A new perspective on cognitive rehabilitation: layout design methods for wandering behavior in dementia patients

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Abstract. The global prevalence of dementia is on the rise, and existing medical models can no longer fulfill the pervasive need for intervention. Dementia is incurable, but the identification of Mild Cognitive Impairment (MCI) provides a window of opportunity for early intervention. The environmental therapy theory has been widely adopted, however, the implementation pathways and empirical evidence for cognitive behavioral interventions are still limited. The role of interior layout design as one of the environmental elements in guiding human behavioural patterns has been demonstrated by numerous scholars and extended to be explored in relation to perceptual and cognitive behavioural dimensions. There has been a great deal of research on Wandering Behavior In Patients With Cognitive Disorders in the medical field, but only sporadic reports in the field of design. Employing an "environment-behavior-neuroscience" research approach, this paper constructs the relationship between wandering behavior, cognitive function, and environmental factors, and explores the possibility of environmental intervention to improve cognitive functions. The study shows that: 1) The wandering patterns of dementia patients can be guided through landmarks; 2) There is a direct relationship between the depth of spatial communication and the layout, and optimizing the spatial layout can foster communication and theoretically have a restorative effect on cognitive function; 3) Centripetal layouts are more effective in behavior guidance, while multicore circulation path layouts can accommodate the wandering needs of dementia patients. As dementia is incurable, early intervention is the most effective approach, making this research highly valuable.

1. Introduction

Dementia, characterized by the decline of memory and executive functions, is a neurodegenerative disease whose onset involves physiological, psychological, and environmental factors [1]. In 2021, the global number of individuals with dementia surpassed 55 million [2], with an increase of one person every three seconds and an annual increment of approximately 10 million cases. It is predicted that this number may rise to 131.5 million by 2050. The existing medical models are insufficient to meet the treatment needs of individuals with dementia. The burden of care and the high costs of treatment are reasons that the majority of patients abandon therapy. Approximately 50.87% of families desire more accessible, cost-effective, and human-centered treatment methods [3]. In the post-pandemic era,

there is an urgent demand for a healthier environmental quality. Among the social driving forces for green buildings, improving residents' health ranks first [4].

The current treatment modalities for this disease are divided into two main types of treatment: pharmacological and mixed pharmacological + non-pharmacological interventions, the former of which is not popular due to its high cost and the risk of unknown side effects. The latter, in turn, is dominated by nursing rehabilitation training. Both inpatient and home care are labor-intensive, and the stress of caregiving and lack of ability to pay are the reasons why most families conceal their illness, choose home care, or even abandon treatment. The lack of professional nursing knowledge makes it difficult for the home care approach to have a positive effect on the patient's condition. Fifty percent of our patients' families express a sense of helplessness, 65% of caregivers say they see no hope for treatment, and 50.87% of families want more convenient, less costly, and more humane ways of treatment [3]. The prevailing healthcare environment assessment framework primarily encompasses two dimensions: the evaluation of health policy initiatives and the examination of health technology innovations. The former applies an effectiveness assessment post-implementation as its primary evaluative criterion, whereas the latter adopts rehabilitative efficacy post-application as its evaluative benchmark, predominantly relying upon clinical treatment data for evaluation. However, this framework lacks an inclusive perspective that considers patients' acceptance of their social environments post-rehabilitation and the extent to which these environments accommodate their needs.

Cognitive impairment has been demonstrated to be closely linked to environmental factors [5]. Studies in this domain aim to uncover how environmental variables exert influence on neural networks and cognitive processes through behavioral pathways [6]. Since the United Nations issued the Sustainable Development Goals in 2015, environmental health has emerged as a central topic on the international agenda [7], and the theory of environmental therapy has gradually been employed to promote physical health and enhance the quality of rehabilitation [8-9]. However, its efficacy remains questionable, and the evidence is still scarce. Using rigorous research methods and validated clinical data, Ulrich [10] confirmed the importance of the environment on patient recovery, finding that patients who faced a green view directly outside their windows had a 30% increase in recovery efficiency and an equal proportional decrease in medication intake than patients who faced an artificial environment directly outside their windows. His research confirmed the existence of a strong correlation between the quality of patient recovery and the physical environment, and advanced the field of environmental therapy theory and practice.

In environmental therapy theory research, Ulrich [10] proposed the theory of "restorative environments," suggesting that the presence of natural environmental elements could alleviate stress and have a potentially beneficial effect on an individual's physiological and psychological recovery. Wilson [11] posited that fulfilling the human need for contact with nature could lead to a range of psychological benefits. Building on this, Eileen [12] emphasized the positive role of exposure to nature in promoting patients' attention diversion. Zhang [13] advocated for integrating spatial elements with mental functions to create environments that evoke individuals' sense of identity and belonging. Claire [14] perceived human behavior as a mental processing of the environment and uncovered the potential governing role of the nervous system in human behavior. Furthermore, she introduced principles for restorative landscape design, including visibility, accessibility, affinity, and positive engagement. The National Health Service [15] proposes a framework for evaluating the patient experience and emphasizes the importance of collaboration, communication, and environmental engagement between physician and patient staff and families.

In terms of behavioral intervention theory, Cui [16] argues that healthcare spaces need to meet the physiological and behavioral psychological needs of various user groups, and Chao and Liu [17] point out that it is important to explore the relationship between users' practical behaviors and space, and to find the best empirical data to guide the design and create healthy and positive healthcare spaces. An important element of environmental behavior is the study of spatial behavior, i.e., looking at the essence of the phenomenon and studying the procedural ways in which people use space and how the quality and quantity of human interaction and information exchange between people and the

environment are governed by space [18]. Guo [19] found that by moving the nurses' station to the central area to create an open public space, the increased level of spatial communication promoted environmental engagement for patients.

In environmental intervention applications, Roberts et al. [20] enhanced the environmental adaptability and promoted memory recovery of dementia patients by utilizing color-rich, home-style rehabilitation environments. In the United States, the Prosperous Life Center satisfied the wandering needs of dementia patients by setting up circular walking areas, cleverly minimizing the likelihood of them getting lost [21]. Wu [22] proposed that the environment should be equipped with stimulus elements and scenarios capable of triggering patients' memories to optimize cognitive function and emotional states. Gary [23] found that social interaction, facilitated through the simple act of passing a coffee pot, holds the potential to slow down cognitive decline in older adults. Lu [24] observed that dementia patients prefer familiar environments and argued that their living environments should remain stable, providing a sense of security through simple layouts. The Calm Heart Room in the Sophia Louise DeBridgeweg Rehabilitation Garden in the United States is filled with a variety of sensory stimulating plants where cognitive patients can comfort each other and relieve psychological stress. Selwyn [25] demonstrated that "doll therapy" effectively reduced aggression and anxiety, and slowed cognitive decline through memory recall.

In summary, the field of environmental therapy has expanded to encompass the interdisciplinary dimensions of "environment-behavior-neuroscience," giving rise to two key issues: 1) Intervention pathways: how environmental variables modulate the neural substrates of cognitive functions through behavioral and psychological means, and 2) Rehabilitation efficacy: the role of environmental design in disease rehabilitation and evidence of its effectiveness. Studer [26] posited that an individual's behavior is influenced by a combination of social and genetic factors. Against this backdrop, this paper focuses on exploring the interrelationship between wandering behavior and environmental factors in patients with dementia and attempts to elucidate the feasibility of enhancing cognitive functions through environmental design interventions.

The objective of this study is to explore spatial design methods conducive to the rehabilitation of patients with dementia. As age progresses, the gradual decline in physical capabilities often accompanies a series of age-related diseases, among which dementia is the most prevalent and quintessential [8]. Dementia is currently incurable [27]. Under these circumstances, delaying the progression of the disease has emerged as an efficient and direct strategy, with environmental intervention regarded as a "low-cost, high-return, sustainable" design method.

2. Methodology

Research Methodology: The paper initially establishes the correlation between wandering behavior characteristics and environmental factors and systematically examines empirical cases of environmental design in improving cognitive functions. Subsequently, employing the "environment-behavior-neuroscience" research methodology, the study analyzes the potential effects of environmental design interventions on modulating wandering behavior characteristics, supported by an in-depth analysis of a practical case (environmental renovation of Guangzhou Dementia Elderly Service Center). Finally, the study delineates effective design strategies and delves into their applicability, universality, and variations in the practical implementation.

2.1. Patients with cognitive impairment and their roaming behavior characteristics

Mild, moderate, and severe are three stages in the developmental trajectory of cognitive impairment, with patients in the severe stage eventually manifesting symptoms of aphasia, agnosia, and apraxia [28]. The prospects for intervention therapies are relatively limited for patients with severe cognitive impairment. Mild Cognitive Impairment (MCI) is a condition that lies between normal cognitive function and mild dementia. Although individuals in this category display cognitive decline, they still maintain fundamental daily living skills [29]. Identification at the MCI stage provides a critical time window for environmental intervention. This study primarily focuses on patients with MCI and mild

cognitive impairment, wherein wandering and pacing are common behaviors that involve harmless exploration of the surrounding environment [30]. In unsupervised situations, patients with MCI are at higher risk of becoming lost or disoriented.

2.2. Theory and Research Ideas

Hamilton posits that an individual's behavior is influenced by a combination of environmental and non-environmental factors, making the adoption of interdisciplinary research methodologies a more rational choice. Consequently, he developed an integrated sociological research framework, termed "environment-behavior-neuroscience."[31] Environmental and non-environmental variables are the two societal factors that affect a patient's behavior. When observing an environment, the first elements mapped by humans are the geometric frameworks composed of points, lines, and planes, followed by physical forms, textures, and tactile sensations. In long and deep spaces, the pedestrian track axis plays the potential to promote the vitality of the environment [32]. Spatial forms, surface designs, furnishing arrangements, and flooring are the four salient visual elements of indoor spaces. Through rational design and organization of space, providing spatial guidance, and enhancing environmental stimuli, the aim is to meet the wandering behavior needs of the patients and improve cognitive functions (Figure 1).

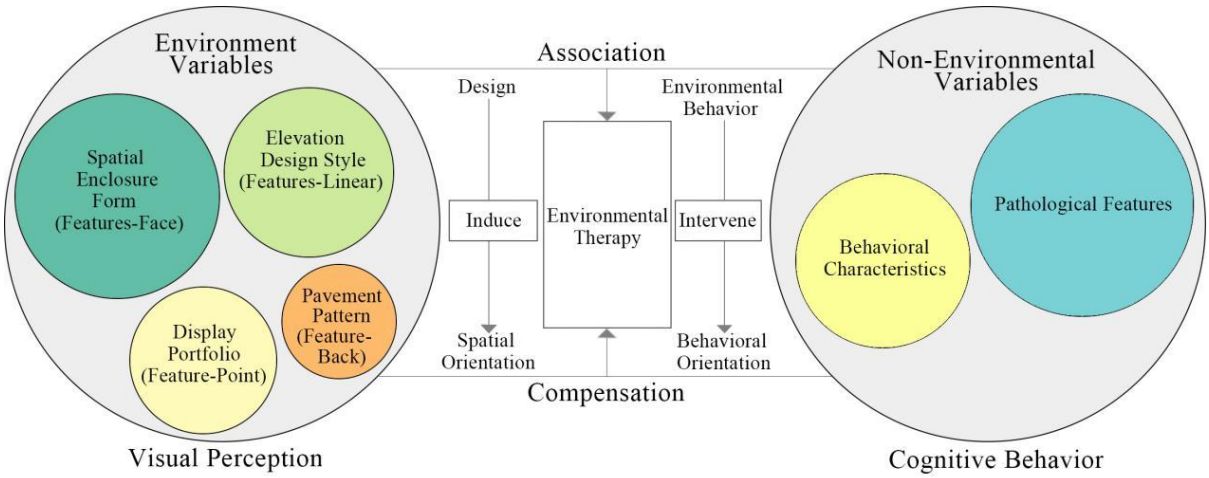


Figure 1. A design pathway for spatial environmental interventions for roaming behavior in patients with cognitive disorders. (Source: drawn by the authors)

2.3. An applied study of environmental design interventions for roaming behavior

The theory of "Behavioral and Psychological Symptoms of Dementia" (BPSD) [33] posits that wandering behavior, commonly exhibited by patients with dementia [34], is an overt reaction to unmet intrinsic needs [35]. The human cognitive system has a close connection with spatial environments [36], and optimizing the spatial environment can slow the decline of cognitive functions [20]. Research evidence indicates that there is a correlation between spatial environments and pacing, wandering, and roaming behaviors (Table 1). Since wandering behavior in such patients is an incurable phenomenon, employing coercive control measures may elicit resistance and emotional agitation [37]. An individual's pattern of behavior in space is closely related to the environment in which they are situated. Changes in the environment can influence human behavior [38]. A hypothesis supporting pacing has been proposed, stating, "it can serve as a means for wanderers to exercise [39], helping to reduce problematic behaviors, and promoting sleep after physical exertion." [40]

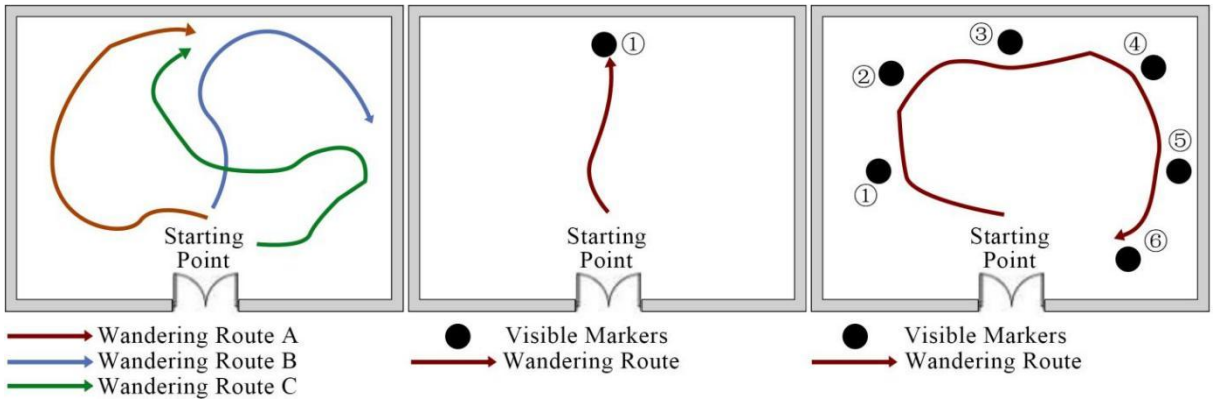
Table 1. Association between roaming behavior and environment in patients with cognitive impairment. (Source: drawn by the authors)

Authors	Opinions or research findings
Bautrant et al. [41]	The rearrangement of the environment, the change in lighting brightness, and the addition of soothing music were effective in improving the wandering behavior of patients with cognitive disorders.
Kamil et al. [42]	Wandering behavior is associated with spatial disorientation, which may be related to the environment. Patients with cognitive impairment showed more frequent number of turns.
Li et al. [8]	The spatial layout pattern has a guiding role for the aimless roaming behavior.
Mazzei et al. [43]	Changes in the physical environment can affect wandering behavior. By designing and coding the color of the environment, the pathfinding ability of people with dementia can be improved.
Song et al. [44]	Wandering behavior in patients with dementia is closely related to environmental influences.
Smith et al. [45]	Through spatial forms, effective pathfinding design forms can be developed to support wandering. Specific pathfinding design strategies have the potential to slow cognitive decline.
Hong and Song [46]	Familiarity with the environment is an important factor influencing cognitive function and wandering behavior in patients with cognitive disorders.
Dickinson and McLain-Kark [47]	Wandering behavior of vagrants may be attributed to boredom or stress.
Algase et al. [48]	Wandering behavior overlaps with the spatial orientation problem, which is closely related to the spatial context of wandering.

3. Layout design method for environmental intervention of roaming behavior of patients with cognitive disorders

3.1. Wrap-around path design to meet the needs of roaming behavior

A spatial behavior experiment in Japan corroborated that wandering individuals exhibit traceable behavior patterns [49]. The experiment (Figure 2) demonstrated that, in spaces devoid of distinct landmarks, patients with dementia engage in aimless wandering and exploratory behavior. In contrast, when presented with a target, they are drawn towards it and move in its direction. When multiple conspicuous landmarks are strategically placed in the space, patients are guided to form a cyclical wandering route. By designing spatial nodes as prominent landmarks and sequentially introducing experiences and memories of the elderly at each node (reminiscence therapy) [50], augmented with inducive flooring materials and colors, a coherent spatial storyline can be established to guide their behavior and cognition. The spatial environment crafted through these strategies has the potential to exercise their brains, delay memory decline, and enhance cognitive abilities, while simultaneously minimizing their chances of getting lost.



(a) Random-no obvious markers (b) Clear-with visible markers (c) Circulation of—multiple distinct markers to guide

Figure 2. Spatial cognition experiment in cognitive patients. (Source: drawn by the authors)

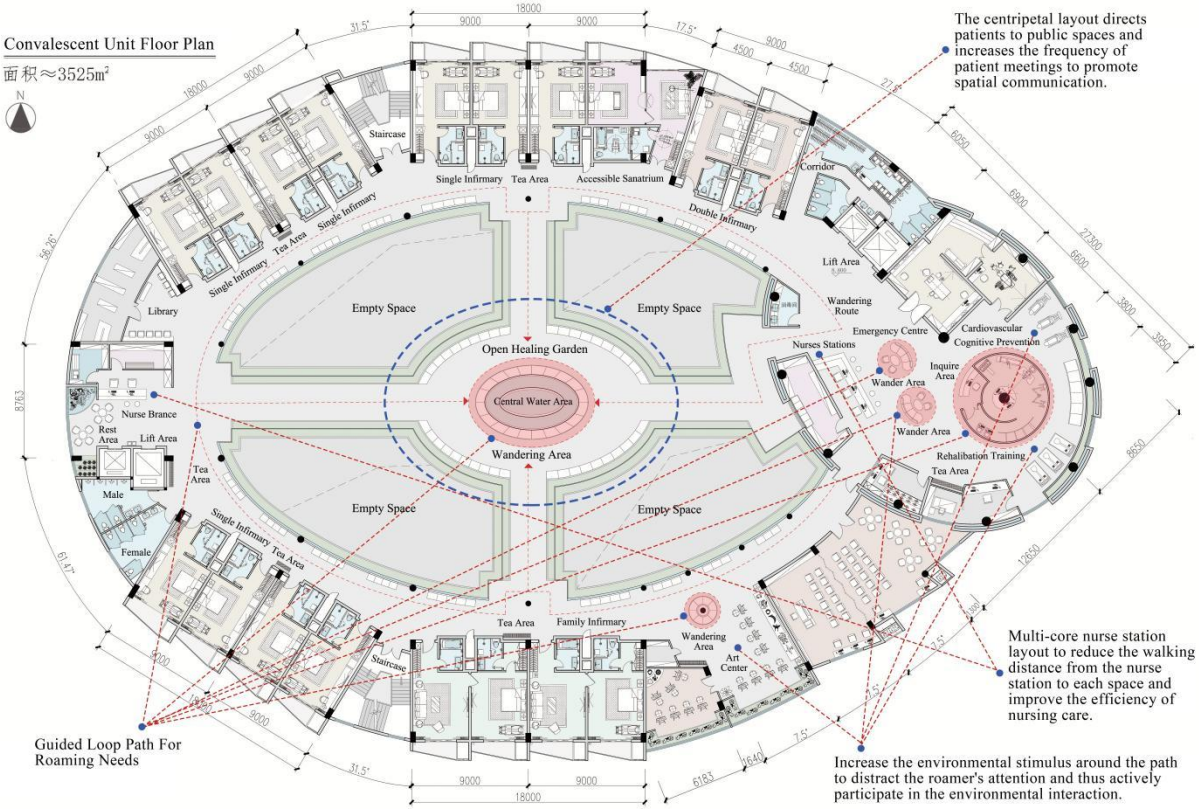


Figure 3. Cognitive Rehabilitation Center Floor Plan. (Source: drawn by the authors)

The space syntax tool Depthmap can simulate movement paths for a specific volume of traffic [51-52]. This aimless behavior simulation parallels the wandering behavior of dementia patients. In a design project for a dementia rehabilitation center in Guangzhou, the author adjusted the floor plan to center around a courtyard, employing a multi-core layout with several nurse stations working in coordination (Figure 3). The space is designed with multiple short circular paths to cater to the wandering needs of dementia patients. By strategically arranging engaging spaces along the wandering

paths, the design promotes multifunctional zones and enhances the accessibility of space [53], thereby making walking more appealing [54]. This design effectively guides wanderers towards communal spaces, consequently amplifying the depth of spatial communication.

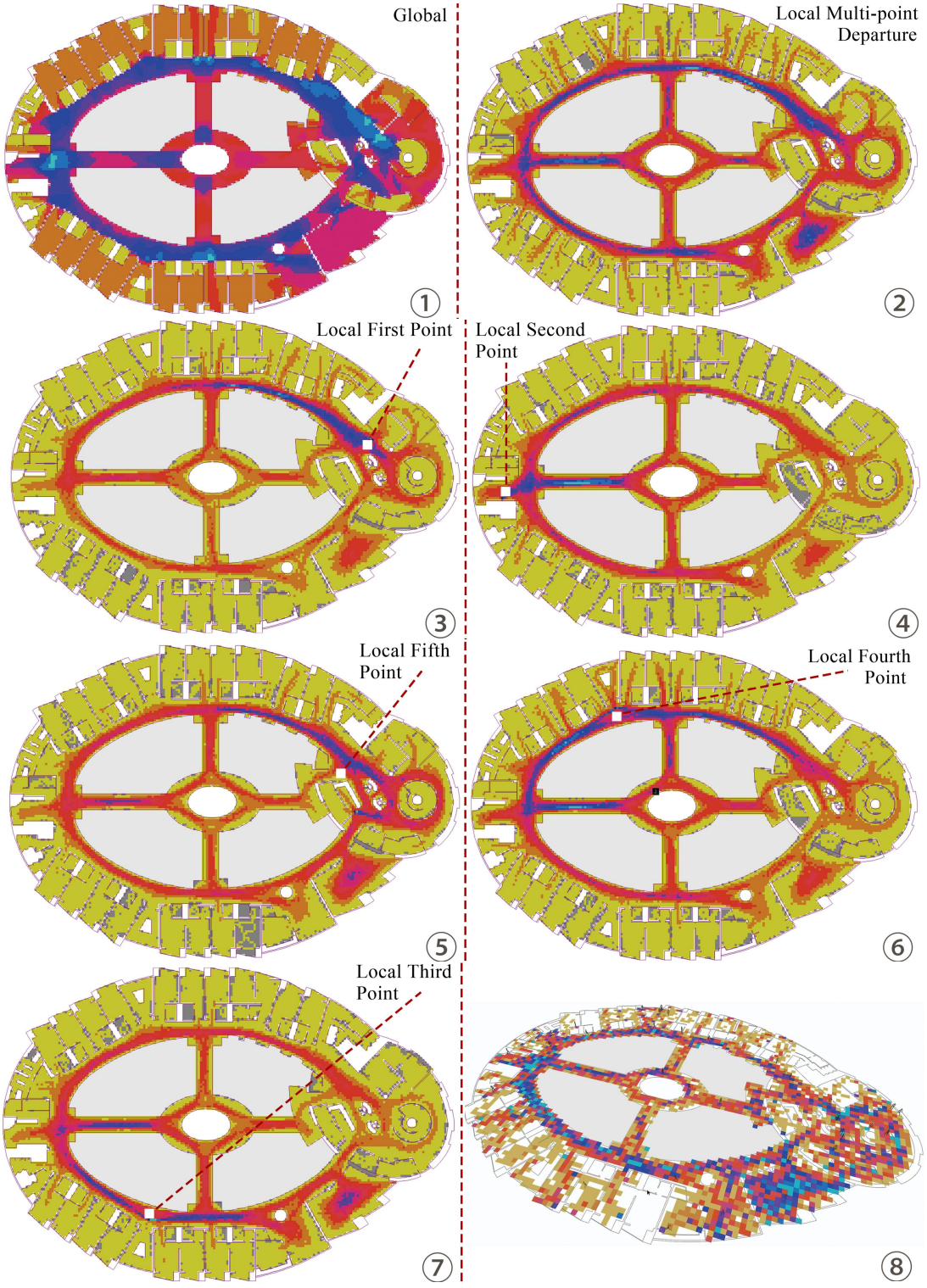


Figure 4. Spatial Connectivity Analysis. (Source: drawn by the authors)

The author employed the Depthmap tool again to simulate random traffic paths and conducted a spatial connectivity analysis (Figure 4). Within the Set Grid settings, a gridline with Space=0.6m (equivalent to an individual's shoulder width) was utilized to analyze Global connectivity. Following this, five entry points within the chosen floor were selected as traffic starting points for re-calculation. The floor accommodates a total of 18 beds, and an equal number of staff members (including janitors, nurses, and recorders) were assigned based on a 1:1 ratio. The spatial simulation imagery was then recorded for one hour in 3D View visualization mode. In Figure 4, the arched corridors are available for dementia patients to wander. The central rehabilitation garden provides a foundation for environmental interaction, while the pillars in the reception area and art center form multiple short-loop paths. These paths cater to patients' short-term wandering needs while facilitating monitoring.

3.2. Create a high level of spatial communication through visual penetration and guidance

High levels of spatial interaction can delay cognitive decline [55]. Even simple non-verbal communication such as eye contact, greetings, and nodding can enhance brain activity [56]. There is a direct correlation between the depth of spatial communication and the layout of the space [57]. In a rational layout, spatial forms and functional zoning can guide people's communicative behavior [58]. Sommer's research indicated that by adjusting the seating arrangement in a hospital activity room from a linear layout to an arc-shaped layout, interpersonal dialogue doubled in a short period of time. Therefore, by optimizing spatial layout and incorporating inducing floor material designs, roaming patients can be guided into public environments and encouraged to communicate with each other [59], thus reducing their tendencies for silence and introversion. This strategy not only enhances social interaction among patients but communication itself also serves as an effective means of cognitive rehabilitation for the brain.

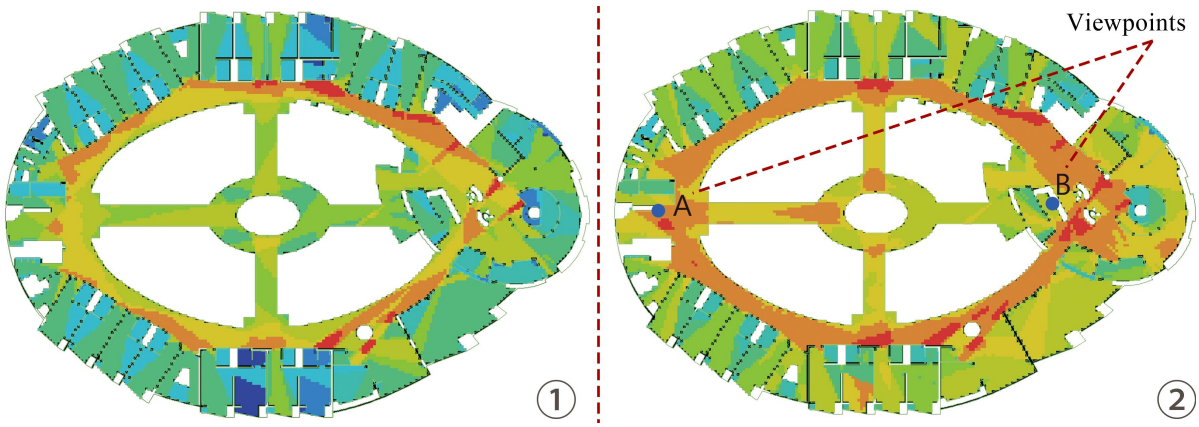


Figure 5. Visibility Graph Analysis. (Source: drawn by the authors)

The Depthmap tool was utilized once again to compute the spatial visual visibility values with one and three iterations respectively (Figure 5). The results from a single computation indicate which areas are most easily seen over a short period. It is evident that the southeastern and northeastern corridors have higher visual appeal, followed by the southwestern and northwestern arched corridors. Consequently, these areas, which are more easily observed, are optimal locations for the implementation of reminiscence therapy and should be complemented with well-planned signage. The results from three computations suggest which areas garner attention through multiple visual penetrations and interactions over an extended period. As depicted in Figure 6, the corridors facing due south and north, the east-west elevator lobbies, and the nurse station facing east are areas that tend to attract attention multiple times over a longer duration; hence, thoughtful placement of localized signage is recommended.

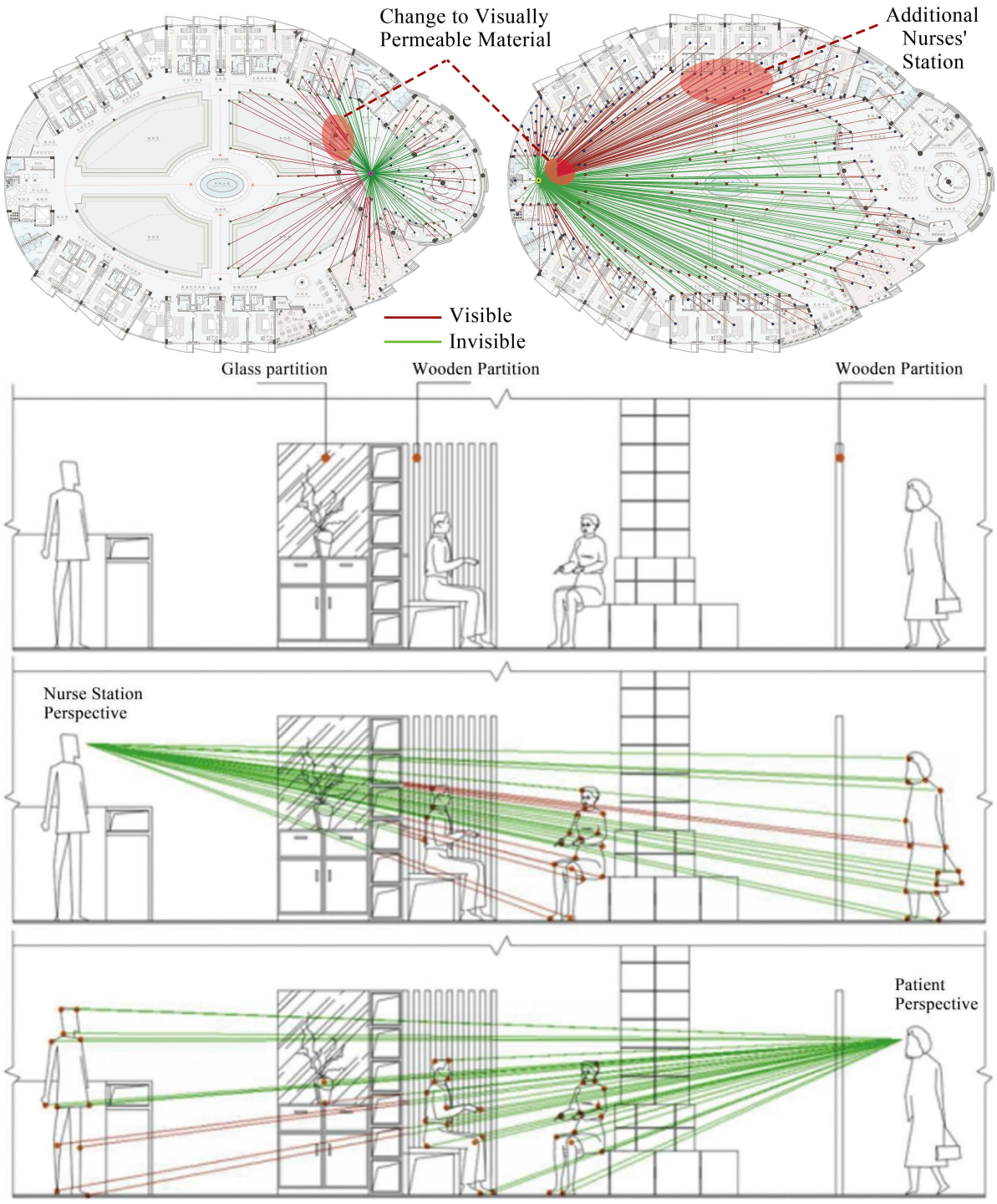


Figure 6. Spatial Visual Visible Path Analysis. (Source: drawn by the authors)

Using two nurse stations as monitoring points, a line-of-sight analysis of the surrounding environment was conducted through ARCGIS (Figure 6). Red lines represent non-visible paths, while green lines represent visible paths. The analysis reveals that the small nurse station facing west has a higher level of visibility, whereas the visibility of the nurse station facing east is constrained due to architectural materials and structure. The entire southeastern area of the space has low observability. It

is therefore advisable to install an additional small nurse station facing north to facilitate monitoring of the southern area. Moreover, employing open shelving, grilles, and glass for spatial partitioning strikes a balance between spatial permeability and privacy. In terms of decorative materials, it is recommended to minimize the use of cold, hard materials such as metal, glass, and marble, and instead, opt for warmer materials like wood and fabric.

4. Discussions

In the realm of environment-behavior research, Li et al. [8] discerned that the crux of iterative hospital layout lies in the transition from spatial behavior orientation to high-quality information exchange. This article corroborates the aforementioned observation through an analysis of spatial layout and visual sharing in a dementia rehabilitation center, as well as simulations of human traffic routes. Furthermore, Li et al. [60] introduced walking distance as an environmental variable and suggested an optimal layout form. The case layout employed in this study bears resemblance to the one proposed by Li, which centers around a main care station and incorporates multiple tiered nurse stations for collaborative management in a multi-core radial configuration. This, to some extent, validates the efficacy of such a layout. Studer [26] posited that human behavior is influenced by three interrelated factors: genetic traits, environment, and the experiences stemming from interactions with the environment. The present research furnishes empirical support for Studer's proposition.

In the context of cognitive behavior research, Neal et al.'s [50] "environmental reminiscence therapy" is static. This paper proposes the enhancement of environmental stimuli around the wandering paths, thus expanding the dynamic application methods of reminiscence therapy. Gary [23] discovered that the reciprocal behavior of passing coffee pots can slow down the cognitive decline in the elderly, providing empirical support for the layout strategy suggested in this paper. Guo et al. [61] categorized the levels of sensory stimulation rehabilitation into three tiers: "natural assistance," "stimulating thoughts," and "active participation benefitting organism development." Zhang et al. et al. extend the interaction between spatial layout patterns and human behaviour to the ideological level. [62]. This paper provides partial data on environmental variables affecting cognitive stimulation (spatial communication, layout forms), however, more supportive data remains to be explored.

It is predictable that the development of environmental intervention therapy applications will show three trends in the future. The first is the formation of pathologically characterized adaptive oriented spatial design. Due to the complex mechanism of disease pathogenesis, there are both environmental and non-environmental factors influencing the recovery of the disease, and the adaptation of the patient's personal pathological characteristics among the non-environmental factors is one of the key elements to be considered in the future design of the rehabilitation environment. The second is the formation of a humanized design from the perspective of the medical patient. In the future, the design of rehabilitation environment for cognitive disorders patients will break the traditional design ideas of "nursing workflow-oriented" or "patient-centered" and will take into account the needs, habits, communication and collaboration of both patients and doctors. The design of the environment will take into account the needs of both patients and doctors, their habits, communication and collaboration. Finally, the design is oriented to a healthy lifestyle. As a place to provide social health and well-being, medical space will pay more attention to the development of healthy life patterns of doctors and patients, of which healthy behavior is only one part, but also includes healthy psychology and healthy social life.

The limitations of this paper are manifested in the inadequate assessment of the efficacy of environmental interventions on wandering behavior. On the one hand, an increase in the frequency of encounters does not directly reflect the extent of cognitive function improvement. On the other hand, the efficacy of the multi-core circular path layout strategy remains theoretical and based on data simulations, without substantial clinical data support. Viable recommendations for relevant research include: 1) employing comprehensive and multivariate arguments, incorporating environmental variables that can indirectly or directly reflect improvements in cognitive functions; 2) striving for

collaboration with relevant departments or medical institutions to implement the proposed design strategies into practice.

5. Conclusions

The research process reveals that: 1) there is a direct relationship between the depth of spatial communication and the floor layout; optimization of spatial layout can facilitate communication and is theorized to have a rehabilitative effect on cognitive functions; 2) the wandering paths of patients with dementia can be guided through the use of landmarks; 3) centripetal layouts are more pronounced in behavioral guidance, suggesting that they can provide a solid foundation for environmental communication; 4) a multi-core circular path layout can cater to the wandering needs of patients with dementia.

Spatial intervention therapy undergoes a three-stage change process from interactive experience → spatial experience to behavioral demand → perceived stimulation to cognitive recovery, and has developed two areas of research: passive treatment in the environment and active patient participation in practice to obtain treatment. Cognitive disorders cannot be cured, and early intervention is the most effective way. This paper investigates the correlation between roaming behaviors, cognitive impairment, and environmental factors in patients with cognitive disorders, and emphasizes the healing nature of the environment itself, leading to a proposed environmental design strategy for roaming behavior interventions for patients with cognitive disorders. This paper provides an innovative concept of environmental therapy by assisting patients to heal through the subtle positive influence of the environment.

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