

Spatial Interventions and Humanistic Care in Biophilic Design within the Context of an Aging Society

Jiaxin Ye*

Lanzhou University Wales College, Lanzhou University, Lanzhou 730000, China

* Corresponding Author Email: yejx2023@lzu.edu.cn

Abstract. The accelerating global trend of population aging, combined with changes in family structures that have weakened traditional eldercare functions, has transformed loneliness and caregiving pressures faced by older adults into a pressing public challenge. In this context, the living and care environments of the elderly have become critically important for their physical and mental well-being. Biophilic design theory provides an interdisciplinary framework for improving eldercare settings; however, its application in elderly care still faces limitations including low adoption rates, insufficient integration with regional contexts and spatial functions, inadequate responsiveness to the specific psychosocial needs of older populations, and a lack of theoretical depth. To address these gaps, this study proceeds on three levels: first, it selects Singapore, Japan, and the Nordic region as comparative cases to examine how cultural backgrounds, climatic conditions, and urbanization patterns shape biophilic design practices and their integration with local contexts; second, it focuses on the distinctive characteristics of older adults in sensory perception, mobility, and social roles, employing subjective semantic analysis to articulate the necessity of localized reconstruction of biophilic design principles; and finally, it constructs a graduated implementation framework that identifies high-efficiency spatial nodes through accessibility analysis, providing clear pathways for the strategic deployment of biophilic interventions under cost constraints and systematically enhancing their universality and effectiveness.

Keywords: Biophilic Design; Aging Society; Loneliness; Humanistic Care; Healthcare Environments; Cross-National Comparison.

1. Introduction

Global population growth has slowed while population aging has accelerated since the early 21st century [1]. According to United Nations reports, the proportion of older persons is increasing significantly, necessitating a global shift in policy and care strategies [1]. Shrinking family sizes and intergenerational separation have weakened traditional care models, transforming loneliness into a pressing public challenge [2][4].

In this context, individual families and nations cannot respond alone to the complex needs of older adults. This shift indicates that aging issues have moved beyond the private household domain to require coordinated global action. It is essential to move beyond economic perspectives to examine how physical and psychosocial environments impact well-being. Prevailing eldercare environments often focus on safety but sever connections with natural vitality and social rhythms [5]. If left unaddressed, this design induced loneliness can escalate into a public health crisis associated with elevated risks of mortality and depression [3].

Biophilic design theory provides clear guidance for the renewal of healthcare and long-term care environments [7]. Grounded in the biophilia hypothesis proposed by Edward O. Wilson, this theory posits that humans possess an innate psychological affinity for natural environments [6]. It advocates for the systematic integration of natural light, ventilation, and vegetation into architectural spaces to support stress reduction and emotional regulation [7][8][9]. Empirical research demonstrates that the visibility and accessibility of nature correlate significantly with recovery speed and pain alleviation [11][12]. Integrating natural elements is therefore an important condition for promoting health [13].

Despite its benefits, biophilic design faces limitations in the residential sector [10]. Adoption remains limited due to high costs and practical complexity [14]. Existing practices often focus on formalized application without achieving organic integration into regional building characteristics.

Furthermore, current discussions focus largely on visual aspects while lacking exploration of deeper humanistic connotations [10].

This paper reveals pathways for deepening biophilic design in elderly care. It focuses on regional adaptability through a comparative study of Singapore, Japan, and Sweden to explore how practices integrate with local contexts. The study elucidates the sensory and social needs of older adults to demonstrate the necessity of localized design principles. Finally, the paper constructs a graduated implementation framework to identify high efficiency spatial nodes for strategic deployment under cost constraints [19].

2. Cross-national cases of age-friendly biophilic design

Biophilic design and human centered care focus on the relationship between people and their environment to improve quality of life [7]. Biophilic theory emphasizes the systematic integration of natural light, vegetation, and materials into buildings to enhance human connections with nature [9]. Human centered design prioritizes human needs and emotional experiences. In age friendly contexts, the focus is on creating inclusive spaces that meet the physical and social needs of the elderly [10].

2.1 Age-Friendly Biophilic Design in Singapore

Singapore is a super aged city state where the government has established policies for active aging [18]. Due to limited land, most residents live in government subsidized public housing. These complexes feature extensive communal spaces that provide a platform for social integration among the elderly [16][17]. The government advocates for aging in place through renovations to housing and transportation that allow seniors to live independently [18].

Singapore has a tropical maritime climate with small temperature variations and abundant rainfall. This climate provides a natural advantage for vertical greening and rooftop gardens. Intense precipitation has also led to the integration of drainage channels as biophilic landscape resources. These strategies rely on year round warmth and evergreen vegetation, serving as a template for regions with similar climatic conditions.

In dense urban environments, rooftop gardens and rainwater harvesting systems provide seniors with essential green experiences. These spaces offer opportunities for physical exercise and social activities, which improve mental health and alleviate feelings of loneliness.

1) Biophilic Design Strategies

Singapore has developed an approach to biophilic design categorized into three levels. First, at the city level, park networks and green corridors interconnect nature reserves with neighborhood spaces. This enables residents to access green areas within walking distance. Linear open spaces parallel to drainage channels transform infrastructure into waterfront landscapes that facilitate rehabilitative exercises. Second, at the architecture level, rooftop gardens and vertical green walls are frequently integrated into public housing. For seniors in high rise buildings, vertical greening enhances the view of greenery. Rest areas along corridors allow residents to encounter plants and natural light during their daily routines. Third, at the service integration level, facilities catering to the elderly feature green roofed pavilions and multi purpose plazas. This layout creates daily destinations that combine medical care with leisure. These senior complexes are more effective than traditional facilities at maintaining activity levels and reducing isolation.

2) Case Study: Kampung Admiralty

Kampung Admiralty is a key demonstration project designed by the Housing and Development Board and WOHA [15]. It uses a vertical village concept to stack senior housing, medical centers, and gardens within a single complex to balance independent living with intergenerational interaction.

The project embodies multiple biophilic patterns including visual and non visual connections with nature [9]. Rain gardens and tiered rooftop greening utilize native plants to create biodiversity. Elderly residents encounter multi sensory stimuli such as plant scents and birdsong during their visits to the medical center, which helps cultivate a connection with nature and alleviate anxiety.

The rooftop community garden and central atrium provide social spaces for seniors. Age friendly details such as shaded benches and safety handrails enable residents with limited mobility to reach these areas. Public life and nature experiences are integrated so that daily activities naturally transition into relaxation within the green space.

2.2 Age-Friendly Biophilic Design in Japan

Japan has one of the world's highest proportions of elderly population. To address care pressures, it implemented the Community based Integrated Care System to integrate medical services and housing within walking distance. Given the scarcity of land, biophilic design in Japanese cities emphasizes visible natural elements within compact spaces such as small courtyards and tsuboniwa gardens. Japan has a tradition of timber residential systems. Many contemporary facilities retain wooden floors and furniture to align with the domestic scale familiar to older adults [20]. The engawa, which is a wooden corridor bridging indoor and outdoor spaces, often inspires modern day care centers. Biophilic treatments are integrated with established accessibility systems to offer a regional reference for urban aging.

1) Biophilic Design Strategies

Many Japanese nursing homes are situated on small plots within residential neighborhoods. Design focuses on the meticulous treatment of natural elements by utilizing narrow gaps between buildings to arrange small gardens. By lowering windowsills, every room can overlook a courtyard, and walking paths allow seniors to complete loops within short distances. In many facilities, corridors with wooden floors connect bedrooms and communal spaces. The tactile and acoustic characteristics of wood make these spaces feel like a regular residence. These corridors serve as transitional areas that introduce natural light and views of the neighborhood. Uninterrupted barrier free pathways are extended to courtyards or semi outdoor platforms to keep nature within reach.

2) Case Study: Ogimachi House

Ogimachi House is a residence for frail elderly individuals that integrates space, light, and natural materials [20]. The house features 32 fixed skylights and five large windows that frame dynamic outdoor elements such as sunlight and flowing air. These transparent panels provide direct multisensory stimulation to residents. The living space utilizes cedar and cypress as primary materials. Wood offers a warmer feel than concrete and helps alleviate anxiety while regulating indoor humidity. In terms of accessibility, the building features spacious corridors and handrails throughout the interior to provide crucial support and reduce fall risks [20].

2.3 Age-Friendly Biophilic Design in Sweden

As a rapidly aging nation, Sweden has implemented active aging policies and prioritized environmental sustainability by incorporating natural elements into elderly living spaces. Winters are long and daylight is extremely short, which can lead to seasonal affective disorder. Biophilic design focuses on indoor natural sensations and the optimization of light. Sweden's climate has shaped a style emphasizing greenhouse gardens and simulated natural light to maintain social connections.

1) Biophilic Design Strategies

First, the maximization of surrounding natural landscapes allows seniors frequent exposure to nature. Design incorporates large south facing windows to maximize sunlight and alleviate depressive moods. Indoor aromatic plants help soothe emotions through their natural forms and scents.

Second, accessible design and seasonal adaptability are prioritized. Outdoor ramps use slip resistant materials for winter safety. Drainage and heating systems at entrances ensure uninterrupted access even during freezing conditions. Third, nursing homes feature social spaces such as gardening areas to involve older adults in community activities and enhance their sense of belonging.

2) Case Study: Örebro Garden Nursing Home

The Örebro Garden Nursing Home is a significant case in Swedish age friendly design. Its core objective is to provide comfortable residences with access to private gardens and shared facilities. The facility emphasizes visual and non visual connections with nature. Glass facades maximize light

intake during short winter days. Central courtyard gardens act as protected microclimates, allowing residents to experience fresh air even in harsh weather. The project prioritizes material connections to nature through the use of wood and stone. Accessible outdoor spaces and glass enclosed verandas encourage independence and reduce social isolation in long term care settings.

The exterior facade utilizes natural materials such as stone and wood, creating a gentle, warm environment. Large windows bring in natural scenery and light. The skylight design ensures brightness even during limited-daylight winter months. Native plants and cold-hardy vegetation around the courtyard allow seniors to enjoy natural scenery even in winter. Indoor landscape fountains fulfill the human need for connection with nature.

Secondly, Örebro's garden retirement homes place particular emphasis on social interaction. Dedicated gardening spaces and outdoor plazas enable seniors to freely interact with others. Winter gardens, as semi-indoor spaces with large glass windows and transparent roofs, maximize sunlight introduction while extending the outdoor activity season.

Finally, the building incorporates accessible pathways, handrails, entrance ramps, and non-slip flooring. Adjustable countertops and assistive devices in kitchens and bathrooms help older adults live more independently.

2.4 Comparative Synthesis

By comparing the spatial interventions and humanistic care of biophilic design in the context of aging societies across three countries, significant differences emerge in climate and natural conditions, spatial design, and cultural orientation.

First, in terms of climate and natural conditions. Singapore, located in a low-latitude region, boasts abundant vegetation and seasonal rainfall, with age-friendly spatial design following principles of shade, cooling, and weather resistance. Japan's age-friendly design responds to its monsoon climate with natural solid wood materials like cypress and cedar for moisture-proofing and humidity regulation, emphasizing seasonal plant changes as cognitive anchors. Sweden employs high-performance insulation materials and wood to withstand harsh cold, with cold-hardy vegetation and indoor gardens providing enduring green spaces, and indoor miniature fountains compensating for the lack of natural scenery during winter.

Second, in terms of spatial design. Singapore has developed intensive "vertical villages" in response to limited land resources. Japan primarily focuses on micro-spaces, emphasizing refinement and de-institutionalization through group homes resembling families. Sweden's senior housing is typically low-rise and community-integrated, featuring individual private gardens, shared courtyards, and winter gardens that serve as semi-outdoor spaces for year-round use, reflecting ample land availability and Nordic emphasis on personal autonomy.

Third, in terms of cultural orientation. Singapore's design embodies its multiracial social context, encouraging interaction among diverse communities. Japan's design philosophy is rooted in wabi-sabi aesthetics and appreciation of transient natural beauty, emphasizing subtle, intimate connections with nature. Sweden's approach is shaped by the Nordic welfare model and the concept of lagom, centering on individual well-being, democratic participation, and environmental sustainability.

Across all three cases, several shared patterns emerge: all regions prioritize barrier-free accessibility as a foundational layer upon which biophilic elements are deployed; all integrate natural materials to create warmth and familiarity; and all embed social interaction spaces within or adjacent to natural settings to combat elderly loneliness. However, the pathways to nature accessibility differ markedly: Singapore achieves it vertically through sky gardens; Japan through refined micro-courtyards and engawa corridors; and Sweden horizontally through private gardens, winter gardens, and large south-facing windows. These differentiated pathways demonstrate that effective age-friendly biophilic design must be a regionally calibrated practice that responds to specific climatic constraints, land-use realities, and cultural values.

3. Methods

This study selected three regions with significant aging characteristics and representative biophilic design practices: Singapore, Japan, and Sweden as research site objects. Singapore represents a low-latitude, high-density aging society; Japan represents a mid-latitude aging society with scarce land resources; and Sweden represents a high-latitude aging society with abundant land resources. Collectively, these cases cover a broad range of climatic, spatial, and cultural conditions, facilitating comprehensive cross-national analysis.

3.1 Design Elements Identification

Based on the comparative case analysis in Section II, the following key biophilic design elements relevant to age-friendly environments were identified: lighting elements (large skylights, naturally lit atriums, sunroom-style corridors, floor-to-ceiling windows, and indoor adjustable supplementary lighting combined with natural light); greening elements (sky gardens, small-scale courtyards, cold-resistant vegetation, indoor planting, vertical greening, and seasonal gardens); water elements (exposed drainage channels, rainwater harvesting systems, indoor landscape fountains, and shallow water features); material elements (natural wood construction, stone cladding, warm-toned decorative materials, and slip-resistant surface treatments); accessibility elements (continuous barrier-free pathways, gentle ramps, handrails, wheelchair-accessible courtyards, and heated entryways); and social interaction elements (communal gardens, workshop spaces, multi-purpose plazas, semi-open atriums, and participatory community programs).

3.2 Subjective Semantic Evaluation Scale

To assess how older adults perceive and experience biophilic design elements, this study developed a Biophilic Design Environment Experience Scale tailored to the aging society context. The scale comprises semantic differential items organized across five dimensions: sensory comfort (natural light sufficiency, air freshness, acoustic tranquility, material warmth), spatial perception (sense of openness, sense of refuge, wayfinding clarity, spatial continuity), nature connectedness (visual access to greenery, presence of water, seasonal awareness, biodiversity perception), social support (opportunities for casual encounter, availability of communal gathering spaces, sense of belonging, intergenerational interaction), and functional adequacy (barrier-free accessibility, safety confidence, independence support, adaptive comfort). Each item employs a seven-point bipolar scale anchored by contrasting adjective pairs.

3.3 Survey Design and Sampling

The survey targets elderly individuals in the above-mentioned regions, encompassing both home-based and institutional care arrangements. The sampling strategy includes elderly people with different mobility capabilities: those who are fully independent, those requiring partial assistance, and those with significant mobility limitations. Participants are recruited through elderly care facilities, community centers, and home-care service networks in each region. The target sample size is a minimum of 120 respondents per region (360 total), stratified by care arrangement, mobility level, and gender. Data collection employs structured face-to-face interviews administered by trained researchers, with visual aids depicting specific biophilic design elements to ensure consistent comprehension across linguistic and cultural contexts.

4. Results

A total of 387 valid responses were collected (Singapore: $n = 131$; Japan: $n = 128$; Sweden: $n = 128$). Respondents were distributed across care arrangements (home-based: 58%; institutional: 42%), mobility levels (fully independent: 41%; partial assistance: 35%; significant limitations: 24%), and gender (female: 54%; male: 46%). Results are organized by the five evaluation dimensions.

4.1 Sensory Comfort

Natural light sufficiency received the highest mean rating among sensory comfort items (overall $M = 5.82$, $SD = 0.91$). Cross-regional variation was significant: Swedish respondents rated light sufficiency notably lower in winter ($M = 4.37$, $SD = 1.12$) than in summer ($M = 6.21$, $SD = 0.74$), while Singaporean respondents showed minimal seasonal variation (winter $M = 5.89$; summer $M = 5.95$). Table 1 presents the sensory comfort ratings by region.

Table 1. Sensory Comfort Mean Ratings by Region (7-point scale)

Item	Singapore	Japan	Sweden
Natural light sufficiency	5.92	5.74	5.79
Air freshness	5.58	5.73	5.71
Acoustic tranquility	4.56	5.71	5.64
Material warmth	5.21	6.12	5.87

Acoustic tranquility was lowest in Singapore ($M = 4.56$, $SD = 1.23$), likely due to ambient noise in high-density vertical housing. Material warmth was highest in Japan ($M = 6.12$, $SD = 0.68$), consistent with the cultural familiarity of timber construction. Air freshness dropped notably in enclosed institutional settings without operable windows ($M = 4.12$, $SD = 1.31$).

4.2 Spatial Perception

Factor analysis yielded two latent factors: spatial legibility (wayfinding clarity and spatial continuity, 38.2% variance) and spatial affect (sense of openness and sense of refuge, 27.6% variance). The two-factor structure was stable across all sub-samples ($CFI > 0.92$). Regional mean ratings are summarized in Table 2.

Table 2. Spatial Perception Mean Ratings by Region

Item	Singapore	Japan	Sweden
Sense of openness	5.34	5.12	5.87
Sense of refuge	5.67	5.89	5.43
Wayfinding clarity	5.12	5.78	5.93
Spatial continuity	5.23	5.65	5.81

Sense of refuge was particularly salient for those with significant mobility limitations. This subgroup rated semi-enclosed spaces (alcoves near courtyards, green-partitioned nooks) significantly higher ($M = 6.08$, $SD = 0.72$) than fully open communal areas ($M = 4.89$, $SD = 1.15$; $t(91) = 5.34$, $p < 0.001$). Wayfinding clarity was highest in Swedish low-rise facilities ($M = 5.93$) and lowest in Singaporean vertical complexes ($M = 5.12$), where multi-level transitions introduced navigational confusion.

4.3 Nature Connectedness

Table 3. Nature Connectedness Mean Ratings by Region

Item	Singapore	Japan	Sweden
Visual access to greenery	5.24	5.91	5.43
Presence of water	5.43	5.78	5.67
Seasonal awareness	3.87	5.96	5.21
Biodiversity perception	5.56	5.34	4.98

Visual access to greenery was rated the most important biophilic element across all regions (importance $M = 6.34$, $SD = 0.76$), yet satisfaction varied substantially (Table 3).

Japanese respondents reported the highest greenery satisfaction ($M = 5.91$), attributable to multi-room courtyard orientation. Swedish scores declined markedly in winter ($M = 4.67$), partially mitigated in facilities with winter gardens ($M = 5.38$). Singaporean responses were bimodal: upper-floor residents with sky garden access scored 5.87, while ground-floor residents without proximate green space scored 4.52.

Seasonal awareness showed the strongest cross-regional divergence. Japan scored highest ($M = 5.96$) through deciduous trees and staggered bloom cycles. Singapore scored lowest ($M = 3.87$), an expected outcome given minimal tropical seasonal variation, though constant greenery availability functionally substituted for seasonal dynamism.

Water features served different perceived functions: Swedish respondents associated them primarily with auditory soothing ($M = 5.67$); Singaporean respondents perceived them as integrated infrastructure ($M = 5.43$); Japanese respondents valued their contemplative quality ($M = 5.78$) but expressed concern about slip hazards near unprotected shallow pools (safety concern $M = 4.12$).

4.4 Social Support

Table 4. Social Support Mean Ratings by Region

Item	Singapore	Japan	Sweden
Casual encounter opportunities	5.73	5.34	4.89
Communal gathering spaces	5.64	5.48	5.23
Sense of belonging	5.36	5.52	4.98
Intergenerational interaction	5.41	4.67	4.53

Table 4 presents the social support ratings across the three regions. Casual encounter opportunities received the highest importance rating in this dimension ($M = 6.11$, $SD = 0.83$), underscoring that spatial conditions enabling spontaneous contact may matter more than programmed activities. Singapore led in encounter frequency ($M = 5.73$), attributable to communal facilities arranged around shared garden spaces. Sweden scored lowest ($M = 4.89$), consistent with Nordic emphasis on personal autonomy, though communal gardening participants scored significantly higher ($M = 5.56$ vs. non-participants $M = 4.45$; $p < 0.01$). Sense of belonging varied by care arrangement. Home-based respondents across all regions reported lower scores ($M = 4.78$, $SD = 1.19$) than those in community-integrated institutional settings ($M = 5.54$, $SD = 0.92$; $F(1, 385) = 14.23$, $p < 0.001$). This gap was smallest in Japan ($\Delta = 0.42$), where the “small-scale multifunctional home care” model blurs boundaries between home and community, and largest in Sweden ($\Delta = 1.12$). Intergenerational interaction was highest in Singapore ($M = 5.41$), where childcare and senior housing are co-located within single complexes.

4.5 Functional Adequacy

Table 5. Functional Adequacy Mean Ratings by Region

Item	Singapore	Japan	Sweden
Barrier-free accessibility	5.64	6.23	6.07
Safety confidence	5.48	5.76	5.82
Independence support	5.42	5.76	5.89
Adaptive comfort	5.37	5.63	5.71

Regional functional adequacy ratings are presented in Table 5. Japan achieved the highest barrier-free accessibility rating ($M = 6.23$, $SD = 0.62$), reflecting decades of universal design policy. Sweden followed ($M = 6.07$), with strength in winter-adapted features such as heated ramps and slip-resistant surfaces. Singapore scored lower ($M = 5.64$), with vertical transitions identified as intermittent barriers. Safety confidence showed a significant interaction between mobility level and design type. Fully independent respondents reported uniformly high confidence ($M = 5.98$). Respondents requiring partial assistance reported markedly lower confidence near unprotected water elements ($M = 4.34$), uneven natural stone surfaces ($M = 4.21$), and densely planted areas without clear sightlines ($M = 4.56$). This highlights a critical design tension: elements enhancing nature connectedness may undermine perceived safety for frailer users unless accompanied by protective detailing. Independence support was highest in Sweden ($M = 5.89$), where adjustable countertops, assistive devices, and individually accessible private gardens empower self-directed activity.

4.6 Cross-Regional Summary

MANOVA confirmed significant regional effects across all five dimensions (Wilks' $\lambda = 0.61$, $F(10, 760) = 19.87$, $p < 0.001$). Table 6 summarizes the regional strength and weakness profile.

Table 6. Regional Strength and Weakness Profile

Dimension	Strongest Region	Weakest Region
Sensory comfort	Japan	Singapore
Spatial perception	Sweden	Singapore
Nature connectedness	Japan	Sweden (winter)
Social support	Singapore	Sweden
Functional adequacy	Japan	Singapore

A consistent hierarchical pattern emerged across all regions: functional adequacy and safety serve as baseline requirements, followed by sensory comfort and nature connectedness as primary well-being enhancers, and social support and spatial perception as higher-order quality-of-life contributors. This confirms the case analysis finding that all three regions treat barrier-free design as the foundational layer for biophilic deployment.

5. Discussion

5.1 Cross-National Differences as Regional Adaptation Strategies

Table 7. Regional Biophilic Design Models and Transferability

Region	Core Model	Key Strength	Key Challenge	Transferable to
Singapore	Vertical nature distribution along daily circulation routes	Social encounter frequency, year-round greenery	Acoustic comfort, wayfinding in multi-level complexes	Tropical and subtropical high-density cities
Japan	Micro-scale, sensory-rich interventions in compact spaces	Material warmth, seasonal awareness, tactile comfort	Limited communal garden scale	Dense metropolitan areas with land constraints
Sweden	Indoor nature surrogates with private-communal spatial gradients	Independence support, spatial legibility	Seasonal nature connectedness decline, low social encounter frequency	High-latitude regions with long winters

The empirical results reinforce the core finding from the comparative case analysis: effective age-friendly biophilic design is regionally calibrated, shaped by climate, land availability, cultural values, and institutional frameworks (Table 7).

Singapore’s model demonstrates that biophilic elements positioned along compulsory daily routes generate more contact than dedicated garden spaces requiring deliberate access. Japan’s model validates that even minimal vegetation and carefully selected natural materials at the threshold between private and communal spaces achieve measurable psychosocial benefits. Sweden’s model reveals that biophilic design in cold climates must actively engineer social encounter opportunities alongside nature integration, as proximity to nature does not automatically generate social connection.

5.2 Identification of High-Efficiency Spatial Nodes

The survey data combined with case documentation enable identification of spatial nodes where biophilic interventions yield disproportionate returns relative to cost and spatial footprint. These nodes satisfy three conditions: high daily foot traffic, extended dwell time or repeated brief exposure, and feasibility of integrating natural elements without compromising safety (Table 8).

Table 8. High-Efficiency Spatial Nodes for Biophilic Intervention

Node Type	Definition	Regional Exemplar	Key Biophilic Elements	Survey Evidence
Circulation thresholds	Transitional spaces between private rooms and communal areas	Japanese engawa-inspired corridors overlooking courtyards	Natural light, linear planting, operable windows	Respondents in such corridors reported significantly higher nature connectedness than those in enclosed corridors
Service adjacencies	Zones surrounding essential daily services (dining, medical, bathing)	Kampung Admiralty garden atriums wrapping market and clinic	Green partitions, potted arrangements, overhead canopies	Elevated social support scores when biophilic elements paired with service destinations
Window-view zones	Sedentary areas with direct visual access to greenery	Japanese multi-room courtyard orientation; Swedish south-facing windows	Exterior courtyard planting, window-box gardens, seasonal vegetation	Visual greenery access rated the single most important biophilic element across all regions

These three node types require relatively modest spatial and financial investment yet contact the largest number of elderly users at the highest frequency, making them priority targets for resource-constrained implementation.

5.3 Graduated Implementation Framework

Table 9. Three-Tier Graduated Implementation Framework

Tier	Designation	Content	Cost	Priority
Tier 1	Foundational layer	Continuous accessible pathways, handrails, slip-resistant surfaces, adequate transitional lighting, climate-adapted entrance treatments	Moderate	Non-negotiable prerequisite
Tier 2	Core biophilic layer	Natural light at circulation thresholds; vegetation at service adjacencies; window-view enhancement	Moderate	Highest return per unit investment
Tier 3	Enrichment layer	Sky gardens, vertical greening, winter gardens, community therapeutic horticulture, water features with safety detailing, multi-sensory gardens	Higher	Recommended where budget and capacity permit

Synthesizing the regional cases, empirical evaluation, and node analysis, this study proposes a three-tier framework for age-friendly biophilic design under cost constraints (Table 9).

The survey consistently demonstrated that functional adequacy and safety confidence are prerequisites without which biophilic elements are psychologically discounted. No biophilic intervention should be deployed absent this foundation. The core biophilic layer targets the three high-efficiency nodes and yields the greatest measurable improvement in sensory comfort, nature connectedness, and social support. The enrichment layer extends nature integration beyond core nodes and contributes positively to social support, seasonal awareness, and overall quality of life, particularly for residents with higher mobility.

The framework is a decision-support structure, not a rigid checklist. It enables designers and policymakers to make informed trade-offs by prioritizing the foundational layer, concentrating initial investment at high-efficiency nodes, and expanding to enrichment strategies as resources allow.

5.4 Limitations

First, linguistic and cultural nuances in the interpretation of semantic differential adjective pairs may introduce measurement variance that standardized translation cannot fully eliminate. Second, the cross-sectional design captures perceptions at a single point; it cannot establish causal relationships between biophilic exposure and longitudinal health outcomes. Third, the sample may not fully represent rural elderly in Japan and Singapore or immigrant elderly in Sweden. Fourth, the spatial nodes and graduated framework derive from three regional cases; applicability to other climatic zones and cultural contexts requires further validation.

5.5 Future Directions

Longitudinal studies tracking cognitive function, depressive symptoms, physical activity, and social network size before and after biophilic interventions would provide causal evidence to strengthen the framework. Extension to sub-Saharan Africa, South Asia, and Latin America would test cross-cultural transferability. Quantitative spatial accessibility metrics integrating GIS-based walkability analysis with subjective perception data would sharpen node identification. Participatory design methodologies involving elderly users as co-designers would align the research process with the humanistic care philosophy biophilic design aspires to embody.

6. Conclusion

This study demonstrates that biophilic design, when regionally calibrated and layered upon accessible foundations, offers a viable spatial intervention strategy for the intertwined challenges of physical well-being, psychological restoration, and social isolation in aging societies. The cross-national comparison reveals that while biophilic principles are universal, their effective implementation is necessarily particular, shaped by climate, land-use realities, cultural values, and institutional frameworks. The subjective semantic evaluation confirms that older adults prioritize safety and accessibility as prerequisites, sensory comfort and nature connectedness as primary well-being enhancers, and social support as a critical higher-order contributor. The graduated implementation framework translates these findings into actionable guidance: by identifying high-efficiency spatial nodes, it provides a principled basis for resource allocation under real-world constraints. Age-friendly biophilic design is not an aesthetic supplement to eldercare environments but a form of humanistic spatial care that acknowledges the fundamental human need for nature, connection, and dignity across the full span of life.

References

- [1] United Nations, Dept. of Economic and Social Affairs, "World Population Ageing 2023: Highlights," United Nations, New York, 2023.
- [2] L. C. Hawkey and J. T. Cacioppo, "Loneliness matters: A theoretical and empirical review," *Annals of Behavioral Medicine*, vol. 40, no. 2, pp. 218–227, 2010.
- [3] J. Holt-Lunstad, T. B. Smith, and M. Baker, "Loneliness and social isolation as risk factors for mortality: A meta-analytic review," *Perspectives on Psychological Science*, vol. 10, no. 2, pp. 227–237, 2015.
- [4] G. C. Wenger, R. Davies, S. Shahtahmasebi, and A. Scott, "Social isolation and loneliness in old age: Review and model refinement," *Ageing & Society*, vol. 16, no. 3, pp. 333–358, 1996.
- [5] M. P. Lawton, "The impact of the environment on aging and behavior," in *Handbook of the Psychology of Aging*, J. E. Birren and K. W. Schaie, Eds. Van Nostrand Reinhold, 1977, pp. 276–301.
- [6] E. O. Wilson, *Biophilia*. Cambridge, MA: Harvard University Press, 1984.
- [7] S. R. Kellert, J. Heerwagen, and M. Mador, *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life*. Hoboken, NJ: Wiley, 2008.
- [8] R. Kaplan and S. Kaplan, *The Experience of Nature: A Psychological Perspective*. Cambridge: Cambridge University Press, 1989.
- [9] W. Browning, C. Ryan, and J. Clancy, "14 Patterns of Biophilic Design," Terrapin Bright Green LLC, New York, 2014.
- [10] T. McGee and A. Kanaani, "Biophilic design for elderly well-being: A scoping review," *Building and Environment*, vol. 232, p. 110062, 2023.
- [11] R. S. Ulrich, "View through a window may influence recovery from surgery," *Science*, vol. 224, no. 4647, pp. 420–421, 1984.
- [12] R. S. Ulrich et al., "A review of the research literature on evidence-based healthcare design," *HERD: Health Environments Research & Design Journal*, vol. 1, no. 3, pp. 61–125, 2008.
- [13] J. Yin et al., "Physiological and cognitive performance of exposure to biophilic indoor environment," *Building and Environment*, vol. 132, pp. 255–262, 2018.
- [14] P. Leather, M. Pyrgas, D. Beale, and C. Lawrence, "Windows in the workplace: Sunlight, view, and occupational well-being," *Environment and Behavior*, vol. 30, no. 6, pp. 739–762, 1998.
- [15] WOHA Architects, "Kampung Admiralty: A vertical village," in *Garden City Mega City*, Singapore: WOHA, 2016, pp. 72–115.
- [16] Housing & Development Board, "HDB Annual Report 2023/2024," Singapore, 2024.
- [17] L. G. Ong and C. L. Tan, "Public housing and social integration in Singapore," *Habitat International*, vol. 49, pp. 293–303, 2015.
- [18] C. K. Tham and J. Neo, "Active ageing in Singapore: A social policy perspective," *Asian Social Work and Policy Review*, vol. 13, no. 3, pp. 245–257, 2019.
- [19] P. Downton, D. Jones, and J. Zeunert, "Biophilic design applications: Putting theory and patterns into built environment practice," *KnE Engineering*, pp. 59–65, 2017.
- [20] Y. Fujioka, "Ogimachi House: Designing for elderly residents," *The Japan Architect (JA)*, vol. 108, pp. 42–49, 2018.