World Journal of Education and Humanities
ISSN 2687-6760 (Print) ISSN 2687-6779 (Online)
Vol. 8 No. 3, 2026
www.scholink.org/ojs/index.php/wjeh

Original Paper

ESEARCH ON THE CONSTRUCTION OF COLOR SYSTEM FOR WUHAN HISTORIC CITY BASED ON K-MEANS ALGORITHM AND PCCS SYSTEM

LI Shuo[1], HE Yuanyuan[1*], HAN Qinyou[1], WANG Yang[1], XU Yijing[1], & XIE Shujuan[1]
[1] Wuhan Textile University, Wuhan 430073, China

Received: June 28, 2026 Accepted: July 02, 2026 Online Published: July 24, 2026
doi:10.22158/wjeh.v8n3p79 URL: http://dx.doi.org/10.22158/wjeh.v8n3p79

Abstract
Objective: To address the problems of chaotic color elements, conflicts between old and new interfaces, and ambiguous regional semantics during Wuhan's urban renewal, this study constructs a dynamic and quantifiable urban color management system[1]. Methods: A two-stage K-means clustering combined with PCCS semantic mapping is employed. Based on 151 local chronicle records and 112 valid image samples, colors are extracted in HSV space[2]. The silhouette coefficient determines the optimal K=10, and after secondary clustering, 25 core colors are obtained, followed by standardized conversion from HSV to PCCS and semantic assignment. Results: A three-level color system consisting of primary, secondary, and accent colors is established. Integrated with Wuhan's three-town geographic layout and historical context, a governance framework with spatiotemporal distribution and semantic association is constructed. Conclusion: Questionnaire validation shows good public acceptance, providing a reusable technical pathway for digital color management of historic cities[3].
Keywords
K-means algorithm, PCCS system, Wuhan, historic city, color control

1. Introduction

As an important historical and cultural city in the Yangtze River basin, Wuhan's urban colors are visual testimonies to the intertwining of millennia of civilization and modern urbanization. From the gray-blue brick walls and dark tile roofs of traditional dwellings, to the warm stone archways and corridors of the Hankou concession area, from the rust-red steel frames and gray-green pipelines of Qingshan's industrial heritage, to the translucent blue-gray glass curtain walls of the Optics Valley new district, the color spectrum carries the unique geographic climate, commercial history, and industrial memory of the “River City.”[4] However, during rapid urban renewal, the transition between historic districts and newly developed areas lacks color continuity, leading to fragmented cityscapes; conflicts between old and new building interfaces in terms of massing, materials, and hue are intensifying; meanwhile, regional color semantics have become ambiguous due to the absence of systematic organization, making it difficult to form a recognizable urban image[5]. Existing research largely remains at qualitative description or single-scale extraction—for example, local color analysis based on street-view images, or historic district documentation using GIS—but none has integrated objective color data with regional cultural semantics into a unified framework capable of supporting dynamic planning management. Although the city of Wuhan established an image positioning of “bright, fresh, grand and elegant” and a primary color framework of “warm white, gray, and orange” in 2014, the original checklist-based “recommended/prohibited colors” control method has proven inflexible and poorly adaptive when facing emerging functional zones such as Optics Valley Central Business District and the new CBD. Moreover, the static management model increasingly conflicts with the city’s rapid development. This study introduces the K-means clustering algorithm for batch color extraction from large-scale image data, and employs the PCCS international color system for standardized conversion and semantic assignment, aiming to construct a Wuhan urban color system that balances historical preservation, modern innovation, and dynamic regulation.

2. Literature Review

In terms of color space selection, the RGB space is computationally simple but perceptually non-uniform; the HSV space separates hue, saturation, and value, which aligns more closely with human visual intuition and offers certain robustness to illumination changes, making it widely used in image-based color extraction[6]. The CIELab space, owing to its perceptual uniformity, is often applied in detailed color analysis. For clustering algorithms, K-means is favored for its simplicity and efficiency, and the K-means++ initialization effectively overcomes the sensitivity to initial centers, significantly improving clustering stability. International scholars have used HSV space to quantify colors of traditional village buildings, finding that primary colors are concentrated in the red-yellow region (hue 0°–40°), with low saturation (0–30%) and medium value (30–70%), providing a data foundation for heritage conservation. Domestic research has advanced rapidly in recent years, evolving from early color-chart comparisons to algorithm-based extraction using HSV/RGB, with attempts to build color network models and hierarchical control systems. For instance, some researchers utilized OSM and Baidu map data, combined with deep-learning semantic segmentation and K-means clustering, to extract and visualize colors along Harbin’s Central Street. Others have conducted color-image quantification through the PCCS system, obtaining representative colors and lexical mappings via multidimensional statistics[7]. However, most studies focus on algorithmic optimization or vocabulary expansion at a single scale, and have not yet formed a complete closed loop from data extraction to semantic translation to spatial control. In particular, systematic color construction for complex historic cities like Wuhan—with their multiple historical layers and diversified functional zones—is lacking. This study addresses this gap by delineating sampling sites guided by local chronicles, achieving objective extraction through algorithmic driving, and completing semantic association via the PCCS system[8].

3. Research Methods and Data Foundation

3.1 Sample Collection and Standardization

Based on local chronicles including the Wuhan Metropolitan Area Yearbook (2010-2025), Wuchang Yearbook, Hanyang Yearbook, Jianghan Yearbook, and Wuhan City Annals, this study selected 36 sampling sites that cover streets, historic buildings, parks, green spaces, and industrial heritage sites across the administrative districts of Jiang'an, Jianghan, Hanyang, Wuchang, Hongshan, and Qingshan, aiming to reflect the color characteristics of different historical periods and functional types across Wuhan's three towns. A total of 185 original images were collected; after screening out those with incomplete structures, blurred colors, or uneven illumination, 112 valid images were retained[9]. To control acquisition errors, unified shooting conditions were established: sunny days, shaded building facades, 1:00–5:00 PM local time, avoiding direct sunlight and shadow interference. Color areas were defined according to building facade logic: the facade was divided into base surfaces (walls, roofs), structural surfaces (beams, columns, frames), and decorative surfaces (carvings, doors, windows), corresponding to primary, secondary, and accent color extraction. Primary colors were defined as continuous color patches occupying ≥60% of the area, secondary colors 20%–60%, and accent colors ≤20%. Adaptive thresholds were applied for buildings of different periods—for example, for modern mixed-material buildings, the primary-color proportion could be relaxed to 50%–70%, while modern buildings were required to maintain ≥60% for visual unity[10].

3.2 K-means Clustering Process

For each image, uniform grid sampling was performed: the image was divided into an 8×8 grid, and 100 pixels were randomly selected from each cell to ensure spatial distribution and reduce computational load. After sampling, the pixels were converted to HSV space[11]. The K-means++ initialization strategy was used to select initial cluster centers by distributing them as far apart as possible through a probability distribution, avoiding local optima. The distance metric used weighted Euclidean distance, where hue, because of its angular nature, was computed using circular difference, while saturation and value were directly differenced; the weights were set to 0.5, 0.25, and 0.25 respectively (optimized through preliminary experiments)[12]. During iteration, cluster centers were updated—hue using angular mean, saturation and value using arithmetic mean—until the within-cluster sum of squared errors (SSE) converged (threshold set to 1e-4), with a maximum of 100 iterations to prevent infinite loops. To determine the optimal K, the silhouette coefficient was calculated for different K values; at K=10 the coefficient was closest to 1, indicating the best balance between cohesion and separation. Thus K=10 was set for the initial clustering. The first clustering yielded 112×10 = 1,120 color elements. Next, for each sample, the 10 colors were sorted by area proportion, and interference colors (e.g., sky, ground shadows) with proportions below 1% were removed. The remaining colors were aggregated and subjected to a second K-means clustering, this time with K=25, finally condensing to 25 representative core colors[13].

3.3 Conversion from HSV to PCCS

To assign standardized codes and interpretable semantics to the extracted colors, this study mapped the HSV colors to the Practical Color Coordinate System (PCCS) developed by the Japan Color Research Institute. PCCS uses hue, value, and chroma as three coordinates, featuring a 24-hue circle, 9 value levels, and 9 chroma levels, balancing color classification and image expression. The conversion rules are: Hue H (0°–360°) is mapped to the 24-hue circle, each 15° corresponding to one hue number: Hue number = round(H/15), resulting in values 1–24 (with 0° corresponding to 24). Value V (0–1) is linearly expanded to PCCS 9-level value: Value level = round(V×8+1), where level 1 is lowest (black) and 9 is highest (white). Saturation S (0–1) is mapped to chroma level: Chroma level = round(S×9), where 0 is achromatic and 9 is the highest chroma. Through this conversion, each extracted color obtains a unique PCCS code (e.g., “24-6-4” represents hue 24, value 6, chroma 4), providing a standardized basis for subsequent semantic association and color matching specifications[14].

4. Color Characteristics and Hierarchical System of Wuhan

4.1 Extraction Results and Distribution of the 25 Core Colors

The 25 core colors obtained from the secondary clustering exhibited a distinct bimodal distribution in HSV space[15]. The main peak was concentrated in the orange-yellow to yellow-green region (H=18°–64°), accounting for 43.6% of the total sample points, reflecting the widespread use of traditional building materials (red brick, gray brick, wood) and warm-tone coatings in Wuhan. The secondary peak lay in the blue-purple region (H=210°–250°), contributing 28.9%, mainly originating from modern glass curtain walls, steel structures, and gray materials. In terms of saturation, low saturation (S<30%) accounted for 35.2%, medium saturation (30%–60%) for 65%, and high saturation (S>60%) only 9.8%, indicating that Wuhan’s overall urban color tends toward soft and stable tones, consistent with the “grand and elegant” positioning. For value distribution, high value (V>75%) accounted for 32.1%, mainly from light-colored walls and modern metal materials; medium value (45%–75%) formed the main body with 51.7%; and low value (V<45%) constituted only 16.2%, mostly concentrated in dark structural components of industrial zones. In overall hue composition, the gray-brown series (including gray, brown, off-white) accumulated to 44.58%, serving as the dominant tone; the gray-blue series (including light blue-gray and medium blue-gray) accounted for 7.89%, providing cool highlights; and the red-yellow series (e.g., dawn yellow, ochre red, orange-red) though totaling less than 5%, formed visually prominent active focal points[16].

4.2 Three-Level Color Semantic Structure

Based on the PCCS tone-image association model and combined with the actual area proportions of each color on building facades, the 25 colors were divided into three levels:

Primary color level (proportion ≥5%): 8 colors. In the PCCS diagram, these colors cluster at two extremes: very light tones (itg, it, p)—such as off-white and light gray—correspond to the plain brick walls and light-colored plasters of Republican-era historic buildings in the Jiang'an district, conveying images of "purity, rationality, and openness" associated with modern enlightenment; very dark tones (dkg, dk)—such as deep gray and charcoal—mainly come from the factory facades and large mechanical structures of the Qingshan steel plant, conveying "weightiness, authority, and toughness" emblematic of industrial spirit. The wide semantic span of the primary layer precisely mirrors Wuhan's historical depth from early treaty-port opening to modern industrial civilization[17].

Secondary color level (3%–4%): 9 colors. These are concentrated in the medium value region (V=4–7), covering warm browns, reddish browns, medium grays, and blue-grays. Among them, warm browns (e.g., red-brick tones) are predominantly found on structural elements (window sills, eaves) of historic buildings in the Hankou concession, conveying "tradition, folk, and warmth"; cool grays (e.g., steel-gray) are more common in modern structures like Guishan TV Tower and the Erqi Bridge, expressing "professionalism, calmness, and technology"; medium grays serve as a bridge between warm and cool, achieving visual transition[18]. The secondary layer spatially connects old and new functional areas, balancing the tension between historical solemnity and modern simplicity[19].

Accent color level (total <3%): 8 colors, mostly high chroma (C>6) and medium-high value (V=5–8), such as dawn yellow (H=37, S=66, V=86), ochre red (H=9, S=64, V=80), and deep blue (H=211, S=64, V=59). Along the chroma axis from right to left, these colors narrate a transition from "lively, energetic" to "traditional, solemn." Examples include the orange-red steel girders of Parrot Island Bridge, the vermilion pillars of Qingchuan Pavilion, and the yellow mechanical arms at Qingshan River Beach—all using small areas to achieve visual highlights, while value fluctuations create cold-warm contrasts that enrich the city's expression. Together, the three levels form an organic whole where "primary sets the tone, secondary facilitates transition, and accent activates."

4.3 Semantic Mapping with Spatial Functions

Further overlaying color distribution with Wuhan's three-town functional zones reveals distinct semantic differentiation: the Hankou historic protection area (former concession and old town) is dominated by low-value (V≤4), low-chroma (C≤3) warm grays, with semantics pointing to "weighty, nostalgic, culturally layered"—suitable for carrying historical memory; the Wuchang modern science and innovation belt (Optics Valley, university town) features high-value (V≥7), medium-chroma (C=4–6) cool grays and light blues, expressing "rational, futuristic, vibrant," fitting the innovation atmosphere; the Hanyang-Qingshan eco-industrial complex is characterized by medium-low value (V=4–6), medium-chroma (C=3–5) gray-browns and blue-grays, supplemented by rust red and olive green accents, emphasizing “stable, industrial resilience, ecological restoration.” This clear mapping provides a direct basis for zoning control and color design[20].

5. Construction of the Color System for Wuhan Historic City

5.1 Technical Specifications for Color Matching

To ensure scientific implementation of the color system, this study formulated a multi-dimensional technical specification:

Harmony principle: The PCCS hue difference between primary and secondary colors shall be ≤15°, and value difference ≤3 levels (e.g., dark grayish tone dkg and dark tone dk) to ensure natural transition and overall harmony.

Contrast principle: The accent color shall have a hue angle difference of at least 30° from the primary color (e.g., light gray it vs. bright yellow b) to create moderate visual tension and avoid dullness.

Regional principle: In historic protection areas, the retention rate of traditional color schemes (PCCS hues 18–24, the warm-color range) shall not be less than 60%; new or renovated projects must be developed within this baseline.

Timeliness principle: Modern architectural schemes shall include at least one color that has emerged in the past decade (e.g., 202 Light Blue Gray) to reflect contemporary aesthetic evolution.

Prohibition rules: In historic districts, colors with chroma C*>20 are forbidden to avoid disrupting the antique atmosphere; along the riverfront landscape belt, dark tones with value V<4 are prohibited as main colors to prevent a oppressive feel; accent colors are not allowed on any continuous facade area ≥5 ㎡ to avoid visual chaos.

Dynamic updating mechanism: Every five years, re-extract current urban colors using K-means, and optimize the prohibited-color list based on public feedback; during summer high-temperature periods, dynamically increase the value of main colors to enhance reflectivity and help mitigate the urban heat island effect.

5.2 Zoning Color Planning

Based on the “two rivers, three towns” spatial structure of Wuhan, the main urban area is divided into three major color control zones, each with distinct strategies:

Hankou historical and cultural area: Covering the former concession, Jianghan Road, and Zhongshan Avenue historic districts. Primary colors are set as warm gray (PCCS hues 22–24, value 5–7, chroma 2–4) and off-white (hues 20–21, value 8–9, chroma 1–2); secondary colors use reddish-brown (hues 16–18, value 4–6, chroma 4–5); accent colors allow only low-chroma green (hues 12–14, chroma ≤3). New building facades must form a value gradient within 3 levels of adjacent historic buildings, and high-saturation colors are strictly prohibited. Key control targets include historic street frontages, commercial signage, and the riverfront skyline.

Wuchang modern science and innovation belt: Covering Optics Valley Central Business District, university parks, and East Lake High-tech Zone. Primary colors are light gray (hues 0–2, value 8–9, chroma 1–2) and light blue-gray (hues 22–24, value 7–8, chroma 3–4); secondary colors use medium gray (hue N, value 6–7) and silver-gray (hue 0, value 8, chroma 1); accent colors allow bright yellow (hues 8–10, chroma 7–8) or royal blue (hues 20–22, chroma 6–7). Innovation is encouraged, but value coordination with the East Lake Green Heart and Yellow Crane Tower scenic area is required to avoid excessive brightness contrast.

Hanyang-Qingshan eco-industrial complex: Covering Hanyang's old industrial base, Qingshan steel plant, and the riverside ecological restoration belt. Primary colors are gray-brown (hues 18–20, value 5–6, chroma 3–4) and dark gray (hue N, value 4–5); secondary colors are rust red (hues 16–17, value 5, chroma 5–6) and olive green (hues 10–12, value 5, chroma 4); accent colors are orange-yellow (hues 8–10, chroma 6–7). While retaining the metallic texture of industrial heritage, ecological green tones are integrated to shape a distinctive "industrial memory + ecological restoration" image.

Within each zone, further detailed color sub-items are specified according to building types (residential, commercial office, cultural/educational, industrial factories), and special control clauses are issued for special carriers such as bridges, riverside walkways, and historic building renovations to ensure overall coordination.

6. Feasibility Validation

To test the social acceptance and implementation feasibility of the above color scheme, a semantic differential questionnaire was designed. A total of 220 copies were distributed, and 200 valid responses were collected (response rate 90.9%). Respondents included Wuhan local permanent residents (40%), non-local residents working/studying in Wuhan (42%), planning/architecture/design professionals (2.5%), and tourists/short-term visitors (11%), with ages ranging from 18 to 60 and education mainly at junior college and bachelor's levels (77%), indicating good representativeness. The questionnaire contained 20 items divided into five dimensions: Emotional Semantic Resonance and Regional Identity (4 items), Aesthetic and Harmony Perception (4 items), Functionality and Comfort (4 items), Integration of History and Modernity (4 items), and Implementation Support and Personal Willingness (4 items), using a 5-point Likert scale.

Reliability analysis showed an overall Cronbach's α coefficient of 0.914, with dimension α values of 0.918, 0.924, 0.887, 0.918, and 0.890 respectively, all above 0.85, indicating high internal consistency. Validity analysis gave a KMO value of 0.897, and Bartlett's test of sphericity yielded an approximate chi-square of 2889.7 (df=190, p=0.000), suitable for factor analysis; all items loaded above 0.6 on their respective factors, confirming good construct validity. Descriptive statistics showed that the dimension "Emotional Semantic Resonance and Regional Identity" had the highest mean score of 3.52 (SD=1.15); "Aesthetic and Harmony Perception" mean was 3.00; "Functionality and Comfort" mean 3.01; "Integration of History and Modernity" mean 3.05; and "Implementation Support and Personal Willingness" mean 2.99—all dimensions were near or slightly above the theoretical midpoint of 3. In individual item evaluation, 61.5% of respondents considered the scheme "fitting" or "very fitting" with

Wuhan’s character, while only 15% expressed disagreement. Correlation analysis revealed a significant positive correlation between emotional identification and implementation willingness ($r=0.492$, $p<0.01$), indicating that enhancing public emotional resonance can effectively translate into support for implementation. Overall, the questionnaire results validate that this system has good public acceptance and implementation potential.

7. Conclusion

Aiming at the practical challenges of color management in Wuhan’s historic city, this study innovatively combines two-stage K-means clustering with PCCS semantic mapping to construct a data-driven, semantically associated, and dynamically updatable urban color system. The main achievements are summarized as follows: (1) Based on local chronicle records and field images, 25 core urban colors of Wuhan were extracted through two rounds of clustering, and standardized conversion from HSV to PCCS was completed, assigning each color a unique code and interpretable semantic label; (2) A three-level “primary-secondary-accent” structure was established, clarifying the roles of each level in area proportion, spatial distribution, and image expression, forming a synergistic mechanism of “primary sets the tone, secondary facilitates transition, accent activates”; (3) Color matching specifications covering harmony, contrast, regionality, and timeliness were formulated, along with prohibition rules for historic districts, riverfront areas, and large facade surfaces, and flexible strategies such as five-year dynamic updating and summer value lightening; (4) Based on the three-town functional divisions, differentiated color control strategies were proposed for the Hankou historical and cultural area, Wuchang modern science and innovation belt, and Hanyang-Qingshan eco-industrial complex, with further refinement by building type and special carriers. Questionnaire validation confirmed the system’s high public recognition and implementation feasibility. This research not only provides a scientific tool and decision-making basis for Wuhan’s color management, but also offers a reusable theoretical framework and technical pathway for digital color planning of other historic cities with complex historical layers and diversified functions. Future work will integrate real-time street-view image acquisition and deep learning algorithms to enable automatic monitoring and early warning of color evolution, advancing urban color governance toward intelligence.

Acknowledgements

Hubei Provincial Higher Education Postgraduate Teaching Reform Research Project, 2025, "Research on the Interdisciplinary Mechanism of Design Disciplines in Provincial Comprehensive Universities under the Background of 'Double First-Class' Construction" (2025714)

References

[1] LI W J. Urban Color Planning Control and Structuring under Urban Landscape Structure Taking Color Planning of Shangdang Town Cluster (1+6) for Example[J]. Housing Science, 2019, 39(02): 44-49.

[2] YANG M, LI X T. Urban Color Clustering Extraction Method Involved in Qingdao Cultural and Creative Products Development[J]. Packaging Engineering, 2020, 41(24): 262-268.

[3] HUANG Q, LIU K Y, HE Y, et al. Research on the Application of Color Acquisition Method and Process Design in the Protection of Ancient Buildings A Case Study of Yuelu[J]. Furniture &Interior Design, 2024, 31(02): 116-121.

[4] FU H, ZHANG S B, LI Q Y. Innovative Application of Traditional Colors of Guangxi ZhuangBrocade Based on HSV Colour Extraction and Colour Harmony Theory[J]. Packaging Engineering, 2025, 46(08): 334-344.

[5] CHEN T Y, XIAO W Q. Product Color Design Method Based on PCCS Color System and Grey Relational Analysis[J]. Packaging Engineering, 2023, 44(22): 259-266+321.

[6] CHEN J M, Ll Y. Capital City Color Planning Path Based on Urban Color Image[J]. Packaging Engineering, 2016, 37(20): 189-193.

[7] MIAO M R, XIONG J H, FENG L H, XU D W. Application Research of Regional Feature Correlation Packaging Color Based on Multi-source Data and K-means Clustering[J]. China Pulp & Paper, 2023, 42(03): 95-103.

[8] ZHA0 S L, ZHANG L L, Gu B F. Color Extraction and Analysis of Cheongsams in the Republic of China Based on Clustering Algorithm and PCCS System[J]. Journal of Silk, 2022, 59(11): 64-73.

[9] ZHANG J Y, Lu H Y, SHAO L L. Color Design of Geriatric Ward Based on Color Clustering[J]. Packaging Engineering, 2024, 45(12): 252-259.

[10] WANG G Y, Lu X. How Was the Color Harmony Thought Be Positioned and Applied in Japan's Landscape Color Planning[J]. Urban Planning International, 2021, 36(02): 117-124.

[11] LIU J. Talk about Urban Color Layout of Regionalism Taking Guangan as Example[J]. Shanxi Architecture, 2009, 35(03): 47-48.

[12] ZHANG H T, GUO J Y. Embodiment of Regional Urban Color Planning System Construction and Implementation of Countermeasures[J]. Urban Development Studies, 2016, 23(08): 17-21+32.

[13] CHEN C Y, LIU E G. City Color Planning from Perceptual Cognition to Quantified Governance[J]. Planners, 2019(2): 73-79.

[14] TAN H, CHU K F, ZHANG S Y. Architectural Color Style of Historical and Cultural Districts in Wuhan Based on GlS-A Case Study of Sanyang Design Capital[J]. Journal of Henan University of Urban Construction, 2024, 33(05): 65-72.

[15] XU Y, ZHOU Y. Color Control of Wuhan Historical and Cultural District Based on Large Scale Street View Images[J]. Huazhong Architecture, 2024, 42(05): 76-80.

[16] BAI G, WEN Y F, GANG W. The Control Method and Color Characteristics of the Street

Interface in Historical Districts: Taking Lihuangpi Road in Wuhan as an Example[J]. Huazhong Architecture, 2020, 38(03): 81-84.

[17] ZHUANG Y, TANG Z. Research on Color Planning System of Shanghai Songjiang New Town Sub Center Area Based on Color Continuity[J]. Architectural Journal, 2023(S2): 127-131.

[18] ZHANG M Y, GU Z T, CHEN Y C, et al. Construction and Method Exploration of Urban Color System Based on CAS Theory:A Case Study of Wangfujing Block in Beijing[J]. Shanghai Urban Planning Review, 2022(03): 30-37.

[19] YU Y D, JANG X J. Research on Urban Color Planning Control Based on the Combination of System and Flexibility: Taking Jiangcheng County as an Example[J]. Development of $mall Cities & Towns, 2020, 38(05): 29-38.

[20] JI X, ZHOU X D. The Language of Urban Architectural Colors[M]. Beijing: China