ISSN 2508-2817 KiDRS Korea Institute of Design Research Society 통권 35호, 2025. Vol.10 No.2

Optimization of Lighting Environment Design in Nursing Homes Based on AHP-CRITIC Multi-dimensional Weighting

AHP-CRITIC 다차원 가중치 기반 요양원 조명 환경 설계 최적화

주 저 자 : 심 육 (Shen, Yu) 가톨릭대학교 공간디자인학과 박사과정

교 신 저 자 : 정미렴 (Chung, Miryum) 가톨릭대학교 공간디자인·소비자학과 교수
mrchung@catholic.ac.kr

https://doi.org/10.46248/kidrs.2025.2.23

접수일 2025. 05. 20. / 심사완료일 2025. 06. 02. / 게재확정일 2025. 06. 09. / 게재일 2025. 06. 30.

Abstract

This study focuses on optimizing the lighting environment in nursing homes, aiming to address the prevalent issues of expert-biased subjective weighting and the lack of user experience data in current lighting design practices. A comprehensive evaluation system consisting of 15 lighting-related sub-indicators (B1-B15) was established, and three representative institutions-Beijing No.1 Social Welfare Institute, Hangzhou Gangguquan Nursing Home, and Guangzhou Yuetree Health Center-were selected as case study sites. Through questionnaire surveys and on-site data collection, a user rating matrix was constructed. The Analytic Hierarchy Process (AHP) was applied at the expert level, while the CRITIC method was employed at the user level to calculate respective weights for each indicator. These were then integrated to produce a set of comprehensive weights. The results show that “Illuminance Appropriateness (B1)” received the highest comprehensive weight (0.1653), followed by “Integration of Green Building Materials and Lighting Design (B15, 0.1177),” “Smart Lighting Control System (B14, 0.1060),” and “Lighting Suitability by Functional Zone (B5, 0.1072).” In contrast, “Support for Circadian Rhythms (B4, 0.0452)” and “Emergency Lighting System Completeness (B7, 0.0372)” were rated with lower weights. Based on these findings, the study proposes specific improvements, including setting a baseline illuminance standard of 300-500 lx, combining natural lighting with high-reflectivity eco-friendly materials, introducing intelligent DALI/ZigBee control platforms, and managing color temperature by zones. The study lays a theoretical foundation for incorporating physiological monitoring data and seasonal demand variations into future lighting evaluation systems, offering both theoretical insights and practical implications.

Keyword

Nursing Home Environmental Design(요양원 환경 설계), Lighting Optimization(조명 최적화), Multidimensional Weighting(다차원 가중치 부여)

요약

본 연구는 요양원의 조명 환경을 최적화하는 것을 핵심 목표로 하여, 현재 요양 공간 조명 설계에서 일반적으로 나타나는 전문가 주관적 가중치 편중 및 사용자 경험 데이터 부족 문제에 대응하고자 하였다. 이를 위해 15개 조명 환경 하위 지표(B1-B15)로 구성된 평가 체계를 구축하고, 대표성을 갖춘 세 기관—베이징제1사회복리원, 항저우강구천의요양원, 광저우월수건강센터—을 조사 대상으로 선정하였다. 설문조사 및 현장 자료 수집을 통해 사용자 평점 행렬을 구축하고, 전문가 층위에서는 계층분석법(AHP)을, 사용자 층위에서는 CRITIC 기법을 적용하여 각각의 가중치를 산출한 후, 이를 통합 가중치로 융합하였다. 연구 결과, ‘조도 적정성(B1)’의 종합 가중치가 가장 높았으며(0.1653), 다음으로는 ‘친환경 건축자재와 조명의 통합 설계(B15, 0.1177)’, ‘스마트 조명 제어 시스템(B14, 0.1060)’, ‘기능 구역별 조명 적합도(B5, 0.1072)’ 순으로 나타났다. 반면, ‘일주기 리듬 지원(B4, 0.0452)’과 ‘비상 조명 시스템의 완비 여부(B7, 0.0372)’는 상대적으로 낮은 가중치를 보였다. 이러한 결과를 바탕으로, 본 연구는 300-500 lx의 기본 조도 기준 설정, 자연채광과 고반사율 친환경 소재의 병행 적용, DALI/ZigBee 기반의 스마트 제어 플랫폼 도입, 구역별 색온도 관리 등 구체적인 개선 방안을 제시하였다. 본 연구는 향후 생리학적 모니터링 데이터와 계절별 수요 변화를 반영한 조명 평가 체계 구축을 위한 이론적 기반을 제공하며, 이론적·실무적 의의를 지닌다.

Contents

1. Introduction

1-1 Research background

With the accelerating trend of global population ageing, the issue of old age has gradually become a focus of social concern. According to United Nations projections, by 2050, the global population of older persons aged 60 and above will exceed 2.1 billion, accounting for about 22% of the total population[1]. In China, with the development of economy and advancement of medical technology, the problem of population aging has become increasingly serious, and the quality of life and living environment of the elderly group urgently needs more attention. According to the China Statistical Yearbook, in 2020, China's elderly population aged 60 and above will exceed 250 million, accounting for 18% of the total population[2]. Among them, the design quality and service level of nursing homes, as places that provide life care and psychological care for the elderly, have a direct impact on the physical and mental health of the elderly. In the design of nursing homes, Sinoo M M (2011) argued that the light environment, as an important environmental factor, has a profound effect on the physiology, psychology and daily activities of the elderly[3]. Specifically, among the physiological characteristics of older adults, Jaglarz A (2023) showed that appropriate light design can effectively regulate the circadian rhythm of older adults and help them to maintain a regular rest and relaxation schedule, thus enhancing the quality of their sleep and the efficiency of their daily activities[4]. In addition, in terms of psychological aspects, Rijnaard M D (2016) argued that the combination of appropriate natural light introduction and artificial lighting can help to increase the sense of well-being and reduce loneliness and

1) World Health Organization. Progress report on the United Nations decade of healthy ageing, 2021-2023. World Health Organization, 2023.

2) Stats, China Statistical Yearbook, (2025.02.20.) https://www.stats.gov.cn/sj/ndsj/

3) Sinoo M M, Van Hoof J, Kort H S M. Light conditions for older adults in the nursing home: Assessment of environmental illuminances and colour temperature. Building and Environment, 2011, 46(10), P.1917-1927.

4) Jaglarz A, Chrzanowski S. The role of lighting in senior care facility design. Architectus, 2023 (2 (74)), P.87-96.

depressive symptoms in older people[5]. It has also been shown that warm shades of light increase the intimacy of the indoor environment, making older people feel warm and comfortable, while too much cold light may cause isolation and alienation in older people[6]. Therefore, it can be found that good lighting design can not only improve the visual health of the elderly, but also regulate their circadian rhythms, elevate their moods, alleviate anxiety and depression, and contribute to the improvement of their sleep quality and quality of life. However, with the changes in the characteristics of the elderly population, there are still many limitations in the practical application of the existing lighting design, and it is difficult to fully respond to the changing physiological and psychological needs of the elderly[7]. Against this background, how to scientifically design the light environment of nursing homes to meet the needs of the elderly in their daily activities has become an important research topic.

1-2 Status of Research and Issues

In recent years, the study of indoor lighting environment in nursing homes mainly focuses on the integrated design of "natural lighting - artificial lighting"[8]. Most scholars first start with building form and spatial layout to introduce soft, even daylight through adjusting window-to-wall ratios, skylight positions, and other strategies to maintain circadian rhythms and mental health of the elderly[9]. Meanwhile, research in artificial lighting focuses on two core metrics: illuminance and correlated color temperature (CCT): considering that the transmittance of the eye in people over 80 years old is only about 20% of that of young people, the literature generally suggests to maintain a forehead illuminance of 1,000-2,500 lx and a cooler light (6,500-7,500 K) configuration for the daytime activity area for a variety of needs such as reading, socializing and rehabilitation. - 2,500 lx and cooler light (6,500 - 7,500 K) in daytime activity areas to meet the needs of reading, socializing and rehabilitation training[10]. In other words, researchers have emphasized the coordinated configuration of natural and artificial light sources in the lighting layout, and optimized the matching of illuminance levels and spectral characteristics to meet the visual needs of the elderly due to physiological degradation. In order to verify the actual effects of these layouts and parameter adjustments, academics usually need to prioritize and comprehensively evaluate various design elements, so as to ensure that the proposed lighting solutions can truly meet the multiple needs of older adults in visual comfort, emotional regulation, circadian rhythm maintenance, and daily activities. In particular, Maier J (2017) used a combination of questionnaires and behavioral observations to compare and analyze the subjective comfort and behavioral activity of older adults in a variety of lighting scenarios[11]; Meanwhile, Jägerbrand A K

5) Rijnaard M D, Van Hoof J, Janssen B M, et al. The factors influencing the sense of home in nursing homes: A systematic review from the perspective of residents. Journal of Aging Research, 2016, 2016(1) , P.6143645.

6) Yang H, Guo B, Shi Y, et al. Interior daylight environment of an elderly nursing home in Beijing. Building and Environment, 2021, 200, P.107915.

7) Wang C, Leung M. Effects of subjective perceptions of indoor visual environment on visual-related physical health of older people in residential care homes. Building and environment, 2023, 237, P.110301.

8) Chen Y, Guo Y, Liu Q, et al. Therapeutic lighting in the elderly living spaces via a daylight and artificial lighting integrated scheme. Energy and Buildings, 2023, 285, P.112886.

9) Bochnia A K, Ruohonen S M, Pajuste M, et al. Evaluating an integrative lighting design for elderly homes-a mixed methods approach[C]//IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2022, 1099(1), P.012028.

10) Chen Y. A theoretical approach for therapeutic artificial supplementary lighting in elderly living spaces. Building and Environment, 2021, 197, P.107876.

(2020) collected illuminance and spectral data from different areas and time periods using environmental monitoring equipment to quantify the synergistic effects of daylight and artificial light sources[12]. It can be found that the current research mostly relies on a single subjective experience or objective data method to determine the weights of elements, which is difficult to take into account the dual advantages of expert intuition and a large amount of monitoring data, and thus restricts the scientific and universal applicability of the optimization scheme of the lighting environment.

Overall, although the existing literature reveals the importance of the lighting environment for the visual health, emotional regulation and daily activity support of the elderly, there are still significant research gaps in the following aspects: (1) lack of systematic demand refinement based on the actual use scenarios and subjective experience of the elderly; (2) lack of a multi-dimensional weighting analysis mechanism that integrates the expert's judgment and the objective data; (3) failure to establish a detailed analysis of the different functional spaces of the nursing home. (3) Failure to establish a detailed light optimization model for different functional spaces in nursing homes. Based on this, this study intends to establish a multi-dimensional and quantitative evaluation index system by qualitatively exploring the activity scene needs of the elderly through rooting theories, and build an operable light optimization path based on it, in order to fill the research gaps in the field of light environment design of nursing homes in terms of the refinement of the functional zoning and comprehensive optimization.

11) Maier J, Zierke O, Hoermann H J, et al. Subjectivity of lighting perception and comfort: the role of preferences and expectations. Environment and Behavior, 2017, 49(10), P.1105-1127.

12) Jägerbrand A K. Synergies and trade-offs between sustainable development and energy performance of exterior lighting. Energies, 2020, 13(9), P.2245.

1-3 Purpose and Significance of the Study

As mentioned earlier, with the accelerating process of population aging, the impact of the environmental design of nursing homes on the physical and mental health and quality of life of the elderly is receiving more and more attention. However, most of the existing research focuses on the architectural layout or interior decoration level, and lacks a systematic exploration of how the light environment can be configured to optimize the daily activities of the elderly through fine-tuning. In order to fill this gap, this study aims to improve the comfort and safety of elderly people's activities while taking into account the efficiency of energy utilization, thus contributing to the sustainable development of nursing homes. Specifically, the study first applies rootedness theory, and through semi-structured interviews and qualitative coding, explores the lighting needs of older adults in typical scenes such as socializing, reading, and resting, and reveals the mechanisms of different light intensities, color temperatures, and spatial layouts on their behavioral patterns and subjective comfort levels. On this basis, a multi-dimensional assessment system covering visual comfort, activity promotion and energy efficiency is constructed by combining AHP (hierarchical analysis method) and CRITIC (comprehensive evaluation method) to realize scientific quantification and comprehensive evaluation of the weights of each factor. Finally, based on the results of the evaluation system, we propose customized optimization plans for light intensity, color temperature and lamp layout for the functional zones of public activity rooms, reading areas and rest areas. This study not only enriches the theoretical framework in the field of elderly facility design, but also provides practitioners with quantifiable and operable paths to optimize the lighting environment, which is of great significance in improving the design quality of nursing homes and the living experience of the elderly.

2. Theoretical Examination

2-1 Overview of Rooted Theory

Grounded Theory is a qualitative research methodology proposed by American sociologists Barney G. Glaser and Anselm L. Strauss in 196 7[13). The core idea is to generate theories based on data rather than validate existing theories through in-depth analysis of the research subjects, and the specific steps of the research are shown in Table 1.According to Walsh I, rooted theory emphasizes data-drivenness, especially in exploratory research, where, through actual contact and dialogue with the research subjects, the researcher continually extracts from the data important categories, concepts, and progressively constructs them through a systematic coding process theory[14)]. The main difference between rootedness theory and other qualitative research methods can be found in its methodological basis of "theory from data".Sarabia-Cobo C (2021) interviewed older adults and their caregivers to reveal the core issues of social interactions, emotional needs, and physical and mental health of older adults in nursing homes, providing a theoretical basis for the management and care of nursing homes. core issues, providing a theoretical basis for nursing home management and caregiving[15)]. Qi Y Z conducts semi-structured user interviews using rootedness theory to explore in depth the key factors that influence users' expectations, needs and satisfaction with short video platform s[16)]. These examples from the literature show that in rooted theory research, the researcher does not rely on existing theoretical frameworks, but rather distills the core categories of the theory through steps such as open coding, axial coding and selective coding of field data. This approach is suitable for those research areas where existing theories are not well developed or have not yet been explored in depth, especially in complex social phenomena, where rooted theory can provide new perspectives for understanding and explanation.

[Table-01] Rooted Theory Research Process

Processes	Content
Data Collection	Data were collected from the research participants through a variety of means, including interviews, observations, and documentation, focusing on the actual experiences and behaviors of the research participants.
Open Coding	Preliminary categorization and labeling of the collected data to extract the main concepts and categories.
Axial Coding	Further organize and summarize the different concepts and categories, identify the relationship and structure among them, and form a preliminary theoretical framework.
Selective Coding	On the basis of the existing codes, the most core categories are selected for deeper analysis, and a systematic theoretical system is finally generated.

In this study, rootedness theory, as an exploratory research method, was used to dig deeper into the light needs of older people in different life scenarios. The qualitative exploratory approach of Zagan Theory enables the discovery of the real needs of older people for light environments from their daily life experiences, especially their specific requirements in different

13) Turner C, Astin F. Grounded theory: what makes a grounded theory study?. European Journal of Cardiovascular Nursing, 2021, 20(3), P.285-289.

14) Walsh I, Rowe F. BIBGT: combining bibliometrics and grounded theory to conduct a literature review. European Journal of Information Systems, 2023, 32(4), P.653-674.

15) Sarabia-Cobo C, Sarriá E. Satisfaction with caregiving among informal caregivers of elderly people with dementia based on the salutogenic model of health. Applied Nursing Research, 2021, 62, P.151507.

16) Qi Y Z, Han J Y, Lu X N, et al. A study on satisfaction evaluation of Chinese mainstream short video platforms based on grounded theory and CRITIC-VIKOR. Heliyon, 2024, 10(9).

functional areas (e.g., socializing, reading, resting, etc.). The flexibility of Zagan Theory enables it to adapt to the diverse demand characteristics in the elderly population and provides a theoretical basis for the design of light environments through a data-driven approach. The qualitative analysis of Zagan Theory can provide more personalized and contextualized insights into the design of light environments, avoiding a monolithic, assumption-based design approach. The use of rooted theory will help to reveal the complex relationship between older adults' subjective experience of light and their physiological responses, providing solid theoretical support and data foundation for subsequent AHP-CRITIC-based multidimensional empowerment design.

2-2 Overview of the AHP-CRITIC Theory

In Multi-Criteria Decision Analysis (MCDM), AHP (Hierarchical Analysis) and CRITIC (Criteria Importance Through Intercriteria Correlation) are two commonly used methods for determining weights. Each of them has unique advantages, and by using both of them in combination, the limitations of a single method can be overcome, thus providing a more scientific and comprehensive solution to complex decision-making problems.

2-2-1 Overview of AHP Theory

AHP (Analytic Hierarchy Process) was proposed by American scholar Saaty in the 1970s and is widely used in complex multi-criteria decision-making problems[17). AHP provides a comprehensive evaluation of multiple alternatives by building a hierarchical model and analyzing the relative importance of each decision element.The basic idea of the AHP method is to decompose a complex decision problem into multiple layers, including an objective layer, a criterion layer, a sub-criterion layer, and an option layer. Elements in each layer are judged for relative importance by comparing them two by two, using a scale of 1-9. Experts derive these importance scales based on their judgments and form a set of judgment matrices. By performing mathematical operations on the judgment matrices, the weights of the factors are finally calculated and provide support for decision making, and the detailed process is shown in Table 2.In the field of design, Benaida M (2023) conducted a hierarchical analysis of hierarchies (AHP) analysis of usability questionnaires to extract priority-based rankings in user-interface design, which guided the evaluators in determining which heuristics needed more attention[18)]. Ruano M (2023) argued that the existing rural B&B remodeling practice lacks scientific data support and relies heavily on the subjective design of architects. Thus, the hierarchical analysis method (AHP) was applied to assign weights to the commercial remodeling objectives - local traditional characteristics, architectural functions, sustainability and comfort[19)]. Therefore, it can be found that the Analytic Hierarchy Process (AHP) helps decision makers to systematically assess the importance of each factor by decomposing complex decision problems into multiple levels. In other words, the advantage of the AHP method is that it can deal with complex decision problems and can take into account both qualitative and quantitative factors. It is suitable for multi-criteria decision-making problems, especially when there are different importance between individual decision factors, AHP can provide systematic quantitative support. In

17) Yu D, Kou G, Xu Z, et al. Analysis of collaboration evolution in AHP research: 1982–2018. International Journal of Information Technology & Decision Making, 2021, 20(01), P.7-36.

18) Benaida M. Developing and extending usability heuristics evaluation for user interface design via AHP. Soft Computing, 2023, 27(14), P.9693-9707.

19) Ruano M, Huang C Y. A novel approach to service design within the tourism industry: creating a travel package with AHP-TRIZ integration. Systems, 2023, 11(4), P.178.

addition, AHP performs well in dealing with uncertainty and complex decision-making problems and can incorporate the experience and knowledge of experts, which enhances the flexibility of decision-making. However, the limitation of AHP is that it relies on the subjective judgment of experts, which may be limited by their experience and cognitive bias, especially when faced with highly complex decision-making problems, where the judgment of experts may have greater inconsistency.

[Table-02] AHP Research Process

Processes	Content
Model the Hierarchy	Decomposition of the decision problem into multiple levels, usually including an objective level, a criterion level, and a sub-criterion level.
Construct Judgment Matrix	Between the levels, the decision maker assesses the relative importance of different factors by comparing them two by two.
Calculate Weights	The judgment matrix is solved by an eigenvalue method (e.g., maximum eigenroot method) to obtain the weight of each factor.
Consistency Test	To ensure the logical consistency of the judgment matrix, the AHP method is checked by calculating the consistency ratio (CR).

2-2-2 Overview of CRITIC Theory

CRITIC is a statistically based multi-criteria decision-making method designed to determine weights by evaluating the correlation and variability between individual decision criteria. Unlike AHP, which relies heavily on the subjective judgment of experts, CRITIC uses data analysis and mathematical modeling to objectively measure the relative importance of each criterion.The core idea of the CRITIC method is that more informative criteria should be given higher weights, while criteria with more redundant information should be given lower weights. The method measures the importance of the guidelines through two main factors: the standard deviation (variability) of the guidelines and the correlation between the guidelines. A review of the relevant literature reveals that the CRITIC method is widely used in many fields, especially in data-rich environments such as financial analysis, supply chain management, urban planning, environmental assessment, etc[20]. In these areas, the CRITIC methodology can help decision makers determine the relative importance of each criterion through objective calculations and provide data-driven support for integrated decision making.

[Table-03] CRITIC Research Process

Basic Process	Content
Calculate the standard deviation of each indicator	For each evaluation indicator, calculate its standard deviation in the dataset; a higher standard deviation indicates a higher variability of the indicator and provides a greater ability to differentiate.
Calculate the correlation between each indicator	The correlation between the indicators is assessed by calculating their correlation coefficients.
Calculate the weights	Based on the variability and correlation of each indicator, its weight was calculated in a comprehensive manner.

In the field of design, especially in multiple directions such as product design, environmental design, and architectural design, design decisions usually involve multiple interrelated criteria and need to evaluate the advantages and disadvantages of different design options.The CRITIC method can help decision makers optimize design options by quantifying the importance of each design criterion, reducing the impact of redundant and repetitive information, and improving the accuracy and efficiency of

20) Wang D, Ha M, Zhao M. The intelligent critic framework for advanced optimal control. Artificial Intelligence Review, 2022, 55(1), P.1-22.

decision making.Song W (2021) determined the objective weights by combining the CRITIC method, thus improving the accuracy of design solution selection for smart product service systems, and the effectiveness of the method was verified by the case of smart washing machine[21]. Lu N (2022) took Smart Health Kiosk (SHK) as an example and established an evaluation index system for ageing appropriateness based on four dimensions of influencing factors. The method comprehensively considers the influence of subjective and objective weights on the evaluation and avoids the limitations of a single evaluation method[22]. It can be found that the advantage of the CRITIC method is that it relies entirely on data, is not influenced by subjective judgment of experts, and can objectively reflect the importance of each criterion. In the design of lighting environments in nursing homes, the CRITIC method can help quantify the effects of different lighting environmental factors (e.g., natural lighting, intensity and color temperature of artificial lighting, etc.) on the comfort, health, and behavioral activity of the elderly, thus providing a scientific basis for the optimization of lighting design. However, CRITIC has its limitations, especially when confronted with missing data or noisy data, the results may be affected.

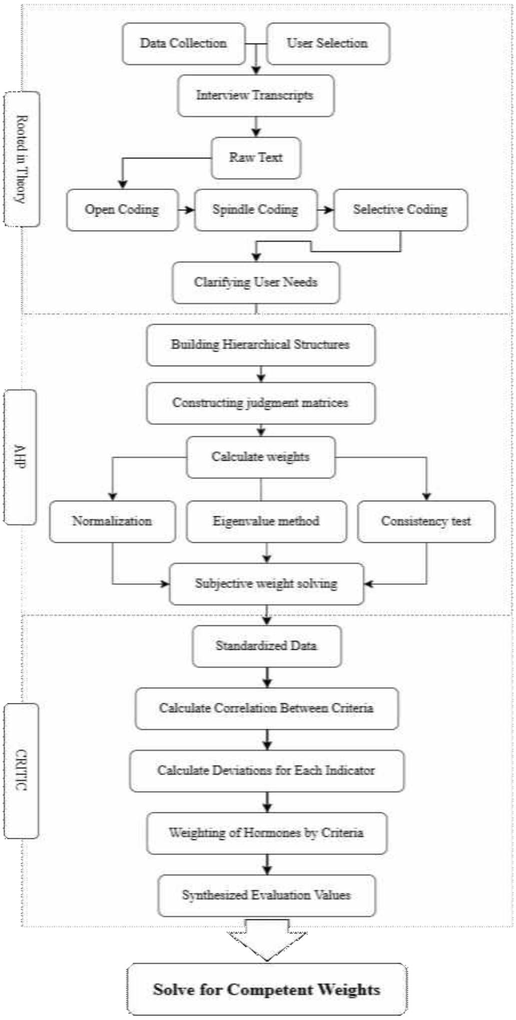
2-3 Structuring the Research Process

In this study, the core of constructing the research process is to combine the Zagan Theory and the AHP-CRITIC model to deeply explore the needs of the elderly population for light environments from a data-driven and theory-generating perspective. First, Zagan theory provides an exploratory research framework for the study. Its research process includes data collection, open coding, axial coding, and selective coding, which ensures that rich, empirically based data are obtained through actual interviews and observations. This process emphasizes the distillation of core categories from field data and the gradual construction of theories rather than relying on existing theories, and is particularly applicable to the needs of older adults that have not yet been explored in depth in the field of designing lighted environments. Second, the combination of the AHP and CRITIC models provides quantitative support for multi-criteria decision making: the AHP quantifies the importance of each factor by decomposing the decision problem, constructing a judgment matrix, and comparing each criterion two-by-two based on expert opinion, while CRITIC relies on objective analysis of the data, and determines the weights by evaluating the standard deviation of each criterion and the inter-correlation of the criteria, which is suitable for coping with data-rich environment. Therefore, the combination of AHP and CRITIC in this study can effectively overcome the limitations of a single method and provide a more scientific and comprehensive basis for decision-making, especially in the allocation of weights to multiple influencing factors in the design of lighting environments, such as natural light, artificial lighting intensity and color temperature. Through the structural design of this research process, the flexibility of the rooted theory and the data-driven nature of the AHP-CRITIC model complement each other, and together they provide a more personalized and contextualized theoretical support for the design of lighting environments, and provide a solid theoretical foundation and data basis for subsequent design optimization.

---

21) Song W, Niu Z, Zheng P. Design concept evaluation of smart product-service systems considering sustainability: An integrated method. Computers & Industrial Engineering, 2021, 159, P.107485.

22) Lu N, Li Y, Xu B. Evaluation of the suitability of smart health products for aging based on the IIVAHP-CRITIC model: A case study of smart health kiosk. Sustainability, 2022, 14(15), P.9212.



〈Figure-01〉 Research Process Construction

3. Exploration of User Needs Based on Rootedness Theory

3.1 Data Collection

As mentioned earlier, rootedness theory contains four main steps: primary coding (open coding), secondary coding (spindle coding), tertiary coding (selective coding), and theory saturation testing[23]. In terms of data collection, semi-structured interviews were used to collect primary data from relevant user groups. This interview method emphasizes an open-ended exploration of participants' perspectives, allowing the researcher to continually adapt questions during the interview process to better understand the phenomenon under study[24]. The outline of the interview is formed by searching the literature in related research fields, and the outline includes the basic information of the interviewees, the existing lighting environment of the nursing home, the needs of the elderly for the lighting environment, and the objectives of optimizing the design of the lighting environment. The questions were set in accordance with the basic principle of “first easy, then difficult”, guiding the interviewees to discuss the details of the use process from the perspective of the overall experience, and some of the interview outlines are listed in Table 4.

[Table-04] CRITIC Research Process

No.	Content
1	Is the existing light environment perceived to meet the needs of older adults in their daily lives?
2	Have problems been encountered with the light environment, such as insufficient light, too much light, over-illumination, uneven lighting, etc.? How does it affect the quality of life of the residents?
3	What are the main needs of older people for light?
4	How does light design affect the emotional and psychological state of older people?
5	What are the main objectives of light environment optimization?
6	Are the currently adopted lighting design solutions

23) Mohajan D, Mohajan H K. Constructivist grounded theory: A new research approach in social science. Research and Advances in Education, 2022, 1(4), P.8-16.

24) Adeoye-Olatunde O A, Olenik N L. Research and scholarly methods: Semi-structured interviews. Journal of the american college of clinical pharmacy, 2021, 4(10), P.1358-1367.

	effective in enhancing the comfort and quality of life of the elderly?
...	......

The respondents of this study included nursing home administrators, architects, lighting designers, and selected nursing home residents. Participants were recruited through a combination of random sampling and expert recommendations to ensure diversity and representativeness of the sample. The interview period is from March 1, 2025 to April 2, 2025. A progressive recruitment strategy was adopted, continuing until data saturation was achieved, in order to ensure both the adequacy of the sample size and the integrity of the collected data. A total of 12 individuals (including nursing home staff and residents) were interviewed, and their demographic characteristics are detailed in Table 5. Given the wide geographical distribution of the respondents, all interviews were conducted online to ensure effective communication and data collection. Prior to the interviews, participants were informed in advance of the possibility of audio recording, and the purpose and handling of the recordings were clearly explained to ensure accurate documentation of the interviews for subsequent data analysis and research use[25]. All respondents provided informed consent for the recordings. Each interview lasted approximately 20 to 30 minutes and was structured around a predefined interview guide to ensure comprehensive information gathering. During the interviews, participants were also encouraged to elaborate beyond the guide based on their experiences and perspectives, in order to gain a deeper understanding of their perceptions and needs related to the lighting environment in nursing homes.

25) Buys T, Casteleijn D, Heyns T, et al. A reflexive lens on preparing and conducting semi-structured interviews with academic colleagues. Qualitative Health Research, 2022, 32(13), P.2030-2039.

[Table-05] Interview User Profiling

No.	Sex	Age	Professional Background	Years of working experience	Interview Focus
1	M	55	Director of Nursing Home	30 years	Management's concern for the light environment, coordination of resources, needs assessment of elderly residents, balance between budget and practice
2	F	40	Architec-tural Designer	15 years	Lighting layout and building structure, the needs of the elderly, design optimization solutions
3	M	38	Lighting Designer	10 years	Light source selection, color temperature adjustment, lighting layout, how to provide comfortable light for the elderly
4	F	45	Nursing home caregivers	20 years	The comfort and health impacts of residents in the light environment, actual feedback and observation.
5	M	72	Nursing home resident	Hospita-lized 2 years	The impact of light on sleep and mood, and the light needs in daily life.
6	F	68	Nursing home resident	1 year of hospita-lization	Perception of different light intensities, impact of indoor lighting on daily activities
7	M	60	Nursing home resident	3 years of hospita-lization	Adaptability of light, whether it meets the physiological needs of the elderly
8	F	70	Nursing home resident	4 years of hospita-lization	Impact of lighting environment on health, especially vision problems
9	M	52	Nursing home	25 years	Comprehensive impact of lighting environment

			program managers		on residents' health, coordination between facilities and design
10	F	47	Lighting suppliers	18 years	Application of lighting products in nursing homes, energy saving and functional design
11	M	55	Environ-mental Psychologist	20 years	The impact of lighting on the mental health of the elderly, and how to improve the residents' mood through design
12	F	65	Lighting Design Consultant	12 years	Differences in the lighting needs of the elderly, and how to optimize lighting design solutions

3-2 Open Coding

In order to ensure the reliability and validity of the coding results of the rooted theory, the following data analysis strategies were mainly used in this paper: first, members of the research group coded individually. On the premise of agreeing on the concepts and categories of the interview texts, members of the group coded together, and each was responsible for labeling the interview texts. Second, memo cross-checking, creating memos for each interview transcript to cross-check the coding and revision process. Third, iterative comparative analysis. In response to the emergence of new or difficult to categorize concepts and attributes, the concepts and categories that had been developed were used as the basis for analyzing and comparing concepts and attributes, and were continually revised to improve the[26]. In the first step of content textualization, initial concepts are conceptualized through cluster analysis and associations and logical relationships are established according to certain rules or paths to form initial categories[27]. By collating the data from 12 user interviews, 356 representative raw data were summarized. Subsequently, affiliation analysis was conducted to obtain 42 concepts, and raw data statements containing the same concepts were collected and merged to obtain 35 initial categories, as shown in Table 6, which are the direct factors affecting users' satisfaction with short video platforms.

[Table-06] User-based Open Coding Process

Initial Scope	Related Primitive Interview Statements
Illumination Requirements for Visual Operations-C1	I always find the light not bright enough when I'm reading or doing needlework, and it's especially hard to see.
Light glare control - C2	Some lights are so harsh that it's uncomfortable to sit down and my eyes wander.
Physiological load phenomenon due to over-illumination -C3	Sometimes the hall light is turned on too brightly and I get so dizzy instead that I want to rush back to my room.
Color temperature-mood coupling effects-C4	Warm yellow light makes me feel relaxed, and cold white light makes me feel cold.
Circadian Rhythm Synchronization Lighting Strategies-C5	If I wake up in the morning and the light is on the bright side, I can recover my spirit faster.
Warm color temperature suppresses sleep disturbance-C6	At night I like to have a softer light in the room so I can sleep faster.
Spatial light homogeneity-C7	Some places are bright, some places are dark, so it's hard to get used to

26) Charmaz K. The genesis, grounds, and growth of constructivist grounded theory[M]//Developing grounded theory. Routledge, 2021, P.153-187.

27) Sithambaram J, Nasir M H N B M, Ahmad R. Issues and challenges impacting the successful management of agile-hybrid projects: A grounded theory approach. International journal of project management, 2021, 39(5), P.474-495.

	walking past them, and it's easy to trip over your feet.
Diffuse treatment of indirect light sources-C8	The kind of light hitting the wall and then reflecting back, look much more comfortable, not blinding.
Spatial cognitive impairment due to light nonhomogeneity-C9	The corridors are both bright and dark, and sometimes I can't figure out where the doorway is for fear of making a mistake.
Biorhythmic light interventions-C10	The doctor said that we should have more sunlight in the morning and not too much light in the afternoon and evening, so that our body can work and rest better.
Morning high light exposure strategies-C11	The hall is especially bright in the morning, and the sunshine makes you feel more energetic.
Low blue light modulation mechanism in the evening-C12	If the light is cold and white at night, you can't sleep well and you feel awake.
Lighting Design for Functional Area Zoning-C13	Lighting should be bright enough in the cafeteria and activity rooms, and softer in the rooms is better.
Cognitive-assisted Lighting Layout-C14	The lights help us to see which is the corridor and which is the rest area, and the sense of direction will be better.
Visual Guide Lighting for the Movable Line-C15	If you follow the small lights on the floor, you won't get lost, which is especially necessary at night.
Lighting continuity for barrier-free access-C16	Wheelchair push routes are very unsafe if the lights are intermittent.
Low-glare Walking Lighting System-C17	I would like to have a little light under my feet when I walk, but not too much to dazzle my eyes, so I can see clearly.
Disaster Response Lighting Plan-C18	In case of power failure, it is best to have a backup light that can automatically come on, so that escape is also safe.
Nighttime microenvironmental lighting maintenance mechanism-C19	In the middle of the night to go to the toilet to have a little light, or too dark easy to fall.
Optimized Design of Natural Lighting in Buildings-C20	In the daytime, the large windows are well lit, so you don't need to turn on the light when you open the curtains.
Light Environment Oriented Spatial Layout-C21	If the windows and lights are well placed, the whole house is bright and easy on the eyes.
Social Promotion Lighting Atmosphere Creation-C22	The light in the activity room is warm, so people are especially comfortable sitting down and chatting.
Application of Comfort Diffused Light Source-C23	Instead of having a blinding bulb over your head, the whole room is lit up softly, which is much more comfortable.
Light Environment Emotion Regulation Mechanism-C24	When the weather is bad and you are feeling down, you can turn on some warm lights and feel warmer in the room.
Lighting Psychological Comfort Enhancement Strategies-C25	Lights that are soft and warm are relaxing and less irritating to me.
Customizable Personal Lighting System-C26	Everyone likes a different brightness, so it would be great if you can adjust it yourself.
Independent Lighting Control Interface Settings-C27	Some beds have their own buttons to control the lights, which I find especially convenient.
Semi-open Space Lighting Boundary Management-C28	The lounge area should not be too bright, but also let people see the outside, the light is the best to get it just right.
Lighting Layout for Visual Privacy-C29	If the light is arranged well, I don't let people look into my room at a glance, and I feel quite safe.
Energy-efficient	I heard that energy-saving lamps

light source configurations-C30	are more energy-saving, and they don't get hot even if you leave them on for a long time.
Application of High Color Rendering Index (CRI) Energy Saving Lamps and Fixtures-C31	Some lamps have strange colors when you turn them on, and it's hard to see people's faces, so good lamps are much more natural.
Lighting Adaptive Intelligent Control System-C32	It is best to be able to adjust the brightness according to the darkness and brightness of the day itself, without the old hands.
Human Factors Perception-Driven Dynamic Lighting Adjustment-C33	Natural brightness during the day, slowly darken down at night, feel very natural, the body also adapted quickly.
Integration of Green Reflective Materials-C34	If the reflective walls are also made of environmentally friendly materials, then the air will be good and we can live in peace of mind.
Integration of Low-Carbon Buildings and Lighting Systems-C35	If the whole building is designed to save electricity and comfortable, it will be good for the people who live in it.

3-3 Axial Coding

Axial coding is the process of organizing and grouping the initial categories obtained from open coding into more abstract and generalized themes or categories. At this stage, the relationship between independent categories is not clear. Therefore, this study reduces the 35 initial categories to the original text data and analyzes the interrelationships among them. Based on this, the research team conducted an iterative comparison and clustering analysis, and finally categorized the 35 initial categories into 15 major themes. The categorization process followed the following steps: first, the 35 initial categories were initially grouped according to their semantic similarity; then, by analyzing the relationships between the categories and identifying the core concepts and their potential connections, 15 themes were finally identified, as shown in Table 7. These themes, which cover the 35 initial categories, constitute the theoretical framework of this study on the design needs of light environments in nursing homes and represent the key factors that influence users' needs for light environments in nursing homes.

3-4 Selective Coding

Selective coding was accomplished by distilling the main categories with overall guidance from the spindle codes, as shown in Table 7. Through multilevel coding and in-depth analysis, the main categories were organically associated with other categories, and a theoretical model of user requirements for the optimal design of the light environment in nursing homes was finally formed. In the selective coding stage of this study, a comprehensive review of the established category system was first conducted to filter out the most representative concepts that could systematically explain the core patterns and themes of the data. The finalized main categories include four major categories: health and comfort, spatial adaptation and safety, social and emotional support, and energy efficiency and sustainability.

[Table-07] Core Scope Code Refinement Process

Core Scope	Main Scope	Initial Scope
Health and Comfort -A1	Suitability of light intensity -B1	Illumination Requirements for Visual Operations-C1
		Light glare control - C2
		Physiological load phenomenon due to over-illumination-C3
	Color temperature adjustment needs -B2	Color temperature-mood coupling effects-C4
		Circadian Rhythm Synchronization Lighting Strategies-C5

		Warm color temperature suppresses sleep disturbance-C6
	Light uniformity -B3	Spatial light homogeneity-C7
		Diffuse treatment of indirect light sources-C8
		Spatial cognitive impairment due to light nonhomogeneity-C9
	Circadian Rhythm Support -B4	Biorhythmic light interventions-C10
		Morning high light exposure strategies-C11
		Low blue light modulation mechanism in the evening-C12
Space Adaptation and Safety -A2	Functional Area Lighting Matching -B5	Lighting Design for Functional Area Zoning-C13
		Cognitive-assisted Lighting Layout-C14
	Barrier-free lighting design -B6	Visual Guide Lighting for the Movable Line-C15
		Lighting continuity for barrier-free access-C16
		Low-glare Walking Lighting System-C17
	Improvement of emergency lighting system -B7	Disaster Response Lighting Plan-C18
		Nighttime microenvironmental lighting maintenance mechanism-C19
	Natural light introduction -B8	Optimized Design of Natural Lighting in Buildings-C20
		Light Environment Oriented Spatial Layout-C21
Social & Emotional Support -A3	Public area light atmosphere-B9	Social Promotion Lighting Atmosphere Creation-C22
		Application of Comfort Diffused Light Source-C23
	Emotionally adjustable light environment -B10	Light Environment Emotion Regulation Mechanism-C24
		Lighting Psychological Comfort Enhancement Strategies-C25
	Personalized lighting needs -B11	Customizable Personal Lighting System-C26
		Independent Lighting Control Interface Settings-C27
	Privacy and openness of the light balance -B12	Semi-open Space Lighting Boundary Management-C28
		Lighting Layout for Visual Privacy-C29
Energy Efficiency and Sustainability -A4	Application of efficient light source -B13	Energy-efficient light source configurations-C30
		Application of High Color Rendering Index (CRI) Energy Saving Lamps and Fixtures-C31
	Intelligent light control system -B14	Lighting Adaptive Intelligent Control System-C32
		Human Factors Perception-Driven Dynamic Lighting Adjustment-C33
	Green Building Materials and Light Integration -B15	Integration of Green Reflective Materials-C34
		Integration of Low-Carbon Buildings and Lighting Systems-C35

Health and Comfort represents the combined needs of users for light physiological comfort and health promotion in nursing home environments. It specifically covers the four aspects of light intensity suitability, color temperature regulation needs, light uniformity, and circadian rhythm support. This suggests that light not only needs to meet the basic visual operational needs, but also needs to improve sleep quality, relieve physiological load and promote the health of the elderly's biological rhythms by controlling color temperature, uniformity and rhythm synchronization strategies. In addition, spatial adaptation and safety emphasize the high degree of fit between light and spatial function as well as access safety guarantee. It mainly includes the subcategories of light matching in functional areas, barrier-free lighting design, improvement of emergency lighting system and introduction of natural light. That is to say, a reasonable layout of the light environment can help to improve the cognitive assistance effect, ensure barrier-free access, and maintain the basic lighting needs in emergency situations.

Social and emotional support reflects the key role of the light environment in promoting social interaction, regulating emotions and meeting individual needs. Including the public area light atmosphere, emotional adjustment light environment, personalized light needs and privacy and openness of the light balance. High-quality light design not only creates a comfortable social space, but also enhances the emotional state and psychological comfort of the elderly. Energy saving and sustainability reflect the concern for green and low-carbon development concepts in the lighting environment of nursing homes. It covers the three major sub-categories of high-efficiency light source application, intelligent light control system and integrated design of green building materials and light. Through the adoption of energy-efficient light sources, dynamic intelligent control systems and sustainable building materials integration strategies, energy consumption can be effectively reduced to promote the sustainable development of the nursing home environment. Finally, based on the standard rooted theory procedure, this study conducted a theoretical saturation test. By repeatedly extracting new categories in the data coding stage and adding more than three rounds of interview samples and data validation, no new, theoretically innovative categories were found to emerge, which verified the robustness and validity of the theoretical model.

4. Solving for Subjective and Objective User Demand Weights

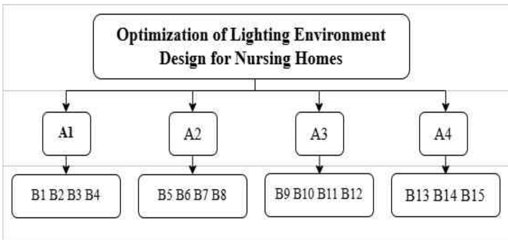
4-1 AHP-based Subjective Weight Assignment

4-1-1 Building Hierarchical Models

In the previous section, through semi-structured interviews with target users (elderly groups, caregivers, etc.), a large amount of first-hand primary data was obtained, and preliminary conceptual refinement of the data was carried out in the open coding stage, and the intrinsic relationship between the various types of sub-scopes was gradually summarized after entering the main axis coding stage. The main categories reflect the middle-level concerns of the elderly population about the light environment, such as comfort, safety and physiological rhythm support of light, while the core categories rise to a higher level, reflecting the essential factors affecting the overall light experience. On this basis, the study further transformed the core and main categories into criteria and sub-criteria layers in the AHP (hierarchical analysis method). By constructing a three-layer structural model of "Goal Layer-Criteria Layer-Scheme Layer", the user language in the interview results is systematically converted into a structured decision-making language, thus realizing a logical transition from qualitative interviews to quantitative analysis.

The first layer of the model is the target layer, i.e., "optimization of lighting environment design in nursing homes"; the second layer is the criterion layer, which combines the core categories extracted from the rooted theory, and is refined into four assessment indexes: health and comfort-A1, spatial adaptation and safety-A2, social and emotional support-A3, energy saving and sustainability-A4; the third layer is the sub-criteria layer, which covers the four assessment indexes. is the sub-criteria level, which covers the sub-level content of the four core categories and is used to compare the performance of each indicator in different design contexts, as shown in Figure 2. In this way, the

AHP hierarchical model not only reflects structural rigor, but also ensures that the indicator settings come from a solid foundation of real user needs, which enhances the scientificity and applicability of the subsequent decision-making results.



〈Figure-02〉 AHP Hierarchical Modeling

4-1-2 Respondent Selection and Expert Judgment Criteria

In order to ensure that the weight assessment of AHP hierarchical analysis method in the optimal design of lighting environment in nursing homes is highly scientific and practically instructive, this study adopts the purposive sampling method, and nine experts with rich experience in related fields are selected to participate in the process of constructing judgment matrices. The source of experts covers the academic, practical and engineering fields, and the composition structure is as follows:

1. 4 experts with the title of associate professor or above in the direction of lighting design, environmental psychology, and geriatric environment research in colleges and universities, who have solid theoretical foundation and experience in elderly design research;

2. 2 persons in charge of medical and nursing organizations, with more than 5 years of practice in elderly services and space operation and management;

3. 3 senior technicians from architectural design firms and lighting engineering companies, who have participated in several senior living facility design and implementation projects and have rich practical experience.

These choices were made to ensure that the judgments underlying the Analytic Hierarchy Process (AHP) analysis were broadly representative and professionally authoritative. To ensure the scientific validity of the application of the hierarchical analysis method (AHP) and the reliability of the results, a small-scale pilot test was conducted prior to formal data collection. Among them, the questionnaire materials for indicator definitions and evaluation guidelines, and guidance notes in the form of online questionnaire completion to ensure that experts understand the specific connotations of each indicator, and the two-by-two evaluation methods are shown in Table 8. In addition, the main purpose of the pilot test was to assess the clarity and operability of the questionnaire content, and necessary modifications were made based on feedback. During the pilot test, experts and users pointed out that some questions were poorly formulated or prone to ambiguity, so we optimized some of the questions to make them clearer. In the formal Analytic Hierarchy Process (AHP) survey, each expert was asked to compare the relative importance of each criterion and sub-criterion two-by-two, based on his or her professional judgment, using the evaluation scale provided in Table 9. The scale ranges from 1 to 9, where 1 means that both factors are equally important and 9 means that one factor is extremely important in relation to the other[28]. In order to minimize possible bias in expert judgment, each expert was asked to complete the questionnaire independently to avoid possible socialization bias in group discussions.

[Table-08] AHP Judgment Matrix

	T	C_1	C_2	C_3	......	C_n
A=	C_1	a_{11}	a_{12}	......	......	a_{1n}
	C_2	a_{21}	......	......	......	......

28) Šostar M, Ristanović V. Assessment of influencing factors on consumer behavior using the AHP model. Sustainability, 2023, 15(13), P.10341.

	C_3	……	……	……	……	……
	……	……	……	……	……	……
	C_n	a_{n1}	a_{n2}	……	……	a_{nn}

[Table-0 9] Saaty Evaluation Standards

Scale	Indicates Significance
1	Two factors are compared and have the same importance
3	Comparing two factors, the former factor is slightly more important than the latter factor
5	Comparing two factors, the former factor is significantly more important than the latter factor
7	Comparing two factors, the former factor is strongly more important than the latter factor
9	When comparing two factors, the former factor is extremely more important than the latter factor
2, 4, 6, 8	The median value of the judgment of two neighboring factors
The Reciprocal of the Above Values	The inverse of the original comparison of the two factors

4-1-3 Compute the Weight Vector

According to the expert evaluation of the relative importance of the factors between the two, constructed into a pairwise comparison judgment matrix $A=[A_{ij}]_{n\times n}$, where a_{ij} indicates the importance of the ith factor relative to the jth factor, to meet the $a_{ij}=1/a_{ij}$, and $a_{ij}=1$. After the construction of the judgment matrix needs to be carried out after the calculation of the weights of the indicators, the weighting formula is shown as follows[29].

1. Add the elements of the matrix.

$$\overline{w_i}=\sum_{j=1}^{n}\overline{a_{ij}}(i.j=1,2,\dots n)$$

2. For $\overline{w_i}$ in the above equation, implement regularization.

$$w_i=\overline{w_i}/\sum_{i=1}^{n}\overline{w_i}(i=1,2,\dots n)$$

Where w_i is the weight of the ith indicator.

After the completion of the calculation of the weight of each indicator, the judgment matrix needs to be tested for consistency, and the test formula is as follows.

2. Calculate the maximum eigenvalue of judgment matrix A.

$$\lambda_{\max}=\frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i}$$

Where n is the order of the matrix, A is the judgment matrix, w_i is the weight of the ith indicator. $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix A[30].

4. Consistent numerical CR solving.

$$CI=\frac{\lambda-n}{n-1}$$

$$CR=\frac{CI}{RI}$$

Where the RI value is known, see Table 10. When CR 〈 0.1, the test meets the requirements, proving that this evaluation passes the consistency test.

[Table- 1 0] RI Walue

N	1	2	3	4	5	6	7	8	9	10	11	…
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	…

29) HUANG Junjie,XU Xinghua,WU Fuhui et al. An operational state assessment method for electromagnetic energy equipment based on improved AHP[J/OL]. Journal of Naval Engineering University. 2023, P.1-8.

30) Podvezko, V. (2009). Application of AHP technique. Journal of Business Economics and Management, (2), P.181-189.

According to the above calculation process, the participants' ratings were organized and summarized to obtain the judgment matrix and weight values for each criterion level and sub-criterion level, as shown in Tables 11 to 15. After calculation, the CR value of each group was less than 0.1, indicating that it passed the consistency test.

[Table-11] Solving for Weights Under the

Core Category

	A1	A2	A3	A4	W_i	CR
A1	1	2	3	4	0.45	0.044
A2	1/2	1	2	3	0.279	
A3	1/3	1/2	1	2	0.166	
A4	1/4	1/3	1/2	1	0.148	

[Table-12] Solving for Weights Under the

Category A1

	B1	B2	B3	B4	W_j	CR
B1	1	3	3	4	0.576	0.011
B2	1/3	1	1	2	0.216	
B3	1/3	1	1	2	0.216	
B4	1/4	1/2	1/2	1	0.1135	

[Table-13] Solving for Weights Under the

Category A2

	B5	B6	B7	B8	W_j	CR
B5	1	4	5	3	0.6118	0.0186
B6	1/4	1	2	2	0.2318	
B7	1/5	1/2	1	1/2	0.1335	
B8	1/3	1/2	2	1	0.2138	

[Table-14] Solving for Weights Under the

Category A3

	B9	B10	B11	B12	W_j	CR
B9	1	1.5	2	1.5	0.4115	0.0074
B10	1/1.5	1	1.5	1.5	0.3045	
B11	1/2	1/1.5	1	1.5	0.2383	
B12	1/1.5	1/1.5	1/1.5	1	0.2198	

[Table-15] Solving for Weights Under the

Category A4

	B13	B14	B15	W_j	CR
B13	1	2	3	0.539	0.0172
B14	1/2	1	2	0.297	
B15	1/3	1/2	1	0.164	

Solving for weights under A1 categoriesThe main category and the core category constitute the two levels of the AHP hierarchical model: the main category is a generalization of user needs, and the core category is a more specific sub-level of content under the main category. It is necessary to calculate the local weights of each level separately, but the local weights alone cannot reflect the combined contribution of each factor to the overall goal. The total weight of each sub-criteria in the hierarchical structure was calculated by multiplying the weight of each sub-criteria layer by the weight of its corresponding criterion, as shown in Table 16. The final ranking results provide a clear priority order reference for the design optimization of the lighting environment in nursing homes, ensuring that the needs of each tier are considered scientifically and reasonably, and also providing a comprehensive weight reference for the extraction of subsequent design elements.

$$W_{AHP} = W_i \times W_j$$

[Table-16] Combined Weights Solution

Criteria Layers	W_i	Sub-Criteria Layers	W_j	W_{AHP}
A1	0.45	B1	0.576	0.2592
		B2	0.216	0.0972

		B3	0.216	0.0972
		B4	0.1135	0.051075
A2	0.279	B5	0.6118	0.170692
		B6	0.2318	0.064672
		B7	0.1335	0.037247
		B8	0.2138	0.05965
A3	0.166	B9	0.4115	0.068309
		B10	0.3045	0.050547
		B11	0.2383	0.039558
		B12	0.2198	0.036487
A4	0.148	B13	0.539	0.079772
		B14	0.297	0.043956
		B15	0.164	0.024272

From the overall comprehensive weight, light intensity suitability (B1) has the highest weight among all the sub-criteria, with a comprehensive weight of 0.2592, indicating that it has a significant impact on the user's perceived health and comfort. This is followed by functional area light matching (B5), with a weight of 0.170692, reflecting the key role of rationally configuring functional area light on space use efficiency and safety. In the guideline layer, health and comfort (A1) has the highest weight (0.450), indicating that the light design should firstly protect the physiological and psychological health of the users, followed by “spatial adaptation and safety” (A2, with a weight of 0.279), which emphasizes the match between light and the function of the building space. Social and emotional support (A3) and energy saving and sustainability (A4) occupy smaller weights (0.166 and 0.148), but their value cannot be ignored in specific use situations.

4-2 CRITIC-based Objective Weight Assignment

The above constructs the subjective and objective preference model at the expert level on the basis of the AHP method, and in order to balance the differences between the expert judgment and the user's actual perception, the CRITIC method is further introduced to mine the information and differences of each index through the user scoring data, in order to obtain the objective weights that are more close to the user's experience, so as to construct the multidimensional fusion of the evaluation system for optimization of the lighting environment.

4-2-1 Determining Who to Evaluate

In the application of the CRITIC methodology, the identification of evaluation objects is a key prerequisite. This is because the core of CRITIC empowerment lies in measuring the objective importance of each evaluation indicator through statistical analysis, which mainly relies on two elements: first, the standard deviation of the indicator among different evaluation objects (for reflecting the degree of differentiation), and second, the correlation among indicators (for identifying redundancy). Only when more than one evaluation object is available, the scoring data of each indicator on different objects can be collected, and then the valid standard deviation and correlation coefficient can be calculated. In this study, three representative elderly care institutions in China were selected as evaluation objects: the Beijing First Social Welfare Institution (public traditional type, representing North China), Hangzhou Kangjiu Sunshine Nursing Home (medical-nursing integration type, representing East China), and Guangzhou Yuexiu Recreation Center (commercial recreation type, representing South China). These three organizations differ significantly in terms of geographic location, mode of operation, lighting design concepts, and user populations, providing a representative data base for CRITIC's analysis.

[Table-17] Representative Case Introduction

	Name	Region	Features	Type
	Beijing No.1 Social Welfare Institution-D1	North China	Better facilities, emphasis on basic lighting and energy saving.	Large Public senior Care institu-tions

	Hangzhou Kangjiu Tianyi	East China	Focus on living comfort and functional zoning lighting.	Private +Public Partn-erships
	Nursing Home-D2	South China	Emphasis on personalized space and emotional lighting environment.	Private High-End Senior Care Comm-unities

In terms of the current status of the lighting environment, the three institutions show different degrees of design maturity and lighting system optimization, see Table 18. Based on the generalized analysis of the current status of the lighting system of the three institutions, this paper constructs the index evaluation matrix from multiple evaluation dimensions and scores the indexes by combining the actual performance of the three institutions, which will provide data for the subsequent application of the CRITIC model for the calculation of user-side weights. Support.

[Table-18] Introduction of Representative

Case Light Environment

No	Indoor Environment	Lighting Environment Status Quo
D1	 	1. Traditional fluorescent lighting is used, and the light color temperature is cold; 2. poor light uniformity, part of the corridors and restrooms have insufficient illumination; 3. High dependence on natural lighting, but insufficient lighting in some areas; 4. Emotional lighting and rhythmic lighting system has not yet been introduced, mainly to meet the basic visual function.
D2	 	1. A large number of LED intelligent lighting systems with adjustable color temperature are used, and rhythmic lighting is introduced in some areas; 2. Good natural lighting design, combined with the introduction of skylight in the green atrium; 3. Low-brightness guided lighting is provided at night to enhance safety; 4. The light environment design of the public space focuses on the warm atmosphere and takes into account the emotional regulation.
D3	 	1. Intelligent sensor + zone control lighting system is applied; 2. Different areas (e.g. gym, book bar, sitting area) are equipped with personalized light solutions; 3. Natural light and artificial light are introduced into the design, and some areas use dynamic light environment to simulate day and night changes; 4. Focusing on the lighting balance between privacy and openness, with clear design objectives for emotional support of users.

4-2-2 Questionnaire Design and Research

The questionnaire is designed according to the light environment design demand indicators of nursing homes derived from the previous interviews with rooted theories, and the questionnaire contains the indicators under the main category: light intensity appropriateness-B1, color temperature adjustment demand-B2, light uniformity-B3, circadian rhythm support-B4, functional area light matching-B5, barrier-free lighting design-B6, emergency lighting system improvement-B7, and the introduction of natural light-B8, Public Area Lighting Atmosphere-B9, Emotionally Adjusted Lighting Environment-B10, Individualized Lighting Needs-B11, Light Balance of Privacy and Openness-B12, Application of High-Efficiency Light Sources-B13, Intelligent Light Control System-B14, Integration of Green Buildings and Lighting-B15 To ensure that the questionnaires cover all types of key indicators. The D1-D3 cases were scored through a percentage system (0-30 indicating unacceptable, 31-50 indicating quite acceptable, 51-60 indicating good, 61-80 indicating excellent, and 81-100 indicating outstanding), and the subsequent statistical process took the average of the scoring results as the final score for subsequent standard deviation and correlation analysis. The distribution of the questionnaires was carried out online, through social media platforms, covering the residents and staff of the relevant case nursing homes, etc., to ensure the diversity and representativeness of the data[31). A total of 400 questionnaires were distributed, of which 380 were validly collected, a recovery rate of 96%. After the data collection was completed, the data were cleaned and invalid or incomplete questionnaires were excluded to ensure the quality of the data. Finally, the mean of the recovered questionnaires was averaged to obtain the scoring means shown in Table 19.

[Table-19] Average User Rating

Norm	D1	D2	D3
B1	45	70	85
B2	30	75	90
B3	40	65	80
B4	20	60	80
B5	50	75	88
B6	35	70	82
B7	25	68	85
B8	50	80	90
B9	30	72	88
B10	20	70	92
B11	15	65	90
B12	25	68	85
B13	40	80	95
B14	20	78	90
B15	30	60	85

31) Campbell S Z, Kuah J Y, Hall-Craggs M, et al. Access to statistical support for medical imaging research: questionnaire survey of UK radiology trainees. Clinical Radiology, 2022, 77(12): 920-924.

4-2-3 CRITIC Calculates and Analyzes Indicators

As mentioned in the previous section, the CRITIC method utilizes the correlation and discretization between indicators to assess the amount of information in each indicator, so as to obtain a more objective weight assignment. In the previous paper, a comprehensive evaluation was conducted for the optimization of lighting design in nursing homes, 3 representative venues were selected as research objects, and a decision matrix was constructed based on the 15 indicators of user experience. The scores of the 3 platforms on each indicator are constructed into the original matrix $X=[x_{ij}]$, where i indicates the platform number and j indicates the user demand indicator number, and the following is the detailed calculation process.

1. Standardized processing: due to the inconsistency of the scale of different indicators, it is necessary to standardize the matrix X[32). An extreme difference standardization formula is used, where $\min(x_j)$ and $\max(x_j)$ are the minimum and maximum values of indicator j, respectively, and Z_{ij} is the standardized score matrix element.

$$Z_{ij}=\frac{x_{ij}-\min(x_j)}{\max(x_j)-\min(x_j)}$$

2. Calculation of the deviation value of each indicator: the deviation value indicates the degree of dispersion of the distribution of the indicator, and is used to measure the objective information content of the indicator. The formula is as follows: where Z_{ij} is the average value of indicator j, and Dj is the deviation value of indicator j.

32) Srinivasan K, Eysenbach B, Ha S, et al. Learning to be safe: Deep rl with a safety critic. arXiv preprint arXiv:2010.14603, 2020.

$$D_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Z_{ij} - \overline{Z}_j\right)^2}$$

3. Calculate the matrix of correlation coefficients between indicators: The correlation coefficients reflect the interrelationships between indicators, as shown in Table 20. Calculate the correlation coefficient r_{ik} between the jth and kth indicators:

$$r_{ik} = \frac{\sum_{i=1}^{m}\left(Z_{ij} - \overline{Z}_j\right) \times \left(Z_{ik} - \overline{Z}_j\right)^2}{\sqrt{\sum_{i=1}^{m}\left(\left(Z_{ij} - \overline{Z}_j\right)\right)^2 \times \sum_{i=1}^{m}\left(\left(Z_{ik} - \overline{Z}_k\right)\right)^2}}$$

[Table-2 0] Correlation Coefficient Matrix

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
B1	0.000	0.009	0.000	0.001	0.001	0.009	0.005	0.009	0.006	0.003	0.001	0.005	0.006	0.024	0.004
B2	0.009	0.000	0.009	0.004	0.005	0.000	0.001	0.000	0.000	0.002	0.004	0.001	0.000	0.003	0.026
B3	0.000	0.009	0.000	0.001	0.001	0.009	0.005	0.009	0.006	0.003	0.001	0.005	0.006	0.024	0.004
B4	0.001	0.004	0.001	0.000	0.000	0.004	0.002	0.004	0.002	0.000	0.000	0.002	0.002	0.015	0.009
B5	0.001	0.005	0.001	0.000	0.000	0.005	0.002	0.005	0.003	0.001	0.000	0.002	0.003	0.017	0.008
B6	0.009	0.000	0.009	0.004	0.005	0.000	0.000	0.000	0.000	0.001	0.004	0.000	0.000	0.004	0.025
B7	0.005	0.001	0.005	0.002	0.002	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.007	0.019
B8	0.009	0.000	0.009	0.004	0.005	0.000	0.001	0.000	0.000	0.002	0.004	0.001	0.000	0.003	0.026
B9	0.006	0.000	0.006	0.002	0.003	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.006	0.020
B10	0.003	0.002	0.003	0.000	0.001	0.001	0.000	0.002	0.001	0.000	0.000	0.000	0.001	0.010	0.014
B11	0.001	0.004	0.001	0.000	0.000	0.004	0.002	0.004	0.002	0.000	0.000	0.002	0.002	0.015	0.009
B12	0.005	0.001	0.005	0.002	0.002	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.007	0.019
B13	0.006	0.000	0.006	0.002	0.003	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.006	0.021
B14	0.024	0.003	0.024	0.015	0.017	0.004	0.007	0.003	0.006	0.010	0.015	0.007	0.006	0.000	0.048
B15	0.004	0.026	0.004	0.009	0.008	0.025	0.019	0.026	0.020	0.014	0.009	0.019	0.021	0.048	0.000

4. Calculate the informativeness,

C_j denotes the informativeness of indicator j, r_{ik} is the absolute correlation coefficient between indicator j and indicator k[33].

$$C_j = D_j \times \left(1 - \frac{1}{m-1} \times \sum_{k=1,\, k \neq j}^{m} r_{jk}\right)$$

5. Calculate the weight of each indicator: according to the amount of information C_j Determine the weight of each indicator W_{CRITIC}: At this time, the weight W_{CRITIC} indicates the importance of each indicator in the lighting design of the nursing home under the user's perspective, such as Table 21.

33) Wang D, Ha M, Qiao J. Data-driven iterative adaptive critic control toward an urban wastewater treatment plant. IEEE Transactions on Industrial Electronics, 2020, 68(8), P.7362-7369.

[Table-2 1] Objective Weighting of User

Experience Metrics

	SIGMA	SUM	C_j	W_{CRITIC}
B1	0.505181	0.084378	0.042626	0.071344
B2	0.520416	0.06539	0.03403	0.056957
B3	0.505181	0.084378	0.042626	0.071344
B4	0.509175	0.046132	0.02349	0.039315
B5	0.508242	0.051429	0.026138	0.043748
B6	0.519573	0.060568	0.03147	0.052672
B7	0.515411	0.043023	0.022175	0.037114
B8	0.520416	0.06539	0.03403	0.056957
B9	0.516475	0.046391	0.02396	0.040102
B10	0.512448	0.038811	0.019889	0.033288
B11	0.509175	0.046132	0.02349	0.039315
B12	0.515411	0.043023	0.022175	0.037114
B13	0.516931	0.048092	0.02486	0.041609
B14	0.534777	0.187721	0.100389	0.168024
B15	0.500688	0.251899	0.126123	0.211095

4-3 Calculation of Combined Weights

In this study, the subjective and objective weights of each indicator have been obtained by AHP and CRITIC methods respectively. In order to ensure the scientificity and comprehensiveness of the evaluation system, the subjective and objective weights are considered on this basis to obtain the final comprehensive weight of each indicator. The comprehensive weights not only reflect the experts' judgment of the importance of the indicators, but also objectively present the data distribution characteristics of each indicator, further enhancing the rationality of the evaluation. The calculation of the comprehensive weight adopts the weighted average method, i.e., equal weights are assigned between the AHP subjective weights and CRITIC objective weights, i.e., α=0.5 and β=0.5, so as to fully reflect the balance of subjective and objective factors, and the formula for calculating the comprehensive weight W_S is as follows, and the final results are shown in Table 22.

$$W_S = \alpha \times w_{AHP} + \beta \times w_{CRITIC}$$

[Table-2 2] Combined S ubjective and Objective W eighting of User Demand I ndicators

	W_{CRITIC}	W_{AHP}	W_S
B1	0.071344	0.2592	0.165272
B2	0.056957	0.0972	0.077078
B3	0.071344	0.0972	0.084272
B4	0.039315	0.051075	0.045195
B5	0.043748	0.170692	0.10722
B6	0.052672	0.064672	0.058672
B7	0.037114	0.037247	0.037181
B8	0.056957	0.05965	0.058303
B9	0.040102	0.068309	0.054206
B10	0.033288	0.050547	0.041918
B11	0.039315	0.039558	0.039437
B12	0.037114	0.036487	0.036801
B13	0.041609	0.079772	0.06069
B14	0.168024	0.043956	0.10599
B15	0.211095	0.024272	0.117683

In the subjective-objective comprehensive assignment results of this study, light intensity suitability (B1), green building materials and light integration (B15), intelligent light control system (B14), and functional area light matching (B5) have the highest comprehensive weights of 0.1653, 0.1177, 0.1060, and 0.1072, respectively, suggesting that they are the core concerns for the optimization of the light environment in nursing homes . First of all, the suitability of light intensity is the basic condition to ensure the visual comfort and safety of the elderly, and both expert judgment and user experience pay high attention to it. Therefore, it is recommended that the horizontal illuminance in key areas such as bedrooms, corridors and activity rooms should be controlled at 300-500 lx, and be equipped with adjustable local illumination, so as to take into account the safety of reading and activities. Secondly, with the deepening of the concept of sustainable design, the attention paid to “green building materials and light integration” at the user level is significantly higher than expected by experts, reflecting the urgent needs of senior care institutions in terms of environmental protection and health. Literature points out that the use of highly reflective and environmentally friendly materials can increase illumination by 15-20% and reduce energy consumption without increasing the power of the lamps[34), t herefore, it is recommended to prioritize the use of light-colored, highly reflective recycled materials for interior decoration and combine them with passive lighting design to achieve the dual benefits of energy saving and comfort. Again, the intelligent light control system combines energy saving, convenience, and mood regulation, and thus receives greater weight in user evaluations; it is recommended to introduce an intelligent lighting platform that supports the DALI or ZigBee protocols, and combines natural light and human sensors to realize circadian rhythm lighting and real-time energy consumption monitoring, so as to improve the quality of life of the elderly[35)]. Finally, different functional areas (such as bedrooms, activity rooms, dining rooms) on the light of the targeted demand for functional areas to match

34) Veloso R C, Souza A, Maia J, et al. Nanomaterials with high solar reflectance as an emerging path towards energy-efficient envelope systems: a review. Journal of Materials Science, 2021, P.1-49.

35) Parise G, Zissis G, Martirano L. Smart Lighting Systems, Controls, and Communication Protocols: Introducing Open Communication Protocols. IEEE Industry Applications Magazine, 2024.

the light has also become an important dimension to improve the efficiency of space utilization and quality of life; for example, the restaurant and social areas can be used for warm light source 3000-3500 K, while in the corridors and the medical area to use more than 4000 K cool white light to improve alertness, and with adjustable luminaires to achieve flexible switching. The light can be switched flexibly with adjustable fixtures[36]. Through these measures, the lighting environment of nursing homes can be expanded from meeting basic visual needs to becoming intelligent and sustainable, thus creating a safer, more comfortable and healthier living space for the elderly.

5. Conclusion

This study innovatively combines the rootedness theory with the AHP-CRITIC multidimensional empowerment method to construct a systematic evaluation and optimization framework for the lighting environment of nursing homes. First, through semi-structured interviews with a number of nursing home residents, caregivers and design experts, coding analysis was conducted based on the Zagan theory, and four core demand dimensions were summarized: light comfort (light intensity and color temperature adjustment), safety and functional matching (zoned lighting, emergency and accessible lighting), mood and rhythm support (ambient light and circadian lighting), and sustainable and intelligent (green building materials and intelligent control). These qualitative results provide solid theoretical support for the formation of the subsequent indicator system. On this basis, this study adopts the AHP method to obtain the expert-level weights, and applies the CRITIC method to calculate the user-level weights based on the field research and user rating data of the Beijing No. 1 Social Welfare Institution, Hangzhou Kangjiu Tianyi Nursing Home, and Guangzhou Yuexiu Recreation and Nursing Center. After weighted fusion, light intensity suitability (w_s = 0.1653), green building materials and light integration (w_s = 0.1177), intelligent light control system (w_s = 0.1060), and functional area light matching (w_s = 0.1072) became the four indicators with the highest combined weight. The study shows that the elderly have the most urgent needs for basic visual safety, environmental protection and health, intelligent and convenient and zoned targeted lighting. Based on the above conclusions, the following optimization suggestions are made: first, control the horizontal illuminance at 300-500 lx in key areas such as bedrooms, corridors and activity rooms, and equip them with adjustable local lamps and lanterns to take into account safety and comfort; second, give priority to the use of highly reflective and environmentally friendly building materials and combine with the design of passive lighting to achieve 15%-20% of the The third is the introduction of intelligent lighting system supporting DALI/ZigBee protocol, combined with natural light and human body sensors, to realize circadian rhythm lighting and energy consumption monitoring; the fourth is for the characteristics of the functional areas, in the dining room and the social area using 3000-3500 K warm light source, in the corridors and the medical area using more than 4000 K cool white light, and with adjustable lamps to meet the needs of safety and comfort. Fourthly, for the characteristics of functional areas, 3000-3500 K warm light source is used in the dining room and social area, while 4000 K or more cool white light is used in the corridor and medical area, and adjustable lamps are used to meet the multi-scene switching. Through the above measures, the lighting environment of the nursing home will move from meeting basic

36) Xu H, Mamat M J B. The impact of regional culture on natural lighting habits: Exploring cultural differences in interior design and museum exhibition spaces. Multidisciplinary Reviews, 2025, 8(9), P.2025272-2025272.

physiological needs to intelligence and sustainability, providing a safer, more comfortable and healthy living space for the elderly.

However, this study also has related research limitations. First, the sample selection was limited to three typical nursing homes in Beijing, Hangzhou, and Guangzhou, which is geographically and type-representative but does not cover nursing homes in central and western China and rural areas, which may affect the broad applicability of the results; second, the user ratings mainly relied on questionnaires and expert observations, and there was a lack of long-term physiological and behavioral monitoring data, which does not provide an in-depth assessment of the health benefits of the light interventions. Future research could expand the institutional sample on a larger scale, especially to include medical-attendant and community-embedded nursing homes, and incorporate wearable devices or environmental sensors to obtain actual activity and sleep data of the elderly to quantify the physiological effects of light interventions; at the same time, multi-seasonal and all-weather illuminance monitoring and tracking of user satisfaction should be carried out, to explore the need for adjustment of light-environment optimization strategies in different seasons and day-night cycles .

References

1. World Health Organization. Progress report on the United Nations decade of healthy ageing, 2021-2023[M]. World Health Organization, 2023
2. Yang H, Guo B, Shi Y, et al. Interior daylight environment of an elderly nursing home in Beijing. Building and Environment, 2021
3. Maier J, Zierke O, Hoermann H J, et al. Subjectivity of lighting perception and comfort: the role of preferences and expectations. Environment and Behavior, 2017
4. Walsh I, Rowe F. BIBGT: combining bibliometrics and grounded theory to conduct a literature review. European Journal of Information Systems, 2023
5. Sarabia-Cobo C, Sarriá E. Satisfaction with caregiving among informal caregivers of elderly people with dementia based on the salutogenic model of health. Applied Nursing Research, 2021
6. Yu D, Kou G, Xu Z, et al. Analysis of collaboration evolution in AHP research: 1982-2018. International Journal of Information Technology & Decision Making, 2021, 20(01).
7. Benaida M. Developing and extending usability heuristics evaluation for user interface design via AHP. Soft Computing, 2023
8. Wang D, Ha M, Zhao M. The intelligent critic framework for advanced optimal control. Artificial Intelligence Review, 2022
9. Adeoye–Olatunde O A, Olenik N L. Research and scholarly methods: Semi–structured interviews. Journal of the american college of clinical pharmacy, 2021
10. Podvezko, V. Application of AHP technique. Journal of Business Economics and Management, (2). 2009
11. Wang D, Ha M, Qiao J. Data-driven iterative adaptive critic control toward an urban wastewater treatment plant. IEEE Transactions on Industrial Electronics, 2020
12. www.stats.gov.cn