Frontiers of Architectural Research 10 (2021) 692—700

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.keaipublishing.com/foar

Higher Education Press

SOUTHEAST UNIVERSITY

RESEARCH ARTICLE

Quantitative contrast of urban agglomeration colors based on image clustering algorithm: Case study of the Xia-Zhang-Quan metropolitan area

Meichen Ding

Faculty of Architecture, Tan Kah Kee College, Xiamen University, Zhangzhou, 363105, China

Received 3 December 2020; received in revised form 21 April 2021; accepted 17 May 2021

KEYWORDS
City color;
Urban agglomeration;
Network image;
Clustering algorithm;
Computer vision

Abstract Color is an important element to consider when shaping urban characteristics. However, previous studies seldom included quantitative analyses of color relationships between urban agglomerations within proximal regions and with similar cultures to distinguish and shape individual urban personalities. This study focused on Xiamen, Zhangzhou, and Quanzhou metropolitan areas, which are influenced by Minnan culture, and collected natural and cultural landscape network images that collectively represent the urban landscape in China. Color extraction, computer vision processing technologies, and clustering algorithms, such as *k*-means partitioning, hierarchical methods, and co-occurrence frequency, were applied using image recognition. We then established an urban color database and quantified color attributes. Finally, we conducted a comparative analysis of dominant colors and color combination associations in Xiamen, Zhangzhou, and Quanzhou metropolitan areas to explore their similarities and differences and define their characteristics. We also considered other cities of the same type for comparison.

1. Background

1.1. Macrobackground: individual needs under the rise of urban agglomeration

Numerous and complicated connections exist among urban color, local geography, history, culture, traditions, and others.

E-mail address: dingmc@xujc.com.
Peer review under responsibility of Southeast University.

https://doi.org/10.1016/j.foar.2021.05.003
2095-2635/

Moreover, color is an important element of urban landscape that intuitively represents urban image and vividly shapes urban personality (Wang et al., 2010; Wu, 2009). However, the long-time neglect of urban color in China has led to the blind use of colors, particularly the large-scale abuse of traditional colors in cities. This disregard of urban color ultimately resulted in the convergence of urban colors and loss of urban characteristics (Dong et al., 2011; Wang, 2017; Day et al., 2013). Chinese cities have gradually shifted from "disorderly expansion" to "directional renewal." Urban color planning has been extensively explored and applied mainly to a selection of cities to renovate and reconstruct their buildings and street style (Zhang et al., 2014; Lu et al., 2019; Zhu et al., 2020) and shape the regional culture (Mehanna, 2019; Bao and Qiu, 2018; Wang and Wu, 2013; Jeong et al., 2015; Shi et al., 2013) in this context. Construction of high-quality and human-built environments has become a common objective for urban managers and builders. Notably, the rapid emersion of megacity groups (i.e., Beijing–Tianjin–Wing, Yangtze River Delta, Guangdong–Hong Kong–Macao, and Xiamen–Zhangzhou–Quanzhou) that has led to new characteristic images of Chinese cities is a new and increasingly evident urban phenomenon. Integration of economy, industry, and transportation has been realized in these megacities. Formulation of the urban landscape of a certain city is no longer limited to itself and needs to consider any associated sibling cities in this context. Finally, urban cultural characteristics of sibling cities should be considered to achieve a harmonious urban group landscape.

1.2. Current dilemma: status of urban color collection and analysis

Verifications of urban color status quo in China are mostly based on traditional methods, such as field investigations and shooting. For example, historical documents and on-site images have been collected and analyzed to determine the formation of urban colors and local visual environment (Dong and Xi, 2007), while field color card comparisons have been carried out to evaluate the current city color status in representative regions (Xu and Zeng, 2019). Furthermore, online and offline public color cognition surveys have been conducted for the collection of urban color subjective images and evaluations (Guo, 2020). These methods inevitably require a considerable amount of manpower and material resources, involve long research cycles, and fail to solve the contradiction between refined analyses and large-scale demands. The analysis of image color attributes showed that the overall tone can be summarized by referring to a coordinate system (Tian and Xu, 2015) and described in terms of grayscale characteristics and spatial color distributions, which can be visualized in color histograms (S. O. Abter and Abdullah, 2017). Moreover, RGB[1] or HSV[2] color space can be decomposed to create statistical charts of graphical attributes (Liu et al., 2016) or elaborated with an image processing software (i.e., MATLAB) for color extraction (H. Yadav et al., 2015). These procedures mostly focus on statistically describing single color attributes and exclude analyses of the combination relationship between colors. Hence, analyzing the inner logic of urban color systems without considering diverse types and combinations of colors occurring in cities is difficult.

1.3. New possibilities: network sharing of images, computer vision, and clustering algorithms

Network images with spatial location attributes have been widely used as open data for studies on the urban built environment with the advent of the big data era (Bahrehdar et al., 2020; Pantano Dennis, 2019). SegNet, histogram equalization, and other image recognition technologies based on the concept of "computer vision area" (Kansal et al., 2018; Bai et al., 2020) have recently become a tool for image quantization research due to their capability of efficient and accurate image data processing and pixel recognition (Long and Liu, 2017; Ye et al., 2018; L. Kennedy et al., 2007). The combination of network images and machine learning allows large-scale and quantitative measurements of urban colors. Clustering algorithms can provide solid classification logic when a large number of urban color analyses are carried out. This method is commonly used for image recognition, classification, and statistical analysis based on color and constituent elements in the field of computer vision (Jia et al., 2019; Saglam and Baykan, 2019; Wei and Zhang, 2020).

2. Research design

2.1. Research object and purpose

The Xia-Zhang-Quan metropolitan area, including Xiamen, Zhangzhou, and Quanzhou cities, which are close to one another in terms of geographical location, language, and culture, is representative of southeastern Fujian Province in China. Xiamen is a special economic zone and famous tourist city, Quanzhou has a long history and an important industrial economy, and Zhangzhou covers a vast area and is rich in agricultural ecological resources. The general public's impression of the Xia-Zhang-Quan metropolitan area relies on its cultural unity, which is blurred by geographical differences. Achieving regional integrated development while maintaining current urban characteristics is necessary to promote social and economic integration of the Xia-Zhang-Quan metropolitan area. We explored and analyzed similarities and differences among cities in terms of color characteristics in this study to determine the independent character of each city and general style of the city cluster as well as provide a basis for refined shaping of the brand of cities.

[1] RGB is a color space based on the variation and combination of the three color channels of red, green, and blue, through which a variety of colors can be obtained.

[2] HSV (hue, saturation, and value) is a color space first proposed by Smith (1978) and based on intuitive characteristics of colors also known as the "hexcone model." Color parameters in this model are hue (H), saturation (S), and lightness (V). Hue was measured in angle degrees, with values ranging between 0° and 360°; particularly, red varied between 0° and 10° and 156° and 180°, orange changed between 11° and 25°, yellow differed between 26° and 34°, green ranged between 35° and 77°, cyan fluctuated between 78° and 99°, blue altered between 100° and 124°, and purple adjusted between 125° and 155°.

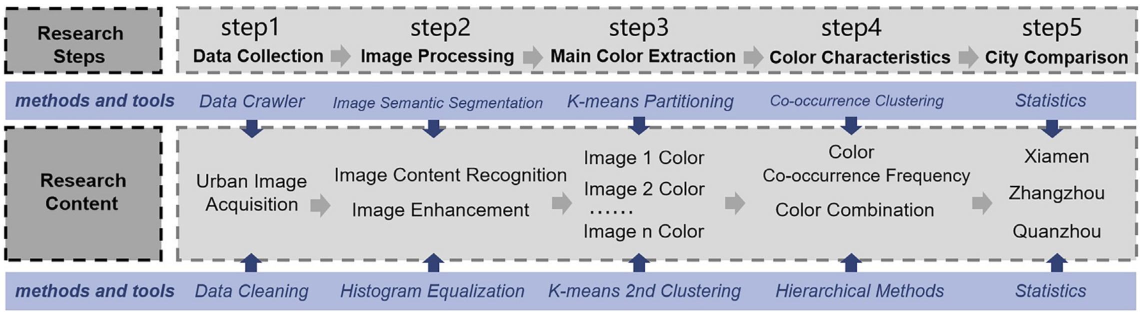

Fig. 1 Diagram of the technical route analysis.

2.2. Research steps

The research process includes the five main steps of data collection, image processing, dominant color extraction, color feature quantitative analysis, and intercity comparative research (Fig. 1). Travel websites are active platforms that showcase cities on the Internet and used as sources of image data for the construction of a city color library. Deep learning-based image recognition technologies, such as image semantic segmentation based on SegNet and histogram equalization based on Python, were used to enhance image effects and reduce the color interference in image processing. The *k*-means secondary clustering was then used to extract image dominant color features and build a library containing dominant colors on the basis of the corresponding HSV color space. Moreover, we analyzed characteristics of urban colors on the basis of group co-occurrence and a cohesive hierarchical clustering algorithm. Finally, the three cities of the Xia-Zhang-Quan metropolitan area with similar geographical locations and regional cultures were investigated using horizontal comparative analysis.

2.3. Image data collection and procession

1. Image data collection

Travel websites[3] in China, such as Ctrip, Mafengwo, and Qunar, are important network information platforms that have been used by people as a reference for planning trips in recent years. A large number of tourists share their knowledge concerning cities through text and pictures on the Internet. Accordingly, these websites can be used as major platforms for the acquisition of information about the appearance of cities. We selected all pictures of Xiamen, Zhangzhou, and Quanzhou from corresponding official tourism websites to ensure the objectivity of pictures used in this work and represent the investigated cities to a large extent. Notably, the number of submitted photos for the three cities reached 38,985, 12,140, and 22,581 on March 5, 2020. We considered the impact of touristic popularity on the number of photos shared and the issue of repetitive photo content. The top 30 scenic spots were selected as the main research objects of our investigation. The top 100 pictures of each scenic spot were chosen (3000 pictures of each city) for a total of 9000 pictures. The content of selected pictures includes important elements of city images, such as their rural landscape, urban landscape, and landmark historic buildings.

However, the selected pictures also contain additional and miscellaneous information. Hence, the results strictly depend on researchers' interpretation of picture content and ability to exclude undesirable elements, such as maps, activity scenes, and advertisement signs. Finally, 6000 pictures were selected, with 2000 of the most popular pictures of each city, and used in this study. All picture materials were saved and processed in one day due to the continuously changing nature of the Internet (Fig. 2).

2. Image data procession

Preprocessing of images during the collection of image materials through computer-aided means was necessary to determine the overall image of each city from pictures and display their colors accurately. Image preprocessing was mainly divided into two steps.

- Research-worthy information was extracted from images to reduce the influence of factors that cause color interference. Notably, the color of the sky changed considerably over time due to varying weather, seasons, and other conditions. We excluded the sky from analyses because it typically occupies large areas of images and exert a serious impact on the calculation results. Natural elements, such as green spaces and water bodies, are important components of urban color images given that large differences must be considered between urban geographical and ecological environments. A semantic segmentation algorithm based on SegNet (V. Badrinarayanan et al., 2017) was used to recognize different elements in images, such as sky, buildings, and green spaces. The corresponding results were used as the base to identify refined architectures and allow both environment recognition and optimization extraction.
- Histogram equalization was used to achieve image enhancement (Voronin et al., 2018). Grayscale and blurring problems linked to illumination intensity and imaging quality were removed to improve the local contrast and brightness of images. However, the overall contrast of images remained unaffected and the interference caused by image color recognition reduced.

[3] Ctrip: www.ctrip.com; Mafengwo: www.mafengwo.com; and Qunar: www.qunaer.com.

3. Analysis of urban dominant colors based on *k*-means clustering

Urban colors are generally divided into artificial and natural. Urban dominant colors represent the sum of all colors of objects exposed in urban public spaces (e.g., buildings, vegetation, and infrastructure).

3.1. Establishment of an urban color category database

The extraction calculation of each city's dominant colors was carried out by considering the color of pixels in city images and the respective composition ratio. We selected the HSV color space as the basic color context to achieve a "physical space—computer—visual perception" and quantify colors seen by the human eye. Notably, this color space is close to the human being's perception of color and description methods. The Python platform and the *k*-means algorithm were used to conduct full-pixel clustering of each city image. The specific procedure is described as follows.

- TMmain color clusters of 10 classes were included in a single picture (10 = number of colors to be extracted). Threshold values between 4 and 10 indicated a level of color abstraction close to that of the human visual space.
- Remaining data objects were assigned to clusters with highly similar centers. Similarity level is usually represented by the "distance" of cluster centers.
- The center of each cluster was recalculated after completing the distribution of objects. These steps were repeated multiple times and reached a maximum number of iterations. The results of each cluster showed no significant changes once the number of iterations exceeded 10.
- Characteristic colors of each city image were determined through calculations. Particularly, 10 colors can be obtained from each picture through clustering calculations while nearly 20,000 colors can be obtained for each city from 2000 images. All these colors reflected the overall color image of the corresponding city (Fig. 3). In addition, ratios and quantity of city colors were obtained at the same time to provide a basis for further analyses on the relationship between city colors.

3.2. Extraction of dominant urban colors

- Main color clusters of 10 classes were included in color category databases of Xiamen, Zhangzhou, and Quanzhou to determine 10 dominant colors for each city.
- Data of 20,000 colors collected for each city were assigned to clusters with highly similar centers, and a *k*-means secondary clustering extraction was conducted.

3.3. Dominant color analysis for the Xia-Zhang-Quan metropolitan area

We identified 10 representative colors through *k*-means secondary clustering extraction of the color database of the Xia-Zhang-Quan metropolitan area. Their respective proportions in each city were also extracted (Fig. 4). We then compared the hue, lightness, and saturation of representative colors according to the HSV color space information and considered the Munsell color value distribution (Fig. 5). Proportions of dominant colors in Xiamen and Zhangzhou showed a trapezoidal decline. This finding indicated that their proportions in Xiamen and Zhangzhou were clearly different although only 10 colors dominated both cities. Specifically, cool colors (e.g., light gray—white and light gray—blue) were more abundant in Xiamen, while neutral colors (e.g., gray and gray—brown) were abundant in Zhangzhou. Overall, these two cities were mainly represented by blue, orange, and green. By comparison, Quanzhou showed a balanced proportion and distribution of dominant colors, such as light gray—yellow, dark brown, yellow—brown, and other colors. The overall trend indicated a predominance of warm colors, such as orange—red.

The comparison of color attributes of Xiamen, Zhang, and Quan demonstrated clear homologies. Overall, their colors were concentrated between the YR—GY and BG—B color systems.[4] Each two adjacent positions were divided into 10 equal parts to obtain a total of 100 parts, and the hue interval was uniformly distributed. However, colors pertaining to the same color system showed significant differences between cities in terms of proportion, lightness, and saturation. Color images of Xiamen mainly include the sea, plants, and modern buildings and are characterized by low saturation, high brightness, light red to light blue hues, and an overall pleasing effect to the eye that provides an impression of brightness and elegance. Color images of Zhangzhou were instead characterized by low saturation, low lightness, and a yellowish to blue—green hue. Overall, solid-colored and plain images provided the impression of a clam environment. Finally, color images of Quanzhou were characterized by low saturation, moderate lightness, and an orange—red to earthen yellow hue that provides an overall impression of warmness and simplicity. We investigate differences between cities in terms of color images to explore tie-in relationships among the 10 dominant colors further.

4. Analysis of city color combinations based on co-occurrence clustering

4.1. Establishment of the clustering formula

A color correlation analysis was carried out on the basis of 10 dominant colors previously identified for each city. First, we calculated how many of the 2000 images showed pairs of colors that appear simultaneously and then set the correlation degree between two colors as the sum of the number of coappearing images. Second, we calculated an

[4] Hue is part of the Munsell color system, where a 360° color ring is divided into five main colors that blend into one another and create five intermediate colors (R: red, YR: red—yellow, Y: yellow, GY: yellow—green, G: green, BG: green—blue, B: blue, PB: blue—purple, P: purple, and RP: purple—red).

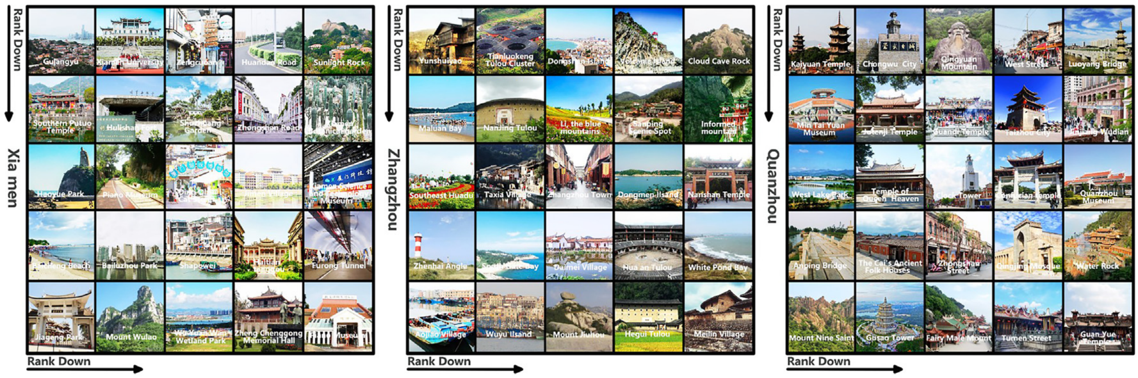

Fig. 2 Popular scenic spots in Xiamen (https://travel.qunar.com/p-cs299782-xiamen), Zhangzhou (https://travel.qunar.com/p-cs299781-zhangzhou), and Quanzhou (https://travel.qunar.com/p-cs299779-quanzhou) (made up of 75 different pictures. All of them come from the website Qunar (www.qunaer.com).

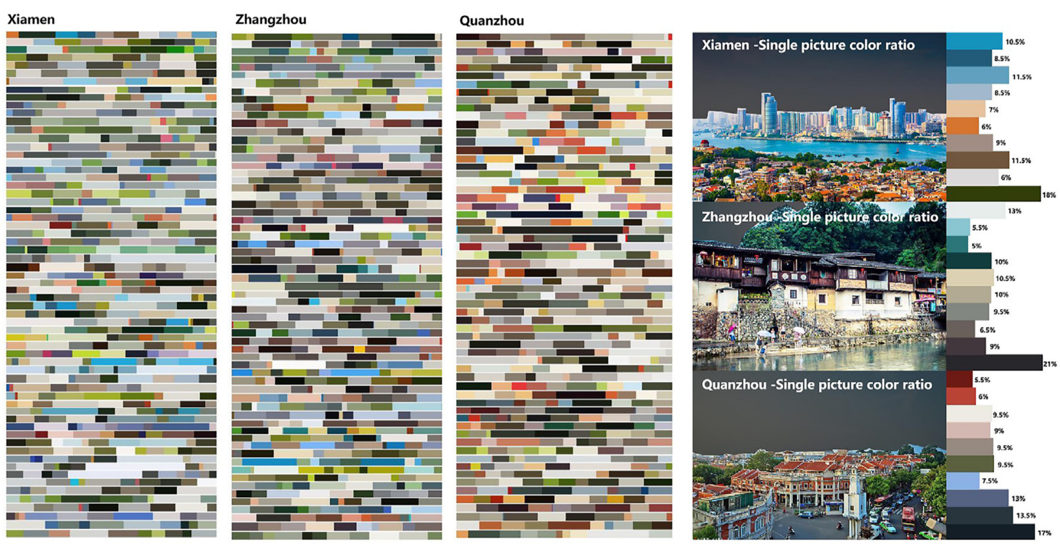

Fig. 3 Popular scenic spots in Xiamen, Zhangzhou, and Quanzhou.

adjacency matrix on the basis of correlation degrees between the 10 dominant city colors. Third, the visual image of the correlation intensity and its relationship between colors was calculated and plotted in the Python platform according to the adjacency matrix. Finally, the tree clustering algorithm in the SPSS statistical software was used for data processing and determining the topological structure and hierarchical network of each city's color images. The formula applied in this study is as follows:

(1) Constructing urban dominant colors' adjacency matrix Q_N

If colors i and j appear in the same photo at the same time, then they demonstrate co-occurrence association. We record number 1 as one time. N_{ij} represents the amount of co-occurrence of colors i and j in the city image database and reflects the degree of correlation between colors i and j. Accordingly, 10 dominant colors of each city are selected as analysis objects, where $i = \{1,2,3, \ldots \ldots,10\}$, $j = \{1,2,3, \ldots \ldots,10\}$, and $i \neq j$.

$$Q_N = \begin{bmatrix} 0 & N_{12} & N_{13} & \cdots & N_{1j} \\ N_{21} & 0 & N_{13} & \cdots & N_{2j} \\ N_{31} & N_{32} & 0 & \cdots & N_{3j} \\ \vdots & \vdots & \vdots & & \vdots \\ N_{i1} & N_{i2} & N_{i3} & \cdots & N_{ij} \end{bmatrix} \tag{1}$$

(2) Calculating the correlation intensity T_{ij} of urban dominant colors

The correlation intensity between colors i and j is significant after repeated calculation only when $N_{ij} > 50$. We set M_{ij} as the associated weight of colors i and j, where $M_{ij} = N_{ij}$ if $N_{ij} > 50$ and $M_{ij} = 0$ if $N_{ij} < 50$. $\overline{N}_{ij}$ refers to the amount of combinations of dominant colors with the significance to measure the correlation intensity, where $i = \{1,2,3, \ldots \ldots,10\}$, $j = \{1,2,3, \ldots \ldots,10\}$, and $i \neq j$.

$$T_{ij} = \overline{N}_{ij} \times \frac{M_{ij}}{\sum_{i=1}^{10} M_{ij}} \tag{2}$$

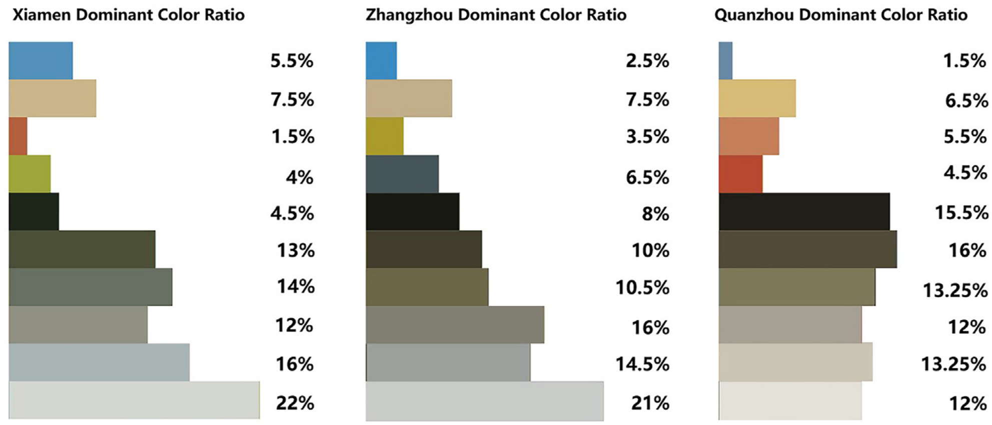

Fig. 4 Proportions between dominant colors in the Xia-Zhang-Quan metropolitan area.

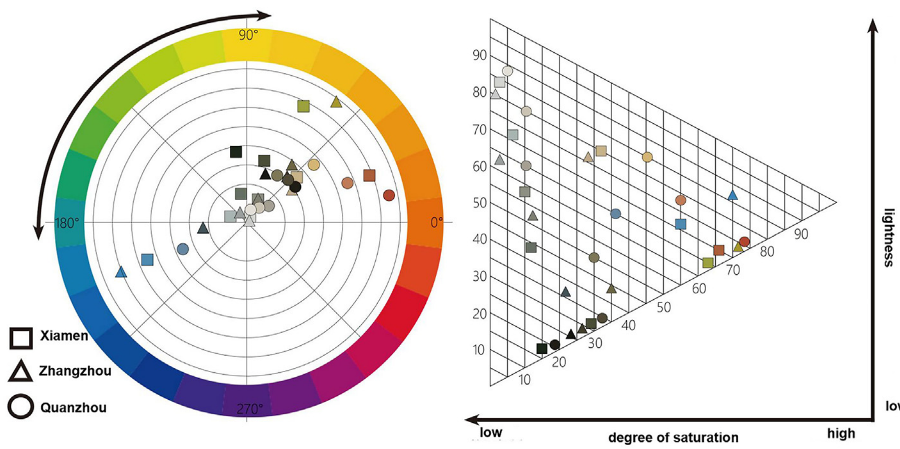

Fig. 5 Distribution of the HSV color space in the Xia-Zhang-Quan metropolitan area.

The SPSS statistical software was used for data processing. We determined the topological structure and the correlation strength among 10 dominant colors to recreate a co-occurrence cluster tree diagram and a hierarchical network on the basis of city color images.

4.2. Color correlation intensity in the Xia-Zhang-Quan metropolitan area

A color correlation line directly reflects the intensity of the interaction between two city colors (i.e., level of relationship between them). The number of dominant color correlation lines identified for Xiamen City was 33, with an average correlation intensity of 270. The correlation intensity between colors presented an evident normal uniform distribution at both poles. Six-tenths of main colors of the city were closely related to white—gray and presented high association intensities (particularly "white grayish light blue" and "white grayish blue gray" that correspond to intensities of 480). By comparison, only slight differences exist in association intensities of other color combinations. Xiamen's urban colors were mainly represented by white and gray, while regional characteristic colors were orange and red and environmental characteristic colors were blue and green. These colors were considered auxiliary colors in the city color system. Overall, the color matching for this city was balanced and highlighted (Fig. 6).

The number of color correlation lines identified for Zhangzhou City was 31, with an average correlation strength of 240. Notably, color combination types identified for this city were less than those of the previous one and the correlation strength was relatively low; in addition, color combinations with stronger correlation intensities were mostly concentrated around "light gray" ("light gray—light brown" showed the maximum correlation intensity of 510), while correlation intensities of other color combinations were considerably lower. The image expression of urban colors of Zhangzhou was unclear but presented evident tonal preferences. Earthy colors (e.g., earth brown and gray) predominated the entire city, with random co-occurrence frequency of other dominant color combinations.

Quanzhou showed 38 color correlation lines, with an average correlation intensity of 330. This city presented numerous dominant color combinations with similar correlation intensities. More than 60% of color combinations exhibited above-average correlation intensities, while the remaining color combinations demonstrated significantly lower intensities. This finding indicated a strong polarization of urban

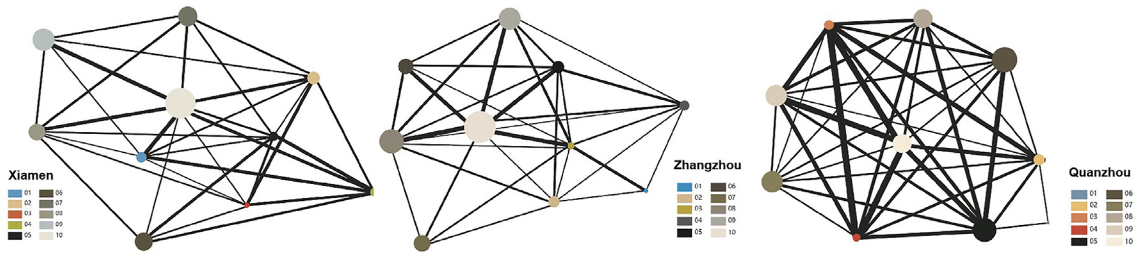

Fig. 6 Comparison of color correlation intensities in Xia-Zhang-Quan metropolitan area.

color correlation lines. The strongest color correlation for this city was "orange—red—light red" (750) and the co-occurrence frequency was significantly higher than that of the two other cities. Although characteristic colors of Quanzhou City in southern Fujian account for only a small proportion, this city's color combinations were extremely evident. In this case, urban color combinations were evenly distributed among light gray, yellow—gray, light brown, dark brown, and gray—black instead of being concentrated in a single color system.

This analysis suggested that Xiamen, Zhangzhou, and Quanzhou show clear differences in the type of correlations and correlation intensities despite their homologous color systems. Quanzhou showed particularly evident urban color combinations and a large variety of color distributions while Xiamen and Zhangzhou presented a strong dominance of one or two color combinations from the perspective of color matching. Xiamen showed a balanced distribution of urban environmental and architectural color combinations while Zhangzhou and Quanzhou demonstrated a predominance of urban architectural color combinations from the perspective of color types. Notably, urban colors of Quanzhou better reflected the regional architectural color combinations compared with those of Zhangzhou.

4.3. Color hierarchy network for the Xia-Zhang-Quan metropolitan area

City colors were divided into levels 1 (0—5), 2 (5—10), 3 (10—15), 4 (15—20), and 5 (20—25). A high color level indicates significant corresponding colors in the context of urban color building. The co-occurrence clustering dendrogram of the Xia-Zhang-Quan metropolitan area in the network image showed different color hierarchical relationships (Fig. 7). Quanzhou City showed distinct dominant color hierarchies, with all levels uniformly distributed and a stable hierarchical structure from the perspective of hierarchical distribution. By comparison, Xiamen and Zhangzhou presented an unstable color hierarchy. For example, the majority of Zhangzhou's dominant color levels were low and presented central dispersion. The five color levels in Xiamen and Zhangzhou all corresponded to gray—white and these cities exhibited the maximum proportion of dominant colors from the perspective of color force. Meanwhile, Quanzhou was dominated by orange—red and showed the third lowest proportion of dominant colors. Color clusters of Quanzhou were mostly hierarchically layered within the same color system or among similar colors while those of Xiamen reflected the combination and classification of color brightness (from light to dark) from the perspective of hierarchical network combination. Finally, color clusters of Zhangzhou were scattered and unorganized.

These results indicated that Quanzhou develops a color combination system with hierarchical rules and stable characteristics through its architecture and built environment. Notably, its primary and secondary colors appeared to be fixed and theme colors were clear. These elements were generally reflected in color images of its buildings to show a vivid and distinct regional architecture. Xiamen's urban color hierarchy system clearly appeared to be under construction and development, as indicated by the uneven distribution of levels obtained through color matching. Therefore, the crucial architectural and environmental colors, combinations and matching of theme and auxiliary colors, and other characteristics are still unclear for this city. Moreover, the overall color image of this city is subjected to the influence of buildings, which accounts for the majority of background colors, and results in partially blurred urban characteristics. Compared with those of the

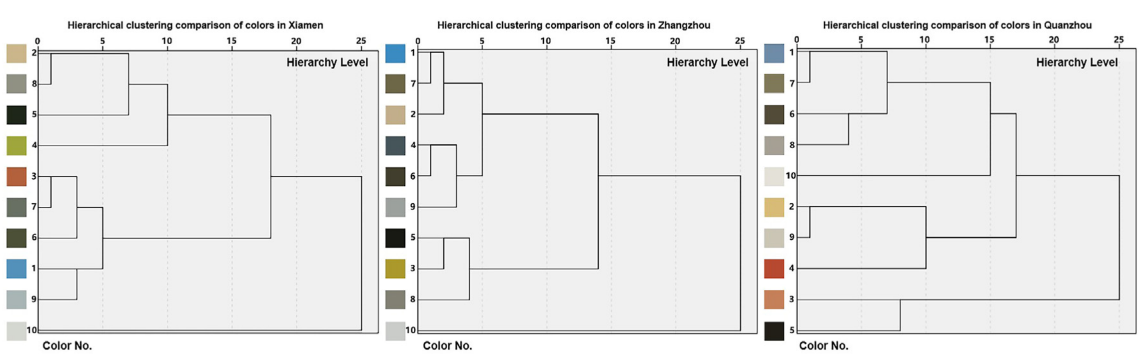

Fig. 7 Hierarchical clustering comparison of colors in Xiamen, Zhangzhou, and Quanzhou.

first two cities, the urban color hierarchy system of Zhangzhou was clearly polarized. Some color relationships were identified within color systems, but irregular color combinations were also observed. Additionally, overall hierarchical relationships were loose and clear urban color relationships were undetected.

5. Conclusion and outlook

5.1. Comparison of urban color characteristics in the Xia-Zhang-Quan metropolitan area

The results of this study clearly reflect similarities and differences of color statuses among cities based on color quantification. Colors of Xiamen, Zhangzhou, and Quanzhou influenced by culture, environment, urban constructions, and other factors clearly showed some common elements as well as combination differences. Colors and phase intervals of Xiamen, Zhangzhou, and Quanzhou were basically the same but differences in proportions of color systems as well as the color lightness and saturation were unclear from the perspective of color properties. Dominant color properties of cities were significantly influenced by built and natural environments, and the composition of their color systems depended on different regional cultures. Color combinations of the three cities demonstrated high overlap rates, but evident differences existed in hierarchical relationships and the number of color combinations. For example, Quanzhou showed a mature color hierarchy network and diverse colors. Additionally, urban colors of Xiamen and Zhangzhou were affected by the geographical environment and their combination of colors showed unstable relationships with only one dominant color. Hence, we can infer that color combinations in urban and building environments must be considered to attain a defined color network although Xiamen is characterized by a "bright and refreshing" color impression. Although Zhangzhou is surrounded by diverse natural features and world cultural heritage architectural attractions, improving its color suggestions and the organization of the color impression in its main urban areas is still necessary. The results of our study can provide a solid base for the improvement and construction of the human settlement environment in these three cities.

5.2. Prospects and shortcomings

We introduced a new urban color research plan based on the comparison and exploration of cities included in the Xia-Zhang-Quan metropolitan area. The results of our study proved that the proposed research method is feasible and reasonable. However, our study presents certain limitations due to limited data sources and research techniques at present. Notably, network pictures are affected by multiple complex factors, such as photographer, shooting time, environmental status, and image processing, and completely eliminating the color calibration deviation associated with image types is difficult. Therefore, exploring new intelligent learning algorithms is necessary to improve the accuracy of color recognition further. The scope of research will be expanded and the number of research objects will be increased in future investigations to explore the improvement space of research algorithms comprehensively.

Declaration of competing interest

The authors declare no competing interest.

Acknowledgments

This research was funded by the Xiamen University Tan Kah Kee College 2019 School-level Research Incubation Project (YY2019L04). I would like to acknowledge the support of my supervisor Yan Liu, who has encouraged me to start investigating the combination of algorithm analysis and urban landscape design.

References

Abter, S.O., Abdullah, N.A., 2017. An Efficient Color Quantization Using Color Histogram. 2017 Annual Conference on New Trends in Inforation & Communications Technology Applications. NTICT), Baghdad, pp. 13—17.

Badrinarayanan, V., Kendall, A., Cipolla, R., 2017. SegNet: a deep convolutional encoder-decoder architecture for image segmentation. IEEE Trans. Pattern Anal. Mach. Intell. 39 (12), 2481—2495.

Bahrehdar, A.R., Adams, B., Purves, R.S., 2020. Streets of London: using Flickr and OpenStreetMap to build an interactive image of the city. Comput. Environ. Urban Syst. 84, 101524.

Bai, Z.J., Yang, K., Xie, L.M., Lee, J.L., Gao, X.R., 2020. A histogram equalization algorithm based on building a grey level binary tree dynamically. Optik - Int. J. Light Electr. Optic. 224, 165695—165701.

Bao, X.W., Qiu, H.Y., 2018. Foreign experience on Urban colour construction and the enlightenment of Shanghai. Shanghai Urban Plan. Rev. 4, 115—118.

Day, K., Alfonzo, M., Chen, Y., Guo, Z., Lee, K.K., 2013. Overweight, obesity, and inactivity and urban design in rapidly growing Chinese cities. Health Place 21, 29—38.

Dong, Y., Xi, L.S., 2007. Formation, evolution and development suggestion of Urban color, example of Urban color planning in Tianjin. Huazhong Archit. 12, 57—60.

Dong, C., Wang, Y.H., Zhang, X.Y., Yuan, S.Q., 2011. Research of Jingdezhen Urban color based on the identifiability. Packag. Eng. 22, 12—15+18.

Guo, A., 2020. Discussion on Shanghai's urban color creation. Sci. Dev. 2, 72—78.

Jeong, J.S., Montero-Parejo, M.J., García-Moruno, L., Hernández-Blanco, J., 2015. The visual evaluation of rural areas: a methodological approach for the spatial planning and color design of scattered second homes with an example in Hervás, Western Spain. Land Use Pol. 46, 330—340.

Jia, C., Wu, G., Kong, F., 2019. Image significance region detection based on global color clustering and contrast. In: 2019 IEEE 4th International Conference on Signal and Image Processing (ICSIP), Wuxi, China, pp. 930—933.

Kansal, S., Purwar, S., Tripathi, R.K., 2018. Image contrast enhancement using unsharp masking and histogram equalization. Multimed. Tool. Appl. 20 (77), 26919—26938.

Kennedy, L., Naaman, M., Ahern, S., Nair, R., Rattenbury, T., 2007. How flickr helps us make sense of the world: context and content in community - contributed media collections. In: Proceedings of the 15th ACM international conference on Multimedia, ACM, pp. 631—640.

Liu, X.J., Cao, Y.J., Zhao, L.X., 2016. Color networks of traditional cultural patterns and color design aiding technology. Comput. Integr. Manuf. Syst. 22 (4), 889—907.

Long, Y., Liu, L., 2017. How green are the streets? An analysis for central areas of Chinese cities using Tencent Street View. PloS One 12.
Lu, X., Li, Y.F., Liang, D., 2019. Research on urban color of Yuncheng based on typically traditional architecture color. J. Shenyang Jianzhu Univ.(Soc. Sci.) 21 (3), 245—251.
Mehanna, W.A.E.H., 2019. Urban renewal for traditional commercial streets at the historical centers of cities. Alexandria Eng. J. 58 (4), 1127—1143.
Pantano, E., Dennis, C., 2019. Store buildings as tourist attractions: mining retail meaning of store building pictures through a machine learning approach. J. Retailing Consum. Serv. 51, 304—310.
Saglam, A., Baykan, N.A., 2019. Evaluating the attributes of remote sensing image pixels for fast k-means clustering. Turk. J. Electr. Eng. Comput. Sci. 27, 4188—4202.
Shi, J.R., Duan, Y.Y., Cui, Y.Y., Zhao, X.M., 2013. The research of regional Coastal City color: a case study of Qinhuangdao urban color planning. Ecol. Econ. 10, 188—191.
Tian, S.X., Xu, L.J., 2015. Comparison between China's and Japan's color culture: the color image based on national mentality. J. Shenzhen Univ. (Human. Soc. Sci.) 32 (4), 13—18.
Voronin, V., Tokareva, S., Semenishchev, E., Agaian, S., 2018. Thermal image enhancement algorithm using local and global logarithmic transform histogram matching with spatial equalization. In: 2018 IEEE Southwest Symposium on Image Analysis and Interpretation (SSIAI), Las Vegas, NV, pp. 5—8.
Wang, F., 2017. Born of geographical environment, coloring for regional context: concept and progress of geo-architecture. J. Geogr. Sci. 27, 631—640.
Wang, Z.Z., Wu, Y.M., 2013. Research on city color scape of Japan. City Plan. Rev. 4, 89—96 (In Chinese).
Wang, Y.H., Zhang, X.Y., Yuan, S.Q., 2010. Color geography theory and its development in China. Trop. Geogr. 3, 333—337.
Wei, X.Q., Zhang, Y.E., 2020. Image segmentation algorithm based on dynamic particle swarm optimization and K-means clustering. Int. J. Comp. Appl. 42 (7), 649—654.
Wu, W., 2009. Urban Landscape Planning: Urban Color Special Planning. Southeast University Press, Nan Jing, Chian, pp. 21—33.
Xu, Q., Zeng, L., 2019. Research on the method of urban color planning based on regional characteristics—take Guilin City as a example. Hous. Sci. 39 (12), 9—13+19.
Yadav, H., Bansal, P., Sunkaria, R.K., 2015. Color dependent K-means clustering for color image segmentation of colored medical images. In: 2015 1st International Conference on Next Generation Computing Technologies. NGCT), Dehradun, pp. 858—862.
Ye, Y., Zhang, L.Z., Yan, W., et al., 2018. Measuning street greening quality from humanistic perspective: a large-scale Analysis based on Baidu street view images and machine learning algorithms. Landsc. Architect. 25 (8), 24—29.
Zhang, H.W., Shen, Q.P., Wang, H., 2014a. A review of recent studies on sustainable urban renewal. Habitat Int. 41, 272—279.
Zhang, S., Liu, Y.J., Nie, H., 2014b. Geographical feature based research on urban color environment - taking Wuhan as an example. IERI Procedia 9, 1900—1951.
Zhu, X., Ye, Z.N., Huang, S.S., 2020. Urban color planning and management in urban built environment: a case study of Putuo district of Shanghai. Shanghai Urban Plan. Rev. 3, 75—81.