

Research on the Application of Digital Twin Technology in Age-Friendly Design of Multi-Generational Households and Strategies for Mitigating Intergenerational Conflict - A Case Study of a Family in Fengtai District, Beijing

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Abstract: *With the popularization of multi-generational cohabitation family structures and the acceleration of the aging process in China, the demand for comfortable and age-friendly living environments is becoming increasingly prominent. Traditional design methods struggle to effectively reconcile the differences among multi-generational members in terms of space-use preferences, lifestyle habits, and safety needs. This study takes a typical multi-generational family in Beijing's Fengtai District as a case study. Through on-site surveys, behavioral observations, and in-depth interviews, it systematically outlines the psychological needs, daily activity flow lines, and behavioral characteristics of different family members, summarizing the usage barriers and potential intergenerational conflicts present in various functional scenarios of the home. Building on this, the research introduces Digital Twin technology to construct a dynamic digital model, enabling real-time mapping and interaction with the physical environment. This method not only optimizes the family's spatial flow layout and functional configuration, allowing members of all generations to directly participate in the dynamic visualization simulation and evaluation of multiple design proposals, but also generates multi-stage renovation plans based on changes in residents' physical conditions, ensuring a perfect match between the living environment and the residents. The study aims to explore the application path of Digital Twin technology in the barrier-free environment of multi-generational households, providing innovative strategies and practical references for mitigating intergenerational conflict and building an inclusive human living environment.*

Keywords: Digital Twin Technology, Age-Friendly Renovation, Multi-Generational Households, Intergenerational Conflict, Smart Furniture.

1. Introduction

In the context of profound changes in the global population structure, aging has become a major challenge shared by all countries. Statistics from the "National Report on the Development of the Aging Cause" show that over ten years, the proportion of the population aged 65 and above nationwide increased from 10.5% to 15.6%, with the size of the elderly population reaching 217 million people. Of greater concern is that the old-age dependency ratio has reached 22.8%, leading to continuous increase in social pressure for elderly care [1]. General Secretary Xi Jinping pointed out, "We must promote the coordinated development of elderly care undertakings and industries, develop inclusive elderly care services, improve the community and home-based elderly care service network, and build an elderly care service system that coordinates home, community, and institutional care, and integrates medical care, nursing, and wellness" [2]. This further highlights the urgency and importance of age-friendly renovation work in urban communities and homes.

On the other hand, China's family structure is also undergoing significant changes, with the multi-generational cohabitation model being particularly common in developed cities such as Beijing and Shanghai. In this context, the living environment must not only meet the elderly's needs for home safety and barrier-free access but also consider the demands of middle-aged, young, and minor family members for comfort,

privacy, and modern living quality. Therefore, how to coordinate the differing needs of multi-generational members in age-friendly home renovation and effectively mitigate spatial use conflicts caused by intergenerational differences has become an important practical problem that needs urgent solution.

Wang Yao et al. [3] proposed a four-dimensional interactive framework for elderly care technology applications — "People-Activities-Space-Technology" — to combine the advantages of cutting-edge technology with the physical and mental characteristics of the elderly, designing technology products and services that are simple, easy to use, and privacy-secure. Yang Xi et al. [4] suggested that the core focus should be on dynamically adapting to changes in the family life cycle, exploring the reconstruction of functional scenarios, the embedding of smart technology, and the optimization of age- and child-friendly details to achieve synergistic satisfaction of intergenerational needs. Building on the theoretical foundations of previous research, this project focuses on typical areas where the multi-generational cohabitation phenomenon is prominent. Taking a representative residential unit in Beijing's Fengtai District as an empirical case study, it introduces Digital Twin technology to provide intelligent design methods for the age-friendly renovation of multi-generational cohabitation housing and proposes specific, actionable updating strategies for mitigating intergenerational conflicts caused by differences in space use.

2. Research Background

2.1 Domestic Research Status

2.1.1 Research on Multi-Generational Cohabitation Families and Age-Friendly Design

The traditional Chinese multi-generational cohabitation model, linked by blood ties, formed two types of community: family and clan. Typical settlements such as Fujian Tulou and Anhui's Xidi-Hongcun, led by a patriarch, integrated residential, defensive, and social functions, reflecting a high degree of integration between family ethics and spatial organization [5]. The unit layout, sequential flow lines, and clear domain division in these traditional paradigms effectively maintained the cohesion of the clan and the privacy of the individual. However, when this cohabitation

model shifts from horizontally spreading traditional courtyards to vertically stacked modern apartment units, the original spatial logic is difficult to apply directly.

In the Ruidong Residential Area in Shanghai's Changning District, under the design of EASBLE, a 57m² old residential space was reorganized. Through systematic renovation of the family layout, the spatial efficiency was maximized, reorganizing it into a flexible layout of three bedrooms and one living room, which both ensured intergenerational privacy and maintained spatial permeability. Fu Benchen et al. [6] suggested that in multi-generational cohabitation design, attention should be paid to ensuring the universality of the residential unit type layout, coordinating the privacy of each generation's life with the convenience of caring for the elderly, and shaping suitable intergenerational living spaces from perspectives such as spatial layout and separation methods.



Figure 1: Flexible layout of a 57m² residence with three bedrooms and one living room (Source: <https://zhuanlan.zhihu.com/p/270336135>)

2.1.2 Research on the Design Application of Digital Twin Technology in Residential Spaces

With the iterative evolution of information technology, the communication method between designers and users has undergone a profound transformation from floor plans to 3D renderings, effectively improving the visualization and design rationality of proposals. However, this approach still remains at the level of static scene construction and has not genuinely integrated users' behavioral characteristics and dynamic needs.

Against this backdrop, the introduction of Digital Twin technology brings new possibilities for design communication. This technology constructs a dynamic virtual model synchronized with the real space and incorporates personal parameters of residents, such as age, physical condition, and behavioral habits, shifting the design process from "unidirectional presentation" to "bidirectional interaction." Therefore, the Digital Twin system can not only magnify construction details and simulate usage scenarios but also present the future living experience pre-construction, allowing users to intuitively perceive the match between spatial flow lines, functional configuration, and living

scenarios before construction. This provides technical support for personalized design in complex scenarios such as multi-generational cohabitation.

2.1.3 Summary

Based on the existing research above, it is evident that although renovation designs targeting multi-generational households continue to evolve in terms of schemes and technology, some issues persist in their practical implementation. Existing solutions commonly suffer from a fragmentation of intergenerational needs, lacking the systematic integration of the elderly's age-friendly requirements with the living demands of other family members, making it difficult for renovation plans to truly achieve intergenerational harmony. Furthermore, the technological presentation methods are lagging, and the theoretical potential of Digital Twin technology has not been fully realized. This makes it difficult for family members to accurately grasp the spatial effect and detect potential functional conflicts, ultimately leading to a gap between the design proposal and the actual living experience.

2.2 Definition of Digital Twin Technology Core Concepts

2.2.1 Core Concept Definition

The concept of the Digital Twin was formally proposed by the U.S. National Aeronautics and Space Administration (NASA) in 2011. The model of the digital twin is created by modeling software, and its behavior follows the objective laws of the physical entity in reality, and can also react based on real-time data.

Digital Twin technology uses highly realistic dynamic digital models to simulate and verify the status and behavior of physical entities. This characteristic of “mapping reality virtually, controlling reality virtually” provides the technical foundation for creating predictable and interactive virtual residences in the field of the built environment.

2.2.2 Application Process of Digital Twin Technology in Design

The application of Digital Twin technology in design establishes a dynamic closed-loop that goes from the physical entity to the virtual model, and then optimizes reality through intelligent feedback, realizing full-cycle verification and iterative optimization of the design proposal, as shown in Figure 2.

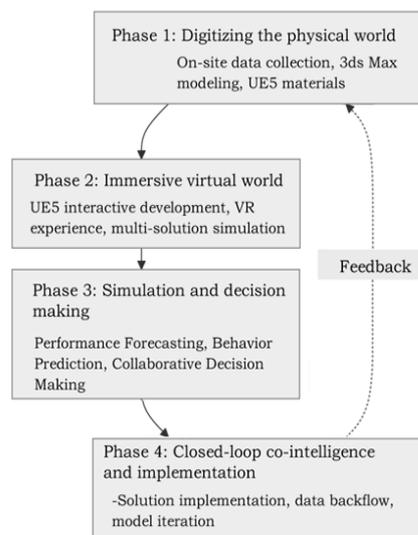


Figure 2: Application Process of Digital Twin Technology in Design

2.2.3 Using Digital Twin Technology for Proposal Evaluation

The residential virtual model constructed based on Digital Twin technology can systematically evaluate design proposals across four dimensions:

- 1) **Functionality:** Assess the rationality of spatial layout and barrier-free facilities and simulate the efficiency of family members' daily flow lines through virtual walkthroughs and VR immersion tests.
- 2) **Safety:** Use behavioral prediction technology to identify potential risks, simulate the elderly's activity paths and passage efficiency in daily life, and verify movement safety under different lighting conditions.
- 3) **Intergenerational Coordination:** Analyze the impact of each functional area on intergenerational interaction, evaluate the

balance effect between private and shared spaces, and collect subjective feedback from different generations through a multi-user VR platform.

- 4) **Adaptability:** Test the spatial layout's capacity to accommodate future changes in physical condition and evaluate the economic and sustainability performance of the renovation proposal over its full life cycle.

2.3 Research Methods

This study employs a combination of literature review, questionnaire survey, in-depth interviews, and on-site mapping research methods. A total of 50 questionnaires were distributed to multi-generational households, with 42 valid samples involving elderly individuals, covering different levels of self-care ability: completely independent (31), mildly dependent (6), moderately dependent (3), and severely dependent (2). The study found that in multi-generational living environments, intergenerational conflict is primarily manifested as differences in space-use habits and lifestyle patterns. In contrast, barrier-free needs present multi-level characteristics, ranging from physical environment renovation to cognitive support systems. Furthermore, there is a significant correlation between the intensity of demand for barrier-free facilities and the degree of intergenerational conflict among elderly individuals with different levels of self-care ability.

3. Analysis of Intergenerational Demand Differences and Behavioral Characteristics

Based on surveys and interviews with multi-generational cohabitation families in Beijing's Fengtai District, this study systematically outlines the differentiated characteristics of residential needs among members of different generations.

3.1 Demand Characteristics of the Elderly Group

1) Barrier-Free Needs

According to the World Health Organization (WHO) data, accidents such as falls have become a major hidden danger threatening the health of the elderly. As the main activity place for the elderly and disabled elderly, living spaces often become the primary location where the elderly suffer accidental injuries due to easily overlooked details [7]. Therefore, the construction of home barrier-free facilities must be promoted based on safety.

2) Convenience Needs

Reduce the burden of the elderly's daily activities by simplifying operation procedures and facility design.

3) Comfort Needs

The mental health of the elderly is an important issue in the current aging context. Compared with other groups, the elderly have a weak self-regulation capacity for environmental changes, and their spirits are more easily disturbed by external fluctuations [8]. Creating a stable and comfortable environmental atmosphere supports the mental

health and emotional peace of the elderly.

3.2 Demand Characteristics of the Middle-Aged Group

The core residential demand of the middle-aged group is to achieve a balance of multiple roles within a limited space. They need to balance work, life, and family roles in a limited space, considering the efficiency of home office, personal privacy, and the coordination of multi-generational cohabitation.

3.3 Demand Characteristics of the Youth Group

The core residential demand of the youth group is to seek a balance of autonomy, personalization, and growth support, providing a growth-oriented environment while ensuring autonomy and individuality.

3.4 Spatial Design Strategy for Multi-Generational Cohabitation Model

This study aims to effectively mitigate intergenerational conflict through intelligent facilities and humanized layout, allowing family members of all age groups to live comfortably and find a sense of psychological belonging. It proposes constructing a flexible space that is both open and private within a limited area. Through the implicit integration of age-friendly facilities and all-age-friendly design, it ensures the safety needs of both the elderly and children while avoiding spatial oppression for other members. At the same time, the spatial layout and material selection should possess necessary flexibility, adopting changeable or recyclable decorative and furniture materials, and implementing the concepts of energy conservation and sustainability to ensure changing needs during expanding life stages and improve the convenience of living [9].

4. Analysis of Renovation Case Status

4.1 Case Selection and Overview

4.1.1 Basic Information of Residents

This study focuses on a typical three-generation family living space in Fengtai District, Beijing. The family consists of four people: an elderly person, a pair of children (their daughter and son-in-law), and a granddaughter. The residential unit is a two-bedroom, one-living room, one-bathroom layout, which is a common mode in Beijing for multiple generations living in a compact space. The family structure has obvious intergenerational differences and a focus on functional needs. The specific resident information is shown in Table 1:

Table 1: Basic Information of Residents

Member	Age	Occupation	Physical	Hobby
Old Homo sapiens	77	Retired worker Homo sapiens	Moderate dependence	Play poker, watch TV
Daughter	54	Freelancing	Health	/
Son-in-law	55	Teacher	Health	/
Granddaughter	22	Student	Health	/

4.1.2 Living Pattern

This household is a typical multi-generational family, with the

care of the 77-year-old moderately dependent elderly person as the core. The daughter is the main caregiver, and her home office space and caregiving space highly overlap; the son-in-law and granddaughter have low involvement. This structure reflects the typical conflict between barrier-free needs and intergenerational conflict in compact living.

In terms of care division, the daughter handles daily living and safety monitoring; the son-in-law only assists in the evening; and the granddaughter is generally not involved. The care pressure is highly concentrated on the daughter alone, which puts forward higher requirements for spatial functional zoning.

In terms of space use, the elderly person's range of activity is limited to the bedroom and living room, mainly involving static activities. The design needs to focus on optimizing the barrier-free flow line and properly handle the spatial competition between caregiving behavior and the children's daily life.

4.1.3 Health Status of the Elderly Resident

In this case study, one resident is an elderly woman aged 77. With increasing age, her physical functions show signs of aging. To objectively understand the elderly person's daily living ability and physical condition, the study systematically evaluated her physical function and self-care ability through a combination of interview methods and a self-care ability assessment scale.

The elderly person has some osteoporosis, accompanied by relatively severe visual and hearing impairments, which slightly affect daily life. In terms of daily living self-care ability, the ADL assessment results show mild dependence in eating, bathing, grooming, dressing/undressing, and toileting, and moderate dependence in indoor walking, bed-to-chair transfer, and bowel/bladder control. The final combined self-care ability assessment score is 26 points, classifying her as moderately dependent—the results indicate no significant dependence in simple self-care aspects, but clear signs of physical aging in walking, lifting heavy objects, and autonomic nervous control, requiring manual assistance.

4.2 Analysis of Current Spatial Problems

This section will deeply analyze the existing problems of the case residential unit from three dimensions: overall layout, various functional spaces, and barrier-free facilities.

4.2.1 Overall Layout Analysis

1) Spatial Flow Line Layout

The current spatial flow lines of the home form a straight linear flow. This design is simple and singular, reducing obstacles for the elderly in terms of walking experience and facilitating smooth and efficient movement within the home. From the family's perspective, it is also convenient for caring for the elderly who use wheelchairs or other assistive devices. However, although the current spatial flow line appears simple, it still has some shortcomings: centrally placed furniture severely encroaches upon the necessary buffer and

maneuvering space, not only making wheelchair turning difficult but also restricting the elders' free movement and increasing the risk of bumps. Furthermore, the unreasonable layout of functional rooms causes the daily flow lines of family members to interweave and interfere, making it difficult to achieve the safety and sense of order associated with "separation of movement and rest."

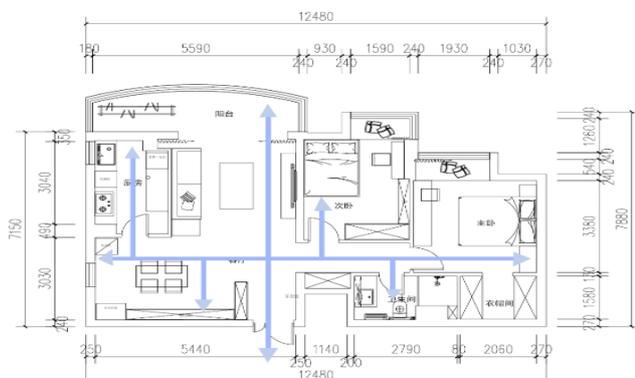


Figure 3: Current Overall Flow Line Analysis

2) Enclosed Spatial Visibility

The residence adopts a traditional method of segmenting functional areas with walls, forming multiple enclosed spaces. This results in the enclosed nature of public activity areas, reducing visual communication and creating caregiving blind spots. When the caregiver performs necessary activities such as cooking in the kitchen, they cannot observe the elderly person's real-time situation due to the enclosed space, posing a significant safety hazard.

Table 2: Caregiving Blind Spots Caused by Spatial Visibility Obstacles (Example: Kitchen)

The area where the elderly live	Space view
Balcony	
Living room	
Restaurant	

4.2.2 Lack of Barrier-Free Facilities and Flow Line Defects in Main Functional Spaces

1) Master Bedroom: Nighttime Routine Flow Line

The walk-in closet in the master bedroom has low practical utility and occupies space needed for a potential barrier-free toilet renovation. The elderly person's flow line from the master bedroom to the toilet at night is circuitous and not smooth, as they must pass through the corridor.

2) Toilet and Kitchen: Obvious Lack of Age-Friendly Facilities and Usage Barriers

The residence, with four residents, has only one toilet, which is insufficient. Furthermore, neither the toilet nor the corridor is equipped with barrier-free facilities.

In terms of kitchen layout, the space is cramped, appliance placement is chaotic, and the refrigerator is placed in the dining room, leading to a mixed flow line. Regarding barrier-free aspects, wheelchair access is restricted due to space constraints.

4.2.3 Spatial and Intergenerational Conflicts Caused by Multi-Generational Cohabitation

The living pattern of this family has led to clear intergenerational conflicts in spatial allocation and core flow lines. Other functional spaces also present corresponding problems, collectively highlighting the current layout's deficiencies in age-friendliness and intergenerational coordination, as shown in Table 3.

Table 3: Current Problems in Each Space

Function Space	Size (mm)	Current Situation Issues	On-site photo
Lobby	1100*1980	The space is cramped and it is difficult to pick up things	
Living room	3380*4070	Public vibrant space is not being used	
Balcony	5590*3570	Single function	
Kitchen	2069*3880	Incorrect flow lines, layout errors, and cramped space	
Restaurant	3780*3030	Space is cramped and mixed with functions	

Toilet	2730*1980	Insufficient storage space and no security measures	
Master bedroom	3850*6380	The space is too small and the functions don't match the user	
Secondary bedroom	3080*4800	Insufficient storage	

4.3 Summary of Key Renovation Issues

Based on an in-depth analysis of the resident profile, health status, living pattern, and current spatial problems of this three-generation residence, this study summarizes five major renovation focus areas: mixed flow lines and overlapping functional spaces; insufficient caregiving visibility; systemic lack of age-friendly facilities; incomplete supporting systems; and insufficient spatial adaptability.

5. Renovation Plan Based on Digital Twin and Smart Furniture Collaboration

5.1 Digital Twin Technology Evaluation and Analysis

This study utilizes Digital Twin technology to construct a VR technology platform. The system allows users to personally experience spatial scale and facility details from a first-person perspective through an immersive walkthrough function. Concurrently, a bidirectional interaction mechanism enables users to provide modification feedback in real-time, forming a “experience-feedback-optimization” closed-loop design process, truly realizing user-centric spatial design solutions.



a. Feeling the corridor dimensions b. Feeling the TV distance

Figure 4: Walkthrough Design Renderings

5.1.1 VR Technology Design Experience Process

During the experience, the spatial layout is optimized, and daily life flow lines are simulated, with the VR perspective matching the real-world perspective in real-time. Considering that life-stage needs continuously change over time, the simulation process references ergonomic parameters. Specifically for wheelchair use scenarios, the VR perspective height is set to 1m, and the minimum travel dimension is set to

900mm, as shown in the figure below:

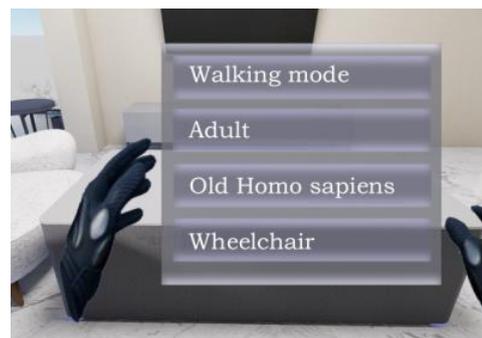


Figure 5: Walkthrough Mode Settings

When the spatial layout cannot meet the requirements for movement or rotation, an “air wall” is used to block progress.

Interactive elements are set up throughout the walkthrough. The interactive functions introduced in this design primarily include material switching, component style and size changes, and position adjustments. As shown, the user can drag the interactive barrier-free shower chair facility to experience the spatial changes before and after its opening and closing. In Figure b, the user is assessing whether the height and placement of the small cart by the bedroom door are reasonable, and adjusting it according to their preference.



a. Object Interaction b. Furniture Placement

Figure 6: Interactive Design Renderings

Based on the continuous feedback and iterative optimization provided by Digital Twin technology, this residential space renovation plan has achieved a high degree of concordance among functional, safety, and intergenerational needs, resulting in a design solution that is both scientific and human-centered.

5.2 Overall Layout Renovation Strategy

5.2.1 Division of Open Shared and Private Independent Space

The spatial layout renovation of this residence is centered on the core concept of “coexistence of open sharing and private independence,” achieving a dynamic balance for multi-generational cohabitation through rational spatial reshaping.

In the public area, an integrated dining-living-kitchen design is adopted. By opening up a semi-wall in the kitchen, a transparent, open space is created. Removing the physical partition between the balcony and the living room introduces ample natural light. This layout not only expands the visual perception and activity range but also cleverly uses furniture to naturally form multiple interactive areas within the open space, promoting intergenerational communication and companionship.

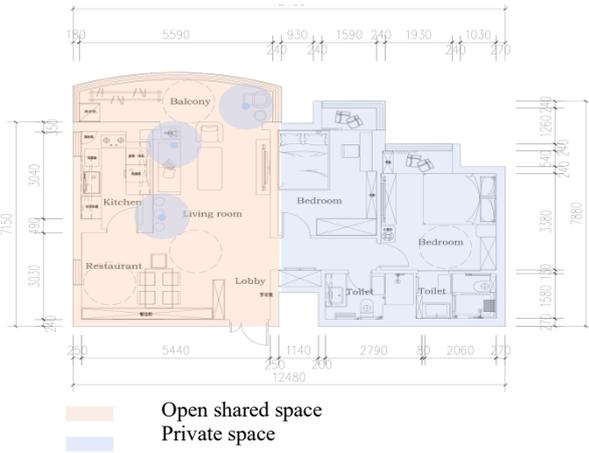


Figure 7: Diagram of Open Shared and Private Independent Space Division

For the creation of private space, a multi-level design strategy is adopted. Independent bedrooms provide exclusive resting places for each family member, and various semi-private spaces are embedded within the public areas (Table 4). This method of spatial organization not only meets the multi-generational cohabitation demand for interaction but also respects the individual’s desire for private space, allowing family members to enjoy their own quiet moments while sharing the joy of gathering.

Table 4: Individual Activity Corners in Public Spaces

Quiet corner of public space	Behavioral Activity	Rendering
Kitchen island	Snack Bar, Temporary Work Platform	
Balcony rest	Scenic viewing	
Living Room Reading Corner	Reading, Resting	

5.2.2 Optimized Flow Line Design

In optimizing the overall floor plan flow line, the basic framework of separating dynamic and static areas is achieved through a clear division between public and private zones. Building on this, a differentiated design layout is used to achieve the harmonious coexistence of flow lines for multi-generational members: a barrier-free path connects the elderly person’s bedroom, toilet, and core functional areas, forming an efficient, short-distance living flow line; the adult flow line ensures efficient connection with the entire family, taking on the role of balancing communication within the household; the children’s activity area is kept as far as possible from the elderly person’s path while maintaining visual accessibility. These flow lines converge moderately in the public space, maintaining the possibility of interaction

while using spatial guidance and staggered timing to avoid conflict, ultimately building an intergenerational living environment that is safe, orderly, and respectful of the individual.

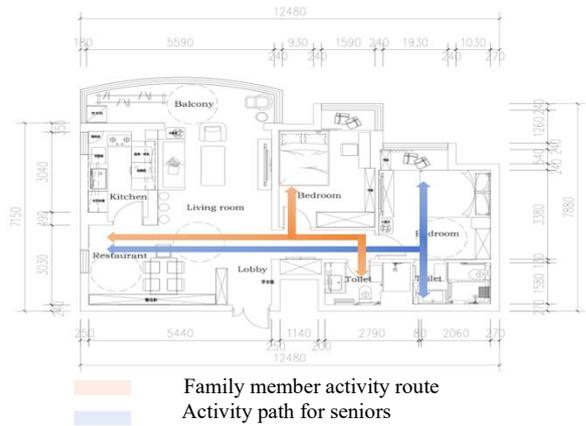


Figure 8: Population Flow Line Diagram

5.2.3 Enhancing Interaction Among Family Members

Rational spatial layout in the residence focuses on strengthening natural interaction and visual connection between generations: opening up a semi-wall in the kitchen allows the person cooking to maintain visual contact with family members in the living room; removing the balcony partition curtain introduces sunlight and scenery indoors while extending the visual permeability of the space; placing the master bedroom office area near the entrance both secures work privacy and facilitates awareness of the dynamics in the family’s public area. These designs not only allow family members to remain closely connected through open sightlines, soft sounds, and a fluid spatial atmosphere even when alone but also implicitly incorporate proactive care and safety assurance for the elderly. The public area creates a transparent view, keeping the elderly person within sight of family members while they are resting. Meanwhile, the barrier-free design and emergency call system in key areas such as the bedroom and toilet complement this open layout, building an invisible safety net that respects privacy while ensuring timely assistance when the elderly person enjoys autonomous living, truly realizing the organic unity of independent living and safety assurance.

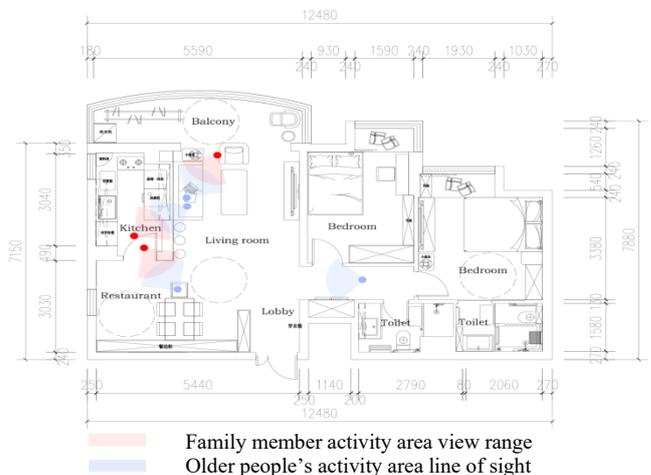


Figure 9: Diagram of Open Shared and Private Independent Space Division

5.3 Renovation Strategy for Smart Furniture and Hidden Age-Friendly Facilities Collaboration

5.3.1 Entrance Hall Renovation

The current entrance hall suffers from insufficient space for changing shoes, inconvenient access/storage, chaotic flow lines, and lack of lighting, urgently requiring age-friendly renovation to improve safety and organizational efficiency. The design focuses on comprehensive consideration and smart care. When the elderly person opens the door, the sensor light automatically turns on, providing illumination and avoiding the risk of fumbling for a switch in the dark. The pull-out shoe-changing stool is cleverly integrated into the cabinet, saving space, while the vertical grab bar hidden on its side can provide stable assistance when standing up. The slight raised edge of the shoe cabinet countertop can act as an invisible handrail and prevent items from sliding off. The smart rotating shoe rack inside the cabinet allows the elderly to easily retrieve shoes without bending over, greatly reducing the risk of falls. A voice assistant at the entrance can not only broadcast the weather and remind them about medication but also help the elderly with diminished vision quickly identify items through a prominent labeling system. These details collectively build a safe and convenient entry transition space, ensuring the elderly person feels ubiquitous care from the very first moment they return home.

5.3.2 Dining Room Renovation

The dining area’s central placement of the dining table obstructs the circulation flow line, not only wasting space but also providing insufficient passage width, leading to a clear risk of bumping.



Figure 10: Dining Room VR Experience Rendering

To address the existing problems in the dining room, the following renovation plan is proposed: Adopt an integrated dining-cabinet design, which enhances space utilization and facilitates the retrieval of daily items; relocate the original washing machine and move the refrigerator to the kitchen, effectively simplifying the functional flow line; add sensor light strips at the kickboard and countertop level to ensure safety during nighttime activities; configure specialized age-friendly seating with armrests and reserve sufficient wheelchair turning space in the layout. This systematic renovation significantly expands the public activity area while ensuring safety and convenience.

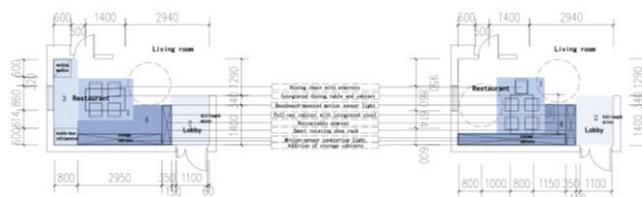


Figure 11: Comparison of Entrance Hall and Dining Room Floor Plans and Renovation Strategies

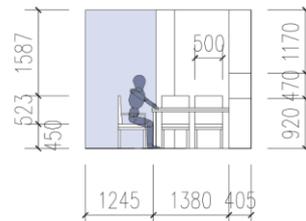


Figure 12: Elevation View of the Renovated Dining Room

5.3.3 Kitchen Renovation

To address the existing problems in the kitchen, such as cramped space, chaotic flow lines, and sight obstruction, this renovation comprehensively improves its functionality, safety, and spatial experience by replanning the overall layout and equipment placement.



Figure 13: Kitchen VR Experience Rendering

Key measures include transforming the kitchen into an open-plan space and adding an island, which breaks the limitations of the original linear layout and effectively widens the operation and circulation areas. The positions of key equipment are simultaneously adjusted, arranging the stove, sink, and cutting board in the sequence of “Washing-Cutting-Cooking.” The steam/bake combo oven, dishwasher, and refrigerator are embedded into the island and cabinetry, forming an efficient and continuous workflow. Furthermore, the addition of smart electric lift-up wall cabinets and wall-mounted spice racks facilitates convenient access to items, reducing the risk of bending or reaching on tiptoes. After renovation, the kitchen is not only visually more open and bright, enhancing visual communication with family members, but truly becomes a safe, efficient, and interactive core home space.

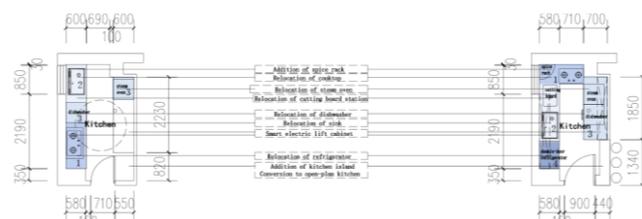


Figure 14: Comparison of Kitchen Floor Plans and Renovation Strategies

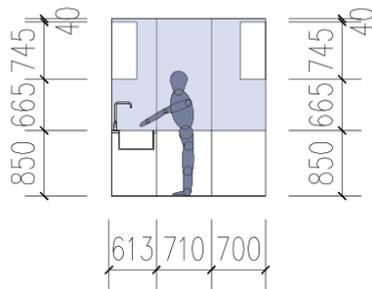


Figure 15: Elevation View of the Renovated Kitchen

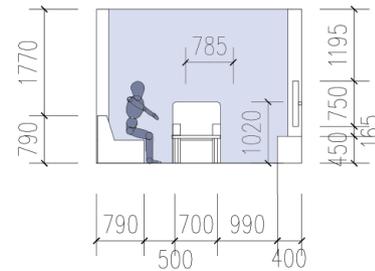


Figure 18: Elevation View of the Renovated Living Room

5.3.4 Living Room and Balcony Renovation

The living room and balcony, as the core public areas of the home, failed to effectively segment personalized corners to create small, quiet spaces amidst activity. Moreover, the potential for light and space on the balcony was not fully exploited, and it lacked organic linkage with other functional areas.



Figure 16: Living Room VR Experience Rendering

This renovation is dedicated to integrating the living room and balcony into a core family space that combines rest, interaction, and age-friendly care. The balcony area introduces smart electric curtains and an automatic lift-up clothes drying rack, moving the washing machine to a corner to form a utility area. While ensuring lighting and functionality, the remaining balcony space is designed as a sunny resting corner for the elderly. The interior of the living room is comprehensively upgraded for age-friendliness and flexibility: an assist-lift sofa, a round-edged movable coffee table, and a multi-functional cart are configured to ensure safety and layout freedom. An adjustable mobile TV stand meets multi-angle viewing needs. Furthermore, by extending the kitchen island to create an interactive bar, the visual connectivity and functional transition with the dining and kitchen areas are significantly enhanced, creating a modern family public area that respects individual privacy needs while encouraging intergenerational communication.

5.3.5 Bedroom Design

The resident of the secondary bedroom is middle-aged, and the renovation focuses on comprehensively enhancing convenience, comfort, and safety by systematically introducing smart home devices to empower the space. Specific measures include installing smart electric curtains and voice-controlled bedside lamps, giving the resident the ability to adjust the light environment without getting up. Simultaneously, a double-control light switch and an emergency call alarm are integrated into the bedside panel, creating an accessible safety node to ensure that emergency calls are instantly sent to family members' notification devices. This series of smart integrated designs collectively transforms the secondary bedroom into a modern rest space that is responsive to needs and meticulously caring.



Figure 19: Comparison of Secondary Bedroom Floor Plans and Renovation Strategies

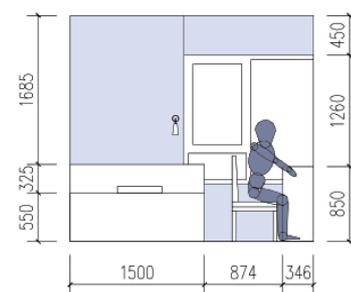


Figure 20: Comparison of Secondary Bedroom Floor Plans

For the master bedroom, where the elderly person resides, the original walk-in closet is replanned as an integrated age-friendly toilet, equipped with a barrier-free toilet and a barrier-free sink. The shower area is enhanced with a soft partition, a shower chair, grab bars, and other barrier-free facilities to facilitate independent use by the elderly.

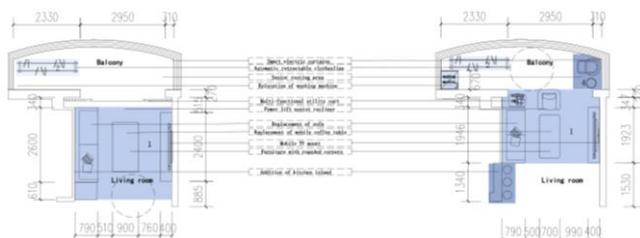


Figure 17: Comparison of Living Room and Balcony Floor Plans and Renovation Strategies



a. Shower room barrier-free facilities b. Toilet barrier-free facilities

Figure 21: Master Bedroom Toilet VR Experience Renderings

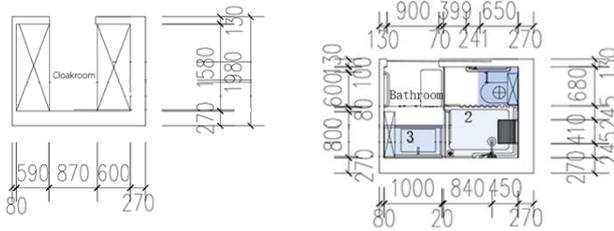


Figure 22: Comparison of Master Bedroom Toilet Floor Plans

Table 5: Master Bedroom Toilet Renovation Strategies and Elevation Drawings

Rebuild area	Rebranding Strategy	Elevation Drawing
Shower room	Add curtains for soft partitions, add barrier-free storage bath chairs, add non-slip mats, and install built-in partitions	
Toilet	Add armrests, emergency alarm button, tissue box, and more storage in the hanging cabinet	
Restroom	Add anti-slip pads, armrests, and an adjustable-angle makeup mirror	

The master bedroom area is equipped with smart electric curtains and a whole-house lighting control system; smart voice-controlled bedside lamps and kickboard sensor lights are set up to optimize the lighting environment; an adjustable lift-assist handrail and an emergency call button are installed by the bed to provide assistance when getting up and emergency protection; concurrently, the bed position is reasonably moved to ensure a clear passage. The overall renovation aims to construct a safe, convenient, and autonomy-respecting rest space for the elderly.



a. Secondary Bedroom b. Master Bedroom

Figure 23: Bedroom VR Experience Renderings

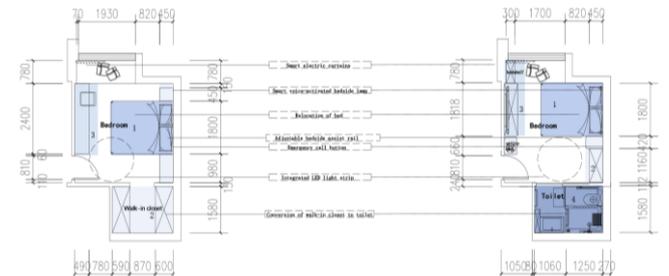


Figure 24: Comparison of Master Bedroom Floor Plans and Renovation Strategies

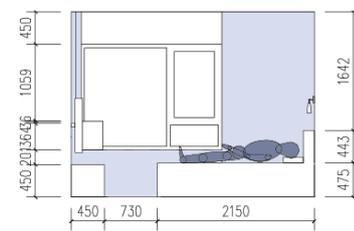


Figure 25: Master Bedroom Elevation View

5.3.6 Corridor Area and Toilet

This renovation implements hidden age-friendly upgrades to the corridor and public toilet. In the corridor, an innovative snap-on handle/book-storage integrated design is adopted using the cabinets, and an embedded handrail is set on the opposite wall, forming a bidirectional assist channel that ensures safe passage without encroaching on the circulation space. The toilet area is improved by changing the partition wall position to expand the shower area and reasonably moving the toilet, while simultaneously adding an emergency call button, comprehensively constructing an assisted living space that is safe, convenient, and respectful of user dignity.



Figure 26: Corridor VR Experience Renderings

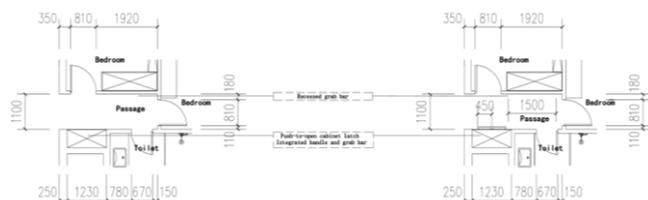


Figure 27: Comparison of Corridor Floor Plans and Renovation Strategies



Figure 28: Comparison of Toilet Floor Plans and Renovation Strategies

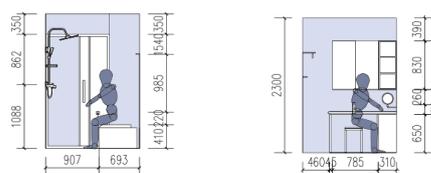


Figure 29: Toilet Elevation View

5.4 Future Precautionary Measures

This plan has proactively considered the trend of functional decline in the elderly during the design phase. Although the current user only requires assistance from grab bars to be self-sufficient, and most furniture has not been replaced with wheelchair-compatible models due to economic considerations, key corridors and functional areas have been reserved with space for standard wheelchair turning and the installation of professional care equipment. Based on the prediction of potentially entering the moderate-to-severe dependency stage in the future, the home can achieve a functional conversion from “hidden age-friendly” to “standard age-friendly” at the lowest cost by quickly replacing furniture and making minor adjustments to the layout.

To achieve systematic age-friendly support, the future Phase 2 plan structurally renovates the living space: the adjacent toilets are consolidated into a spacious, fully barrier-free integrated bathroom, equipped with professional barrier-free facilities and an assisted bathing tub. The elderly person’s bedroom is relocated to the secondary bedroom, selecting a professional physical therapy bed, and care space is released by streamlining storage. The overall family layout forms an efficient and convenient daily flow line network centered on the elderly person’s living needs.



Figure 30: Comparison of Phase 1 and Phase 2 Renovation Floor Plans

6. Conclusion

This study systematically explored the application of Digital Twin technology in the age-friendly design of multi-generational cohabitation families. Through theoretical construction, empirical research, and technical verification, it implemented an age-friendly interior renovation plan aimed at intergenerational harmony and supported by Digital Twin technology. The research revealed the structural differences in intergenerational needs in multi-generational living environments and provided solution strategies. Building on this, through the integrated application of VR walkthrough and interactive technologies, this study achieved the visualized presentation and dynamic optimization of the design plan, allowing users to pre-enact future living scenarios in a virtual environment. Designers, in turn, used data feedback to identify potential problems in the design, ultimately realizing a closed-loop design process of “experience-feedback-optimization,” truly achieving a user-centric spatial design solution. Case practice shows that this technical path not only enhances the scientific validity of design decisions but also achieves the organic unity of safety, convenience, and emotional care within a limited space.

With the sustained deepening of the aging process and the increasing diversity of family structures, Digital Twin technology will play an even more critical role in the age-friendly renovation of the human living environment. Subsequent research can further explore its value in broader contexts, such as the construction of full life cycle housing and the establishment of community-based elderly care service systems, providing sustained technical support and theoretical foundation for promoting the construction of an inclusive society.

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