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2025 Volume 3, Issue 5
Lecture Notes in Education, Arts, Management and Social Science
ISSN(Online): 2705-053X

Research on the Variable Module Space of Elderly-Friendly Bathrooms Based on Movement Behaviors

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Abstract: As China enters an aging society, home-based elderly care has become the mainstream. Therefore, it is necessary to improve the safety and comfort of the elderly when using bathroom facilities at home. Through the identification and research of existing problems, this paper uses the research methods of movement behavior analysis and ergonomic principles to draw more rigorous conclusions, and proposes a complete optimization design plan for elderly-friendly bathroom spaces, including three modules and two spatial layouts. Meanwhile, the innovation points are put forward to illustrate the design thinking different from the past. Combined with existing literature, the design key points and practical value of elderly-friendly bathroom spaces are explored, aiming to provide theoretical support and practical guidance for improving the quality of life of the elderly.

Keywords: Elderly-friendly design; Bathroom space; Movement behavior analysis; Modular design; Safety; Comfort

Online publication: June 26, 2025

1. Introduction

1.1. Background and significance

China has fully entered an aging society. By the end of 2023, the elderly population aged 65 and above accounted for 15.4% of the total national population. The home-based elderly care model has gradually received more attention. According to the data of the National Health Commission, about 90% of the elderly choose home-based care. However, the traditional living environment does not fully consider the physical functions and special needs of the elderly. Especially in the bathroom space, approximately 20 million elderly people in China slip and fall in the bathroom each year due to wet floors, which seriously affects the quality of life and safety of the elderly. Therefore, how to improve the living experience of the elderly through scientific and reasonable elderly-friendly design has become an urgent problem to be solved.

1.2. Research objectives

The aim of this study is to explore the optimization design method of elderly-friendly bathroom spaces through movement behavior analysis and ergonomic principles. The specific goals include:

(1) Analyze the movement behavior characteristics of the elderly in the bathroom space and their impact on the spatial layout.

(2) Propose a solution for elderly-friendly bathroom spaces based on modular design to ensure their flexibility and adaptability.
(3) Explore the application of intelligent technology in elderly-friendly bathroom design to improve the convenience and safety of use.
(4) Expect that the research results can provide reference for future elderly-friendly building designs.

1.3. Existing problems

Currently, there are many deficiencies in the design of elderly-friendly bathroom spaces. According to research (as shown in **Figure 1**), the physiological characteristics and sensory-perception abilities of the elderly change with age, such as height reduction, decreased color sensitivity, and weakened eyesight. These changes make it difficult for traditional bathroom spaces to meet the needs of the elderly [1]. In addition, problems such as unreasonable spatial layout and low-level intelligence are also common.

Percentiles of Static Human Body Dimensions for Adult Women Aged 61-70								
Measurement		Percentile						
		P1	P5	P10	P50	P90	P95	P99
1	Weight/kg	39	45	47	59	71	76	83
Standing Posture Measurement Items (mm)								
2	Height	1415	1450	1472	1541	1614	1639	1683
3	Eye Height	1305	1339	1357	1425	1498	1520	1557
4	Shoulder Height	1144	1171	1189	1252	1316	1338	1371
5	Elbow Height	849	871	885	939	994	1010	1041
6	Functional Hand Height	596	623	633	682	730	745	777
7	Pubic Height	611	631	644	689	738	751	782
8	Tibial Point Height	351	366	374	403	433	442	457
9	Upper Arm Length	253	264	271	289	311	318	329
10	Forearm Length	184	195	199	217	235	241	252
11	Thigh Length	365	389	401	437	474	483	501
12	Calf Length	288	305	312	338	368	378	392
13	Maximum Shoulder Width	363	377	383	409	439	448	471
14	Shoulder-Shoulder Width	304	317	324	349	371	378	391
15	Chest Width	232	247	254	284	311	319	335
16	Hip Width	282	294	301	324	351	360	378
17	Chest Thickness	178	191	197	221	247	254	275
18	Upper Arm Circumference	230	253	264	300	340	351	385
19	Chest Circumference	747	807	836	943	1043	1080	1136
20	Waist Circumference	628	693	733	851	977	1015	1085
21	Hip Circumference	802	838	858	933	1036	1070	1149
22	Thigh Circumference	424	454	454	525	587	610	640

Figure 1. Percentiles of Static Human Body Dimensions for Adult Women Aged 61-70 (Source: The Dimensions of Chinese Adults)

For example, many bathrooms lack designs to assist the elderly in getting up, failing to meet their basic living needs. The absence of intelligent products leads to inconvenience in use and increases the operation difficulty for the elderly.

2. Research methods

2.1. Collection of movement behavior data

To deeply understand the movement behavior characteristics of the elderly in the bathroom space, this study uses motion-capture technology. The experiment set up simulated and real-life bathroom environments and invited elderly people with different physical conditions (such as being mobile, using a walking aid, or being wheelchair-bound)

and age groups (young-old, middle-old, and old-old) to participate. By collecting data such as movement trajectories, joint movement angles, limb extension ranges, movement durations, force magnitudes, and directions, researchers can accurately master the behavior patterns of the elderly in different situations.

2.2. Data analysis

The collected data are comprehensively analyzed to reveal the main movement obstacle points and spatial-demand pain points of the elderly in the bathroom space. For example, the process of changing from a standing position to a sitting position for bathing requires a large-scale space conversion, and the elderly need additional support when getting up and sitting down. These findings provide important quantitative bases for subsequent modular designs. To more intuitively display the data analysis results, as shown in **Figure 2**.

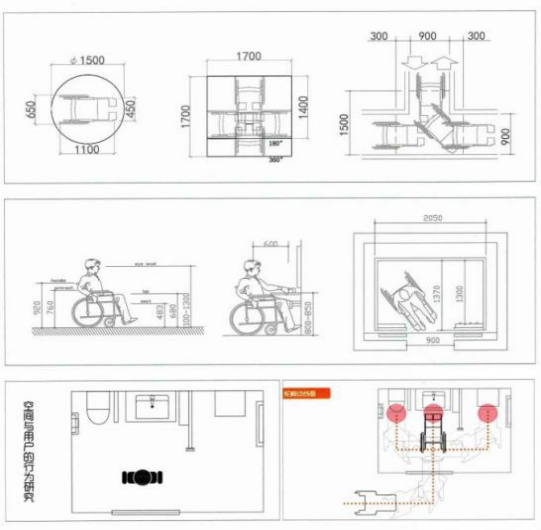

Figure 2. Research on space and user behavior (Source: Hand-drawn by the authors)

3. Analysis of the movement behaviors of the elderly in the bathroom

3.1. Construction of the modular system

Based on the movement behavior analysis, this paper proposes a brand-new variable-module system for elderly-friendly bathrooms, mainly including the following three modules:

3.1.1. Washing module

Electrically adjustable washbasin: Design an adjustable-height washstand. Through electric or manual devices, it can be freely adjusted between 70-90 cm. Different from previous designs that mainly moved left and right, this design allows for more up-and-down movement, making it convenient for the elderly to use even in inconvenient positions. The washstand countertop can adopt an arc-shaped design to prevent collision injuries, and the sink should be shallow and wide for easy use. It is not only convenient for the elderly but also suitable for daily use. Folding auxiliary brackets are installed on both sides of the washstand according to the behavior habits of the elderly to help them support. Usually, the elderly may need to use auxiliary facilities when washing [2]. For example, a sitting-type washstand can reduce the burden on the legs. Their movement range is relatively small, but they have special requirements for the height of the washstand, the depth of the sink, and the convenience of faucet operation. The height of the washbasin can be adjusted according to the height or use posture of the elderly to meet the needs of standing or sitting while washing, ensuring comfort and safety during use.

Safe bathroom system: When an emergency occurs to an elderly person alone in the bathroom space, it is necessary

to ensure that they can be rescued within the golden rescue time. A safety monitoring system is essential, but traditional camera-based monitoring systems are not feasible in the bathroom space. Considering safety and dignity requirements, a monitoring system solution based on Internet of Things technology can be implemented. It includes an infrared monitor. The infrared detector can closely monitor the activity status of the elderly while protecting their privacy. When an accident occurs to the elderly, the data is automatically transmitted to the background, and the background directly contacts the nearest medical station for rescue. An intelligent care system and an information-based elderly-care platform are established to achieve functions such as voice alarm, touch alarm, body-slip recognition alarm, and behavior-habit-triggered alarm (**Figure 3**).

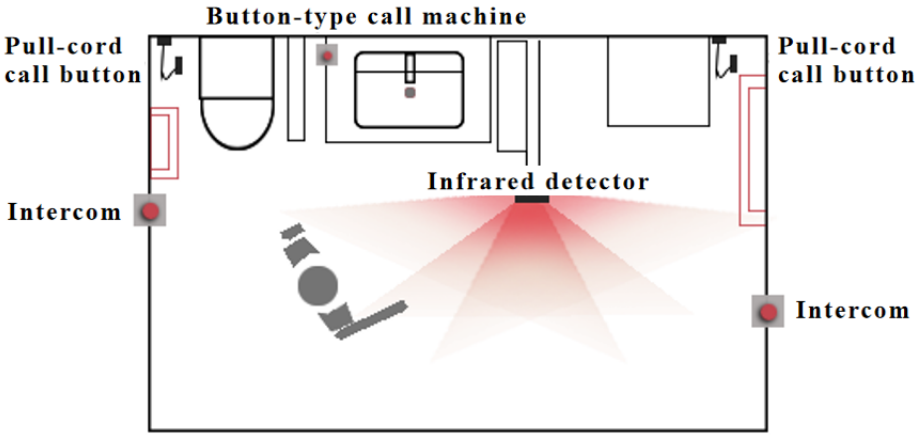

Figure 3. Safe bathroom system (Source: Hand-drawn by the authors)

3.1.2. Bathing module

Adjustable-height and rotatable shower head: In the shower area, install adjustable-height handheld and ceiling-mounted shower heads to meet the needs of different heights. The shower bracket is designed to be movable and combined with the toilet module. When the elderly sit on the toilet, they can move the shower head without additional movement for bathing. The floor should be paved with non-slip floor tiles, and a drainage groove should be set to speed up the drainage. In addition, a foldable shower chair and shower armrests can be equipped to ensure the safety of the elderly during bathing. The shower head has multiple water-outlet modes and a constant-temperature function to avoid discomfort caused by sudden changes in water temperature.

3.1.3. Toilet module

Intelligent electrically adjustable toilet seat: The toilet seat and lid can be electrically adjusted for easy sitting and standing of the elderly. At the same time, an intelligent sensing device can be installed, such as an automatically opening and closing cover and an induction night-light. An emergency call device should be installed on its side for easy use by the elderly in case of inconvenience. Secondly, it can be combined with the washstand, and its height can be adjusted to match the leg-bending and standing-up movements of the elderly. It is also equipped with functions such as automatic-sensing opening and closing, deodorization, flushing, and warm-air drying to improve the convenience and hygiene of use.

3.2. Material and environmental design

Ventilation environment: In the supporting design of the elderly-friendly bathroom space, attention should also be paid to the HVAC system, which is an integral part of the bathroom space quality standard. In the design, it is necessary to ensure bathroom ventilation and air circulation to maintain normal breathing functions, which is particularly important for the elderly. Therefore, an air-circulation system needs to be designed to ensure an adequate supply of oxygen-rich

air. A warm and humid environment is prone to breeding bacteria. Designing a floor drain to quickly dry the bathroom and keep it clean is an effective means to inhibit bacteria. A constant-temperature environment can effectively reduce the probability of sudden illnesses in the elderly. In addition, among bathroom building materials, anti-slip floor tiles with a large friction coefficient, such as ceramic tiles, natural stone, and rubber mats, should be selected to enhance the stability of the elderly when standing and reduce the risk of slipping and injury.

3.3. Storage module

Design a combination of an under-counter cabinet and a mirrored cabinet [3]. The mirrored cabinet should be designed at a certain angle for the convenience of wheelchair-bound elderly people. The under-counter cabinet adopts a combination of drawers and shelves. Drawers are convenient for storing small toiletries and are easy to access, while shelves can hold larger items such as spare toilet paper and cleaning supplies. The mirrored cabinet is designed with multiple layers. The shallow layer is for storing commonly used medicines and skin-care products, and the deep layer can store less-used sundries. The mirror is in the form of a hinged door or a sliding door that is easy to open. Side-wall-embedded niches or hanging storage cabinets can also be set up.

4. Innovation points

4.1. Precise design

Obtain the specific needs of the elderly through motion-capture technology to achieve a more practical design. For example, an intelligent remote-controlled adjustable-height washbasin can automatically adjust its height according to the height and use posture of the elderly to ensure the best comfort every time. The auxiliary handrails that are suitable for the height of the elderly and the foldable auxiliary bathing seats as needed are safer and more reliable (**Figure 4**).

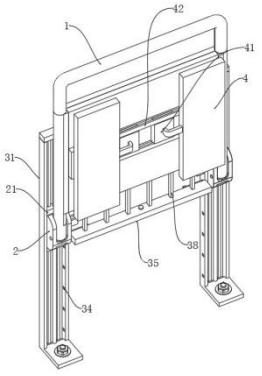

Figure 4. auxiliary handrails (Source: Hand-drawn by the authors)

4.2. Intelligent interaction

Emphasize the role of intelligent elements in enhancing the user experience. For example, functions such as automatic-sensing opening and closing, deodorization, flushing, and warm-air drying not only improve the convenience of use but also enhance hygiene and reduce the operation burden on the elderly.

4.3. Multi-dimensional elderly-friendly design

Combine elderly-friendly designs in the physiological, psychological, and environmental aspects to form a comprehensive and multi-level design innovation model [4]. In terms of physiological elderly-friendliness, pay attention to the decline of the physical functions of the elderly, and set up handrails, anti-slip floor tiles, adjustable-height equipment, etc. to reduce the difficulty and risk of use. In terms of psychological elderly-friendliness, create a warm and comfortable living environment from aspects such as spatial colors, material textures, and lighting design. In terms of

environmental elderly-friendliness, pay attention to the coordination between the bathroom space and the overall living environment and the barrier-free accessibility to ensure that the elderly can move freely at home.

5. Spatial layout modules

5.1. Wet-dry separation module

Use a trackless glass partition or curtain to separate the shower area from other spaces to achieve wet-dry separation. The floor of the wet area should be equipped with a strip-shaped floor drain, and there should be no height difference on the floor to avoid tripping risks, making the space relatively barrier-free and allowing the elderly to move freely. The dry area can be equipped with facilities such as a washstand and a toilet to keep it relatively dry and improve the safety of use. Secondly, relatively hard floor tiles may be less suitable. Softer materials can be used for floor paving to buffer in case of falls and other dangers.

5.2. Passage and turning module

Ensure that the passage width in the bathroom is appropriate, and reserve at least 800mm of barrier-free passage space to facilitate the smooth entry, exit, and turning of wheelchairs [5]. The passage floor should be flat and continuous, without height differences or protrusions to avoid tripping the elderly. In the spatial layout, avoid narrow corners and blind spots so that the elderly can clearly observe the surrounding environment while walking. Handrails can be installed on the walls of this area. The handrails are in the form of a ring or a semi-ring around the turning area, with a height between 700-900mm, which is convenient for the elderly to use for balance when turning, ensuring safe and convenient movement.

6. Conclusion

Through in-depth analysis of the movement behaviors of the elderly in the bathroom space and combined with ergonomic principles, this study proposes a complete optimization design plan for elderly-friendly bathroom spaces. This plan not only takes into account the decline of the physical functions and special needs of the elderly but also introduces intelligent technology to improve the convenience and safety of use. The research results show that reasonable elderly-friendly design can significantly improve the living experience of the elderly and enhance their quality of life [6]. In the future, with the further intensification of the aging problem, elderly-friendly design will become an important development direction in the construction industry, creating a more suitable living environment for the elderly.

Funding

The 2025 Innovation and Entrepreneurship Training Program for College Students of the University of Science and Technology Liaoning

Disclosure statement

The author declares no conflict of interest.

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