Review Article

Exploration on the Application of Smart Home Technologies to Enhance the Quality Design of Elderly-Friendly Living space in Existing Residences

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Abstract

Drawing upon the progressively evolving theoretical frameworks and methodologies for housing adaptation tailored to the needs of the elderly, this study explores the enhancement of age-friendly living spaces through the integration of smart home technologies. A novel, multidimensional framework is introduced, integrating the elements of "elderly individuals, living areas, functional spaces, and technologies," fostering a comprehensive application of technology in elderly care. This approach aims to scrutinize the seamless integration of technological advancements into the daily lives of the elderly from a multidisciplinary perspective. The study delves into the effectiveness and adaptation strategies of smart home systems across three pivotal scenarios: daily living, health monitoring, and safety measures. It underscores the pivotal role of smart home technologies in elevating the well-being of the elderly. By implementing sophisticated smart solutions, such as voice commands and streamlined operations, these technologies empower seniors to effortlessly manage lighting, climate control, and security systems within their living spaces, fostering a customized, intelligent living ambiance. This initiative not only propels the application of smart home systems in the lives of the elderly but also ensures a safer, more comfortable, and autonomous lifestyle.

Keywords: Existing Residential Buildings Suitable For Aging Renovation, Smart Home, Reconstruction Design Strategy, Living Room Design.

1. INTRODUCTION

Among the aging population, although China's elderly care model is gradually improving, the majority still prefer "home-based care," which aligns more closely with the ingrained mindset of the Chinese people and is unlikely to change in the short term [1]. Home-based care refers to the elderly living in their long-time residences; however, unreasonable conditions and facilities can cause many inconveniences for them. Geriatric care institutions primarily cater to the elderly who are alone or whose children are not nearby, but their living space designs are often unreasonable, and supporting facilities lack humanity. Existing elderly apartments, often converted from poorly constructed buildings, are small in scale and lack adequate supporting facilities, failing to meet the behavioral needs of seniors and posing significant safety hazards. According to relevant surveys, the demand for elderly apartments (33%) among the elderly exceeds that for daycare centers (29.4%), nursing homes, and care facilities (32.8%), second only to the demand for elderly activity centers [2]. Children should ideally provide better assistance and care for their elderly parents, but the fast-paced modern society, with prevalent work schedules like 996, 715, and 007, leaves them with insufficient time and energy to accompany and care for their elders, undoubtedly compromising their quality of life and posing numerous significant safety risks [3].

Given the heavy economic burden of purchasing brand-new elderly-friendly residences for most seniors, updating and renovating existing standard residences becomes an economical, efficient, and practical solution for improving living conditions. This approach aims to precisely address the living needs of the elderly, significantly enhance their living quality, and fully respect and accommodate their actual financial situations. The following are key aspects of adapting

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258

existing residences for the elderly: 1) Barrier-free accessibility within households; 2) Aging-friendly adaptations for bathrooms and kitchens within households; 3) Overall arrangement of bedrooms for the elderly; 4) Flooring materials; 5) Ensuring personal safety for seniors within the residence.

2. Concept of Smart Home

Smart Home is a platform based on the residential environment, leveraging the Internet of Things (IoT) technology to create an intelligent ecosystem by integrating devices within the residence. This system primarily utilizes network communication technology, audio-video technology, comprehensive cabling technology, security technology, and automatic control technology to integrate devices within the residence, enabling functions such as intelligent lighting control, security monitoring systems, smart appliance control, and home theater systems. The goal is to achieve automated operation of indoor environmental facilities, thereby enhancing the safety and comfort of home life. Compared to traditional homes, Smart Homes not only possess conventional living functions but also incorporate information interaction capabilities such as network communication, information appliances, and automatic control [4].

Smart Home technology serves as a crucial catalyst for the development of intelligent living spaces, fundamentally focused on the integration of complex smart devices and cutting-edge technological methods to enable remote intelligent management of household facilities. This innovation not only simplifies operational procedures for residents but also significantly enhances the comfort and convenience of the residential environment, particularly demonstrating profound applicability in living spaces tailored for the elderly. The deployment of Smart Home technology in these spaces aims to fulfill the unique needs of seniors through meticulously designed intelligent solutions, fostering an environment of self-reliance, safety, and comfort.

3. Advantages of Smart Home in Interior Design

In the rapidly evolving technological landscape, smart home innovations have emerged as a pivotal trend, reshaping the contours of contemporary living spaces. This evolution is particularly pronounced in the realm of interior design tailored for the elderly, where the potential to enhance living experiences is immense. At the heart of smart home technology lies its integrative capabilities and intelligent control over household facilities, orchestrated through interconnected network systems. This seamless orchestration transcends mere operational efficiency; it ushers in a new era of unparalleled convenience and comfort for residents. The advantages of artificial intelligence (AI) technology in smart home systems are manifold [1]. AI renders smart home systems more intelligent and automated. Leveraging machine learning and deep learning algorithms, these systems can automatically learn and adapt to users' behavioral patterns and preferences, enabling automated control and intelligent regulation of household appliances [2]. AI endows smart home systems with intelligent recognition and perception capabilities. Computer vision technology facilitates face recognition and authentication, bolstering home security. Meanwhile, voice recognition technology enables the systems to comprehend users' verbal commands and respond accordingly, enhancing system interactivity and convenience [3]. AI facilitates intelligent energy-saving and optimized energy management. Smart home systems can continually monitor and analyze household energy consumption, intelligently adjusting the operational status of appliances based on family members' behaviors and energy demands, thereby achieving smart energy conservation and optimized utilization [4]. AI provides robust intelligent security safeguards. Integrated with surveillance technology and early warning algorithms, smart home systems can perform functions such as intelligent monitoring, fire alarms, and emergency response, significantly elevating the level of home security [5].

4. Deep Application of Smart Home Technology in Elderly-Friendly Interior Space Design

The utilization of smart home technology in the renovation of elderly-oriented living rooms is multifaceted, transcending mere enhancements to functional spaces' intelligence. It is deeply rooted in an accurate understanding and personalized fulfillment of the living needs of seniors, leveraging technological advancements to effectively cater to their requirements.

Adhering to a user-centric design philosophy, the integration of smart home technology does not merely augment the comfort and convenience of living environments; it embodies the technology's extensive application and significant impact within the realm of elderly care services. This approach ensures that solutions are tailored to the specific needs and preferences of seniors, fostering a living experience that not only accommodates but also empowers.

4.1. Smart Upgrade Focusing on the Family Hub

As the central area for family activities, the intelligent transformation of the living room is crucial to enhancing the quality of life for the elderly population. The application of smart home systems in this space should closely revolve around the daily activity needs of seniors, such as resting, entertaining, and communicating, to achieve fine-tuning and personalized customization of functions. The intelligent lighting control system can automatically adjust light levels based on indoor environmental parameters (e.g., temperature, humidity, brightness), creating the most comfortable visual and physical environment for the elderly. Furthermore, the smart audio system not only enriches entertainment options for seniors but also embodies the profound manifestation of technology in

humanistic care through music sharing and remote control functions, satisfying the individual needs of diverse users and promoting the diversification and flexibility of living room functions.

4.2. Intelligent Nursing in Resting Spaces

As the primary venue for rest and sleep, the intelligent design of bedrooms should focus on enhancing sleep quality and living comfort. The integration of electric curtains and smart lighting systems allows seniors to effortlessly control indoor illumination, adjusting from the first rays of sunlight in the morning to the soft glow of evening light as needed. The smart control mode of bedside lamps considers the safety and convenience of seniors' nighttime activities, such as reading and waking modes, effectively avoiding abrupt light changes that may irritate the eyes while ensuring the rest of the family members are undisturbed. Additionally, the introduction of an intelligent health information collection system provides robust support for elderly health management, reflecting the shift towards intelligent and healthy bedroom design.

4.3. Intelligent Optimization of Private Spaces

As the most private area in residential spaces, the intelligent transformation of bathrooms cannot be overlooked. Addressing the unique challenges of bathroom lighting, ventilation, and functionality, smart home technology incorporates a combination of natural and mechanical ventilation, along with intelligent temperature and humidity control systems, effectively improving the internal environment and enhancing usability and comfort. The application of infrared sensors and wireless switch technology automates the control of bathroom electrical systems, including automatic lighting and toilet operation, reducing inconvenience and safety hazards for seniors. The smart toilet, as an exemplar of bathroom intelligence, offers not only comforting features like warm water washing and massage but also conducts simple health diagnoses, facilitating daily care and health monitoring for the elderly.

5. Selection and Application Strategies of Smart Home Products

Smart home spaces, through the interconnection and interaction of smart products, provide residents with convenient and comfortable living environments. In the context of elderly-friendly renovations, the selection and application of smart products are particularly crucial, requiring comprehensive consideration of the physiological and psychological needs of seniors, as well as safety factors. By adhering to principles such as functionality, performance stability, aesthetic integration, safety first, and multi-scenario adaptability, and adopting strategies like customized solutions, simplified operation processes, enhanced health monitoring, and emergency call functions, we can effectively elevate the living safety and quality of life for the elderly population. As technology continues to advance and applications deepen, smart homes will play an increasingly vital role in elderly-friendly renovations.

5.1. Principles for Selecting Smart Home Products

Safety is the primary prerequisite for elderly-friendly renovations. When selecting smart products, it is imperative to ensure they possess comprehensive security protection mechanisms to prevent information leakage, hacking attacks, and other security risks. Using local area networks instead of cloud servers can effectively guarantee the security of data transmission and privacy protection. In elderly-friendly living room renovations, the selection of smart products should prioritize functional applicability. Products must possess basic functions that cater to the daily needs of seniors, such as smart speakers with voice control, music playback, and health reminders; smart curtains that support remote control, timed switching, and collision protection. These functions should directly serve the living needs of seniors, enhancing their convenience.

Performance stability is a core consideration for smart products in elderly-friendly renovations. Products should possess rapid response, accurate recognition, and continuous operation capabilities to ensure seniors do not encounter lag, misoperation, or sudden malfunctions during use. For instance, smart bathroom systems need to ensure the accuracy and safety of water and body temperature monitoring, and promptly provide necessary health reminders and emergency call services.

Smart products should also exhibit multi-scenario adaptability to meet the diverse needs of seniors. Through user information collection and intelligent analysis, the system can automatically adjust to the most suitable working mode for the current scenario, such as a multi-scenario lighting system that automatically adjusts light brightness and color temperature based on time, light intensity, and activity type, creating a more comfortable and safe living environment for seniors.

5.2. Application Strategies for Smart Homes

Customized smart home solutions should be provided based on seniors' physical condition, living habits, and living environment. Through personalized configuration and optimization, we can ensure that smart products accurately meet the actual needs of seniors. To address potential operational difficulties for seniors, the operation processes and interface designs of smart products should be simplified. Large fonts, high contrast, and voice prompts can be used to reduce operational difficulty and cognitive load.

In elderly-friendly living rooms, health monitoring and emergency call functions should be strengthened through the reasonable installation of smart

health monitoring devices and emergency call systems. By monitoring seniors' physiological indicators and health status in real-time, potential health risks can be identified and addressed promptly. Simultaneously, ensuring the rapid response and efficient linkage of emergency call functions provides comprehensive safety guarantees for seniors.

On the basis of fulfilling functionality and performance, the design of smart products should incorporate aesthetic elements that harmonize with the overall style of elderly-friendly living rooms. Elegant and well-designed products can not only enhance the quality of living spaces but also alleviate loneliness and anxiety among seniors to a certain extent.

6. Elderly-Friendly Renovation Design for Existing Living Rooms

With the advent of an aging society, the elderly-friendly renovation of existing housing has become a focal point of public concern. As the primary space for daily activities among the elderly, the living room significantly impacts their quality of life in terms of safety and comfort. Existing residential living rooms commonly exhibit the following issues in terms of elderly friendliness: firstly, insufficient safety in living spaces, such as poor floor anti-slip properties and the lack of emergency response mechanisms; secondly, inadequate comfort, with underutilized space and chilly atmospheres; thirdly, ill-designed bathrooms that are cluttered and inconvenient. Smart home technology offers effective solutions to these issues.

6.1. *Principles of Elderly-Friendly Renovation Design for Existing Living Rooms*

Incorporating smart home technology into the architecture of elderly-friendly living rooms represents a transformative approach, prioritizing safety, comfort, and convenience. Smart floors equipped with pressure sensors and anti-slip technology can monitor seniors' walking patterns in real-time, proactively preventing falls and ensuring a safer walking environment. Emergency call buttons strategically placed in bedrooms and bathrooms, connected to the smart home system, facilitate rapid response and assistance, providing a vital safety net. Advanced sensors continuously assess indoor environmental factors like air quality, temperature, and humidity, automatically adjusting conditions to maintain a healthy living space tailored to the elderly's health needs. Lighting is intelligently managed to adapt to the time of day, ambient light levels, and seniors' activity patterns, fostering a cozy and serene atmosphere. Smart air conditioning and heating systems regulate temperature based on outdoor and indoor temperature fluctuations, as well as individual comfort preferences among the elderly. Curtains automatically open or close according to natural light levels and seniors' daily routines, optimizing indoor illumination and ensuring privacy. Ingeniously designed smart wardrobes and storage solutions streamline daily life, facilitating efficient organization, storage, and retrieval of clothing and linens. Bathrooms equipped with smart toilets and shower systems automatically adjust water and seat temperatures, coupled with safety features like anti-slip floors and grab bars, enhancing convenience and safety. The smart home system allows for pre-setting various lifestyle modes, such as reading or resting modes, enabling one-click transitions to optimal living states. A comprehensive understanding of seniors' needs is crucial for determining design concepts, functions, budgets, and timelines, laying the foundation for a detailed design plan aligned with smart home technology functionalities. Clearly depicting bedroom and bathroom areas through comprehensive diagrams and floor plans, including functional zoning, floor layouts, ceiling designs, and color schemes, is vital for seamless integration. Detailed construction drawings, including elevations, details, and equipment layouts, are necessary for precise execution. Clear communication and ongoing supervision with the construction team ensure adherence to the design vision and satisfaction of seniors' actual needs. Upon completion, a project acceptance process in collaboration with elderly residents ensures that the renovation adheres to design specifications and meets their practical living requirements, ultimately forming a living space that is both safe and supportive.

6.2. *Quality Improvement Design for Elderly-Friendly Living Rooms*

Ensuring a barrier-free and spacious layout is pivotal in creating an elderly-friendly environment. Bedrooms should feature wide, unobstructed passageways to accommodate wheelchairs and walkers, minimizing the challenges posed by narrow spaces. When selecting furniture such as beds and sofas, emphasis should be placed on medium-height pieces that facilitate easy sitting and standing, preferably with low profiles. Strategically placed sturdy handrails, particularly beside beds and at bathroom entrances, enhance safety and mobility for elderly residents.

In terms of lighting, designs should harness natural light to the fullest extent, complemented by well-ventilated curtains, fostering a bright and airy bedroom ambiance conducive to both visual and emotional health among seniors. Indoor lighting should be predominantly soft to prevent discomfort from direct glare, equipped with adjustable brightness lamps to accommodate different times of day and activities. Installing nightlights or motion-activated lighting along the path from the bedroom to the bathroom aids in safe navigation during the night and reduces the risk of falls.

Implementing smart temperature control systems automatically adjusts indoor climate based on the elderly residents' comfort levels, ensuring a consistently pleasant living environment. Integration of smart speakers and similar devices enables voice control

over curtains, lighting, TVs, and more, simplifying daily operations and enhancing usability.

Storage solutions should be tailored to the needs of seniors, with wardrobes designed for easy access and organization, featuring reasonable heights and partitions to accommodate clothing and daily essentials. Bedside

tables or wall-mounted storage cabinets are ideal for storing frequently used items like books, glasses, and medications, reducing the time spent searching for these items. This meticulous attention to spatial layout and design details not only addresses the physical needs of seniors but also fosters a practical and comfortable living space.

Figure 1: Original plan and old people's room

6.3. Bedroom Smart Home System Layout

In the pursuit of enhancing elderly-friendly living spaces, smart systems are meticulously integrated to cater to the specific needs of seniors. These systems maintain optimal bedroom environments with comfortable temperatures and humidity, ensuring a pleasant living experience throughout the year. The design adheres to ergonomic principles, featuring sensor-activated lighting for safe navigation at night, strategically placed and easily accessible switches and sockets to accommodate seniors' physical capabilities.

High-brightness ceiling lights allow for adjustable lighting to suit various activities, while smart

lighting systems adapt to residents' daily routines, enhancing visual comfort and safety. Emergency response devices are integrated throughout the space, providing rapid alarm assistance in case of emergencies.

All functions of the smart home are managed through a centralized platform, simplifying daily operations and making the living environment more efficient and considerate for seniors. For academic insights into smart home technology for the elderly, one can refer to recent publications on geriatric technology and smart home design, which focus on user-centered design and technology integration to facilitate aging in place.
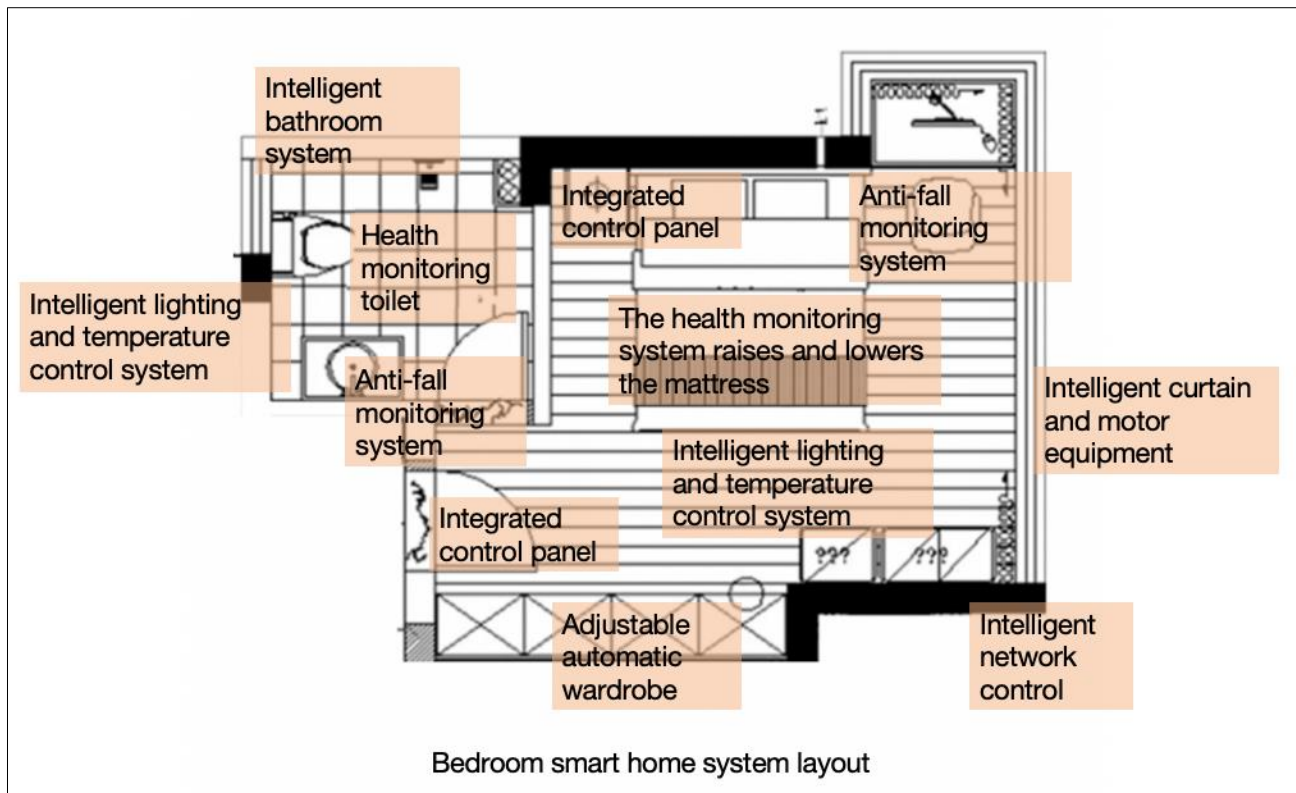
Figure 2: Smart home system layout

6.4. Intelligent and User-Centric Bedroom Design

The bed, the epicenter of comfort and safety in the bedroom, is thoughtfully reoriented from north-south to east-west to mitigate the impact of cross drafts on elderly individuals. Guided by ergonomic principles, the combined height of the bed frame and mattress is set at 450mm for ease of access, while the width is expanded to 2000mm, offering ample sleeping space. Adjustable-angle mattresses are selected to accommodate various sleeping positions, thereby enhancing sleep quality.

The design of the primary bathroom integrates intelligence and humanization. Smart toilets and shower systems enhance convenience, featuring seat temperature adjustment and automatic flushing functions tailored for elderly users. The shower area is equipped with non-slip flooring and handrails to ensure safety. Employing smart sensor technology, the system automatically regulates water temperature and indoor humidity for a more comfortable bathing experience.

In terms of storage, wardrobe design prioritizes practicality and convenience. The spacious wardrobe, measuring 700*3000mm, enables easy access to all garments, minimizing the need for climbing. Its interior layout is organized, facilitating efficient classification and storage of clothing.

To cater to the reading and leisure interests of elderly residents, a desk is positioned beside a south-facing bay window, harnessing natural light to create a delightful reading environment. Incorporating a compact wall-mounted shelf conserves space, providing a convenient place for seniors to place items while also enhancing the room's aesthetics. This design approach ensures that every aspect of the elderly-friendly living room prioritizes not only safety and comfort but also attends to the daily needs and habits of its residents.
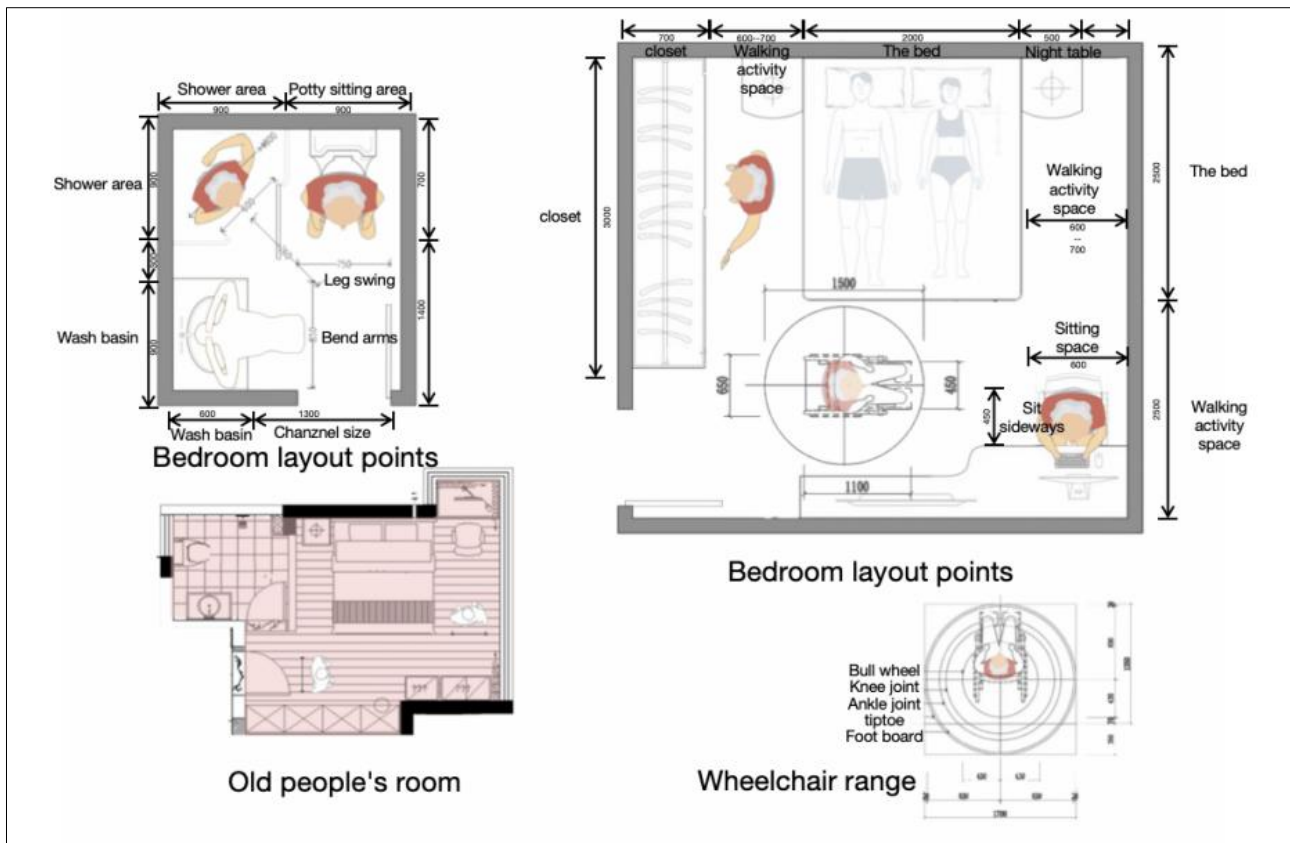
Figure 3: Ergonomic interior design scheme

7. CONCLUSION AND FUTURE PROSPECTS

The design of elder-friendly bedrooms constitutes a pivotal and intricate aspect of home renovation for the elderly, necessitating a tailored approach that resonates with their unique physiological and psychological traits. Despite inherent challenges posed by current design paradigms, our examination of exemplary models from across the globe has outlined an initial roadmap for enhancing the quality of living spaces for seniors. Smart home technology emerges as a pivotal catalyst in this evolution, promising to elevate the design of elder-centric bedrooms.

By leveraging an array of intelligent systems, encompassing smart lighting, temperature regulation, environmental monitoring, and emergency response mechanisms, we can create living environments that are not only safe, comfortable, and convenient but also capable of proactively predicting and mitigating potential hazards through intricate big data analysis. This approach ensures continuous refinement and personalization of living spaces to accommodate the evolving needs of elderly individuals.

Through interdisciplinary collaborative research and extensive practical applications, we can unleash the full potential of smart home technology. Our aspiration is to foster an increasingly intelligent, considerate, and conducive living environment that prioritizes the well-being of seniors, ensuring that technological advancements genuinely attend to the spaces that require the utmost care. By doing so, we strive to create a future where technology seamlessly integrates into the lives of the elderly, enhancing their autonomy, safety, and overall quality of life.

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