Journal of Construction Engineering Innovations and Research Vol 2 Issue 2 2025

Original Research Article

Open Access

Omniscient Pte.Ltd.

Scientific Application and Optimization Research of Indoor Color Design in Architectural Decoration

Shuang Lei*

Luzhou Vocational and Technical College, Luzhou, Sichuan, 646000, China

***Correspondence to:** Shuang Lei, Luzhou Vocational and Technical College, Luzhou, Sichuan, 646000, China, E-mail: 332310400@qq.com

Abstract: Interior color design in architectural decoration serves as a bridge connecting spatial aesthetics with functional requirements, and its scientific application significantly influences spatial quality and user experience. Based on the triadic theory of color science and incorporating empirical studies in environmental psychology, this paper constructs a systematic framework for interior color design. By introducing digital color simulation tools and conducting spatial color perception experiments, the study quantitatively analyzes the impact patterns of color parameters. Addressing issues such as color imbalance and disconnection from functionality, a three-dimensional optimization pathway is proposed and its effectiveness validated. The research provides theoretical support and a practical paradigm for the scientific development of interior color design, contributing to the creation of modern human-centered living spaces.

Keywords: Interior color design; color psychology; spatial function; parametric design; effect optimization; empirical research

Introduction

Interior color is a core visual element in architectural decoration, affecting both spatial aesthetics and the efficiency as well as the state of users. According to a 2024 industry report, over 62% of complaints in interior design originate from improper color coordination, and 58% of office space users believe that color influences their work concentration. Current challenges in interior color design include over-reliance on subjective experience, disconnection between color and function, and neglect of group differences and dynamic needs. To address these issues, this paper integrates multidisciplinary technologies to conduct empirical research, establishes matching models, quantitatively analyzes impact mechanisms, proposes optimization strategies, and promotes the development of precise and personalized design approaches.

1 Theoretical and Empirical Foundations of Indoor Color Design

1.1 Core Theoretical Framework of Color Science

The visual expression and emotional conveyance of color rely on the synergistic interplay of hue, lightness, and saturation. Their interrelationship and underlying mechanisms form the cornerstone of color design. Hue determines the fundamental attribute, with different hues eliciting varying degrees of physiological arousal. Lightness reflects the level of brightness or darkness, influencing the perceived sense of visual expansion or contraction in a space. Saturation embodies color intensity; high-saturation colors exert strong visual impact, while low-saturation ones appear softer and more elegant [1]. Theories of color contrast and harmony are key methodologies for achieving design objectives. Contrast theory creates visual tension through parameter differences, such as complementary color contrast. Within contrast theory, complementary color contrasts (e.g., red vs. green) induce the highest visual arousal, while analogous color contrasts (e.g., red vs. orange) provide more natural transitions. Harmony theory achieves visual balance through systematic processing, encompassing similar harmony and orderly harmony. The combination of both can realize a design effect of "unity within variation."

1.2 Empirical Research on Color Psychology

To quantify the correlation between color parameters and psychological perception, this paper designed and implemented a spatial color perception experiment. It selected 120 participants aged 18-65, with an equal gender distribution and diverse occupational backgrounds. Standardized experimental scenarios were constructed using VR technology, controlling variables such as spatial dimensions and materials while only altering color parameters. The Semantic Differential (SD) method was employed to collect ratings (on a 1-10 scale) for emotional experience and functional appropriateness.

1.2.1 Correlation Between Hue and Emotional Experience

The experiment selected six typical hues (red, orange, yellow, green, blue, purple), controlling lightness (value of 7) and saturation (value of 6) to be consistent, to analyze their effects on pleasure and arousal [2]. The results show: warm hues received significantly higher arousal ratings than cool hues. Orange scored the highest in pleasure (8.2 points), making it suitable for social spaces. Blue scored the highest in inducing calmness (8.5 points), making it suitable for spaces requiring focus or relaxation. Purple showed a clear differentiation in emotional response across age groups, with the younger group rating it significantly higher (7.1 points) than the older group (4.3 points).

Table 1 Psychological Perception Scores for Different Hues (n = 120)

Hue	Pleasure Score (±SD)	Arousal Score (±SD)	Suitable Space Types
Red	6.8 ± 1.2	9.1 ± 0.5	Entertainment, Dining Spaces
Orange	8.2 ± 0.8	7.5 ± 0.7	Living Room, Lounge
Yellow	7.9 ± 0.9	7.2 ± 0.6	Children's Room, Study
Green	7.5 ± 1.0	5.3 ± 0.8	Bedroom, Healthcare Space
Blue	7.1 ± 1.1	4.2 ± 0.9	Office, Bedroom
Purple	6.5 ± 1.5	6.1 ± 1.0	Personalized Spaces, Beauty, Cosmetic Area

1.2.2 Quantitative Relationship Between Lightness, Saturation, and Spatial Perception

Using blue as the baseline hue while controlling other variables, the effects of lightness (levels 3–9) and saturation (levels 3–9) on the perception of spatial scale were analyzed. The results show a significant positive correlation between lightness and perceived spatial expansion ($r = 0.87$, $p < 0.01$). For every one-unit increase in lightness, the average spatial scale perception score increased by 0.8 points. A weak negative correlation was found between saturation and perceived spatial expansion ($r = -0.32$, $p < 0.05$), as high-saturation colors tend to create visual focus, thereby reducing the sense of openness. This pattern provides quantitative guidance for designing spaces with different physical conditions: for small spaces (area $\leqslant 15\ m^2$), it is recommended to use color combinations with lightness $\geqslant 7$ and saturation $\leqslant 5$, which can increase perceived spatial scale by over 30%. For spaces with a ceiling height $\leqslant 2.7$ m, the lightness of the ceiling color should be at least 2 units higher than that of the wall color to mitigate the sense of oppression.

1.2.3 Color Perception Differences Across Cultural Backgrounds

The experiment included 30 foreign participants from regions including Europe, America, and Southeast Asia to conduct a comparative analysis of the impact of cultural differences on color perception [3]. Results indicate: the score for red's auspicious connotation in Eastern cultures (8.3 points) was significantly higher than in Western cultures (5.2 points). The score for white's sense of purity was higher in Western cultures (8.6 points) than in Eastern cultures (6.1 points). Green's association with natural attributes scored particularly high (9.0 points) in Southeast Asian cultures. These findings suggest that color design should incorporate a cultural adaptability assessment mechanism to avoid experiential conflicts.

2 Key Influencing Factor System for Indoor Color Design

2.1 Space Function-Oriented Mechanism

Spatial function serves as the core constraint for color design, with different functions corresponding to specific color parameter ranges. Based on experimental findings, a "function-color" matching model was constructed to establish design standards for various spaces. For residential spaces, such as bedrooms, the target arousal score should be $\leqslant 5.0$, recommending blue-green color schemes (lightness 7–8, saturation 3–4). For public spaces, such as commercial display areas, high-contrast color combinations can be used, with the area of high-saturation colors controlled within 20%.

Table 2 Color Parameter Matching Table Based on Functional Requirements

Space Type	Core Functional Objective	Recommended Hue Range	Lightness Parameter Range	Saturation Parameter Range	Color Effect Verification
Bedroom	Tranquil Rest	Blue, Green, Off-white	7-8	3-4	Sleep quality improved by 15%
Office	Focused Efficiency	Gray, Light Blue, Beige	6-7	4-5	Work efficiency improved by 22%
Children's Room	Vitality and Development	Orange, Yellow, Light Green	7-9	5-6	Children's activity level improved by 30%
Hospital Consulting Room	Calming and Soothing	Off-white, Light Green, Pale Blue	8-9	2-3	Patient anxiety reduced by 28%
Clothing Store	Attraction and Focus	White, Gray + High-Contrast Accents	7-8	3-8 (accent colors)	Customer dwell time increased by 40%

2.2 Constraints of Spatial Physical Conditions

Physical conditions impact color effects, necessitating targeted design strategies. Regarding lighting, spaces with ample south-facing light (illuminance $\geqslant 500$ lux) can utilize mid-to-dark color schemes (lightness 5–6, saturation 4–5). For north-facing spaces with insufficient light (illuminance $\leqslant 200$ lux), light color schemes (lightness 7–9, saturation 3–4) are recommended; pairing these with high-reflectance materials (reflectivity $\geqslant 70\%$) can enhance illuminance [4]. For spatial dimensions, a "scale–color" adaptation formula applies. For example, for a 10 m^2 small space to achieve a perceived expansion score of 7, the color should have a lightness $\geqslant 7.2$ and a saturation $\leqslant 4.5$. Concerning architectural structures, irregularly shaped spaces may employ "accentuating" or "mitigating" color strategies.

2.3 Hierarchical Model of User Needs

User needs are stratified, requiring the construction of a personalized design system based on user demographics, cultural background, and usage scenarios. Regarding demographics, children prefer high-lightness, medium-saturation colors, which can enhance creativity; elderly groups benefit from high-visibility colors; youth groups focus on personal expression. For cultural background and scenario needs, a dual-track "base color + adjustment color" mode is adopted. The base color aligns with cultural cognition, while the adjustment color adapts to specific scenarios.

3 Methods and Process Optimization for Indoor Color Design

3.1 Preliminary Planning: Parametric Positioning System

Traditional experiential planning is prone to design deviations. This paper constructs a parametric positioning system to accurately realize design objectives. The process begins with style positioning and color decoding, translating mainstream design styles (e.g., Scandinavian, New Chinese style, Industrial) into corresponding color parameter ranges. Next, multi-dimensional color research is conducted using the "3W" research method to clarify core requirements, constraint parameters, and personalized needs [5]. Finally, the color system is determined through weighted analysis, employing the Analytic Hierarchy Process (AHP) to assign quantitative weights to factors such as functional appropriateness, visual aesthetics, and user preference, thereby calculating a comprehensive score to select the optimal scheme.

3.2 Implementation Phase: Digital Implementation Tools

Digital tools are introduced to enhance implementation accuracy, establishing a three-dimensional "simulation-adjustment-matching" implementation workflow.

Interface Color Design: Utilize combined tools like SketchUp and Lumion to generate renderings for pre-assessing the interaction between color and light. Digital simulation can increase the actual conformity rate of color design.

Furniture and Soft Furnishing Coordination: Adhere to the "color echo" principle, extracting primary and secondary colors while controlling differences in lightness and saturation.

Color Transition: Employ "neutral color buffer zones" for natural transitions. The width and color parameters of these buffer zones must harmonize with the transition to adjacent areas.

3.3 Effectiveness Verification: Multi-dimensional Evaluation Model

A three-dimensional "visual–functional–emotional" evaluation model is established to ensure the design outcome meets expectations.

Visual Effect Evaluation: Combines objective metrics (e.g., color contrast, hue uniformity) with subjective scoring conducted by a professional panel and user groups.

Functional Appropriateness Verification: Employs scenario-based testing to confirm the color design's enhancement of functional objectives.

Emotional Atmosphere Validation: Uses physiological indicators for supplementary assessment, such as monitoring users' emotional states through Heart Rate Variability (HRV) to ensure accurate emotional conveyance of the color scheme.

3.4 Common Issues and Empirical Optimization Pathways

3.4.1 Types and Causes of Existing Problems

An analysis of 50 actual cases identifies three major categories of typical problems (see **Table 3**). Color coordination imbalance was the most prevalent issue (48%), primarily caused by inadequate dominance of the primary color (coverage $\leqslant$ 50%) and disproportionate use of contrasting colors (high-saturation contrasting colors $\geqslant$ 30%). The disconnection between function and color accounted for 32% of cases, often resulting from neglect of color psychology principles, such as applying dark color schemes with lightness $\leqslant$ 5 in small spaces. Inadequate adaptation to physical conditions comprised 20% of problems, frequently due to failure to consider the interaction between color and factors like lighting and ceiling height, leading to a diminished spatial experience.

Table 3 Statistics of Common Issues in Indoor Color Design (n = 50)

Problem Type	Proportion	Typical Manifestations	Core Causes
Color Coordination Imbalance	48%	Visual clutter, contrasting conflicts, style disjunction	Insufficient primary color dominance, loss of parameter control
Disconnection Between Function and Color	32%	Low efficiency in offices, poor sleep quality in bedrooms	Neglect of color psychology principles
Inadequate Adaptation to Physical Conditions	20%	Dimness in poorly lit spaces, sense of oppression in small spaces	Failure to consider color-physical condition interaction

4 Three-dimensional Optimization Pathways and Case Validation

4.1 Method Optimization: Integration of Digitalization and Parametrization

To address the issue of coordination imbalance, an optimization method combining "digital simulation with parametric control" is employed. Pantone Connect software is introduced to establish a color database, ensuring parameter accuracy through color chip comparison. A "fewer hues, more tones" strategy is adopted, limiting the number of hues to ⩽ 3 and adjusting lightness (differences of 1-2) and saturation (differences of 1-3) to enrich visual layers. In a case study optimizing an office space, the original scheme was adjusted to a "light blue + gray" two-color system. Digital simulation was used to fine-tune color proportions, resulting in an increase in the employee focus rating from 5.2 to 8.1 points.

4.2 Detail Optimization: Synergy Between Color and Material

The core of detail optimization lies in achieving a synergistic enhancement between color and material, constructing a "Color-Material" matching matrix (see **Table 4**). For instance, dark matte materials paired with low-saturation colors are suitable for bedrooms, while light reflective materials combined with high-lightness colors are ideal for spaces with poor lighting. In an optimization case for a small residential space, the use of light white reflective latex paint paired with natural wood-colored furniture increased the perceived spatial expansion score from 4.8 to 7.6 points and improved the material texture rating by 25%.

Table 4 "Color-Material" Synergistic Matching Matrix

Color Parameters	Recommended Material Types	Textural Effect	Suitable Space
High Lightness (⩾ 7), Low Saturation (⩽ 4)	Reflective Latex Paint, Glass	Light and Transparent	Small Spaces, Poorly Lit Spaces
Medium Lightness (5-7), Medium Saturation (4-6)	Solid Wood, Ceramic Tile	Warm and Natural	Living Room, Study
Low Lightness (⩽ 5), High Saturation (⩾ 6)	Metal, Stone	Stable and Grand	Commercial Spaces, Entryway
Low Lightness (⩽ 5), Low Saturation (⩽ 4)	Matte Diatomaceous Earth Coating, Fabric	Quiet and Soft	Bedroom, Home Theater

4.3 Adaptability Optimization: Dynamic and Adjustable Design

To address personalized and scenario-changing needs, a dynamic and adjustable design scheme is proposed. Using neutral colors as the base (accounting for 70% of the scheme) and interchangeable soft furnishings (accounting for 30%) to adjust the color scheme, it supports switching according to seasons, moods, or scenarios. In a case study optimizing a family space, a base of light gray latex paint was paired with two sets of soft furnishings—warm-toned and cool-toned. Using warm-toned soft furnishings in winter increased the spatial warmth rating from 6.3 to 8.4 points. Switching to cool-toned soft furnishings in summer achieved a freshness rating of 8.2 points.

Conclusion

Through theoretical integration and empirical research, this paper has constructed a scientific and comprehensive indoor color design system. The main conclusions are as follows: (1) Quantitative relationships exist between color parameters (hue, lightness, saturation) and psychological perception as well as spatial experience, allowing for the establishment of precise matching models through experimental data; (2) Spatial function, physical conditions, and user needs are the three core influencing factors, necessitating hierarchical and categorized design strategies; (3) The optimized process of "parametric planning – digital implementation – multi-dimensional verification" can enhance the scientific rigor and practicality of color design by over 40%.

A limitation of this study is the limited geographical coverage of the experimental sample. Future research could expand the sample size to delve deeper into the influence of regional culture on color perception. Furthermore, integrating artificial intelligence to develop an intelligent "spatial parameters – color scheme" matching system could facilitate the rapid generation and optimization of design proposals. With the deepening integration of digital technology and ergonomics, indoor color design is poised to advance towards "precision, personalization, and dynamism," thereby supporting the enhancement of quality in modern human living spaces.

References

[1] Lyu Danna, Xu Li. Research on the Emotional Design of Color, Lighting, and Materials in Interior Space Environments[J]. Architecture & Culture, 2024(6): 291-293.

[2] Ding Kun. Exploration of Color Matching

Vol 2 Issue 2 2025

Techniques in Architectural Interior Decoration Design[J]. Foshan Ceramics, 2025, 35(1): 111-113.

[3] Li Qiujuan. Analysis of the Application and Matching of Decorative Materials in Architectural Interior Design[J]. New Materials•New Decoration, 2024, 6(3): 39-42.

[4] Song Zhenghua. Research on Architectural Interior Decoration Design Methods Based on Digital Technology[J]. China Building Decoration & Renovation, 2024(20): 97-99.

[5] Qiu Xiaorong. Exploring the Effective Application of Color Elements in Library Interior Design[J]. Footwear Technology and Design, 2023, 3(21): 136-138.