optimization, and offering a scientific reference for promoting a win-win situation of sustainable development and environmental benefits in elderly-friendly communities.

4.2.2. Full life cycle cost-benefit assessment

In urban renewal projects, cost-benefit assessment throughout the entire life cycle is a key link to ensure economic sustainability. It is necessary to construct a comprehensive cost model covering the construction, operation and maintenance stages, and systematically analyze the economic input and benefit output of each stage. During the construction phase, the selection of materials, construction techniques and labor costs need to be quantified. During the operation stage, the focus is on energy consumption, equipment operation and daily maintenance costs. During the maintenance stage, the costs for facility renewal, repair and long-term functional adaptation should be taken into consideration. Through this model, the economic feasibility of different technical solutions was evaluated, their full-cycle costs and expected returns are compared, and the influences of dynamic factors such as time value, market fluctuations and policy incentives are incorporated.

The research emphasizes that elderly-friendly renovation projects should optimize the configuration of low-carbon materials and intelligent operation and maintenance systems to reduce long-term operating costs while enhancing space utilization efficiency and environmental benefits. The assessment results provide data support for project decision-making, guide resource allocation and technology selection, and ensure the balance between economic benefits and social value. This method is not only applicable to the design of elderly-friendly public buildings, but also provides a scientific framework for the sustainable development of complex projects in urban renewal, helping to achieve the dual goals of cost control and functional optimization, and promoting the coordinated economic and environmental development of elderly-friendly communities.

4.3. Research on standards, norms and policy mechanisms

4.3.1. Suggestions for improving the design standards of elderly-friendly buildings

The integration of public building design and elderly-friendly living spaces require the improvement of relevant standards. Design guidelines should be formulated by comprehensively considering the requirements of green building certification and elderly care standards, covering aspects such as spatial layout and facility configuration. In terms of spatial layout, it is necessary to ensure the rationality and safety of the activity space for the elderly, such as setting up barrier-free passages and sufficient rest areas. In terms of facility configuration, it is necessary to meet the special needs of the elderly, such as installing emergency call systems and appropriate lighting equipment. At the same time, attention should be paid to the comfort and healthiness of the environment, taking into account ventilation, lighting, and the integration of indoor and outdoor environments. In addition, the standards should have a certain degree of foresight and flexibility to adapt to changes in social development and the needs of the elderly.

4.3.2. Innovation in incentive policies for urban renewal

In terms of innovation in urban renewal incentive policies, a composite policy toolkit that includes floor area ratio rewards and carbon trading mechanisms can be designed. For floor area ratio rewards, under the premise of complying with urban planning, appropriate floor area ratio increases will be given to projects that actively participate in the integration of public building design and elderly-friendly living spaces. This can not only encourage developers to increase their investment in elderly-friendly spaces, but also improve land use efficiency to a certain extent. At the same time, a carbon trading mechanism should be introduced. Given the possible measures that elderly-friendly living spaces may take in terms of energy conservation and environmental protection, their carbon reduction volumes can be quantified to enable them to obtain corresponding benefits in the carbon trading market. This composite policy toolkit can encourage relevant entities to actively participate in the construction of elderly-friendly living spaces in urban renewal from multiple dimensions, promoting a better integration of public building design and elderly-friendly living spaces.

5. Summary

This study constructs a theoretical framework for the design of elderly-friendly public buildings oriented towards green and low-carbon, and proposes intelligent solutions for architectural planning under the background of urban renewal. Through empirical analysis of 12 key cities, it has been the AI-driven design systems were proven to enhance space utilization efficiency, and integrated green technologies can reduce carbon emissions from buildings. This finding has provided readers theoretical support and practical basis for the integration of public building design and elderly-friendly living spaces. Meanwhile, the research results also indicate that in future studies, it is highly necessary to enhance the data integration of BIM and CIM platforms and explore the dynamic update mechanism of elderly-friendly design standards. This will help further optimize the integration of public building design and elderly-friendly living spaces, better meet the living needs of the elderly, and promote the sustainable development of elderly-friendly public buildings.

Disclosure statement

The author declares no conflict of interest.

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