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Impressions of Guangzhou city in Qing dynasty export paintings in the context of trade economy: a color analysis of paintings based on k-means clustering algorithm

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Abstract

Study on export paintings has gradually shifted from artistic form to cultural connotation, with an emphasis on cross-cultural communication. Although the economic and social dimensions of their artistic value have been explored, few studies delve into the connection between Qing-era Guangzhou's trade culture and its color characteristics. Utilizing the HSV color model and the k-means algorithm, this study analyzes the color traits of 35 export paintings depicting Guangzhou landscapes and works from the "Thirteen-houses commercial zone," revealing Qing-era Guangzhou's urban impressions and Sino-Western artistic interactions. Key findings include: (1) the hue pixel range in Guangzhou export paintings primarily spans 10°–60° and 120°–250° (dominated by red and yellow-green), saturation values range from 1–82% (primarily low saturation), and value values range from 11–94% (with a wide variance); (2) compared to traditional Chinese paintings, the transformation from pure color (正色) → inter-color (间色) → projection-perspective and light source illustrates both the blending of Eastern and Western artistic cultures and a diminishing influence of traditional ceremonial culture; (3) in contrast with Western artworks, some Guangzhou export paintings display a Westernization trend in color structures, evident in vibrant colors and stark chiaroscuro contrasts. As bespoke art commodities, export paintings microscopically reflect Guangzhou's unique trade culture and socio-political dynamics. The shifts in color schemes, integration of realistic styles, and human-centric characteristics unveil the intricate interplay between quasi-realism and transcendental aesthetics in Qing-era Guangzhou, as well as the nuanced dynamics between social capital and art within a global trade network.

Keywords Commercial culture, Qing dynasty, Export paintings, Guangzhou, K-means clustering, Color, Urban impression, Murals, Western painting

Introduction

Visual arts authentically reflect the societal landscapes and humanistic ideologies of specific eras, elevating from pure formal language to the realms of semiotics and anthropology [1]. Since the release of the United Nations Convention for the Safeguarding of the Intangible Cultural Heritage in 2003 [2], the safeguarding and restoration of tangible cultural heritage has been gradually emphasized [3, 4], and early visual arts heritage has also begun to receive attention. In eras preceding advanced replication and dissemination technologies, visual

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cultural heritages, superior to verbal and written communication, became primary conduits for understanding the past and experiencing traditions. As "art commodities," this paper spotlights the unique structures and values of the color palettes in export paintings—a visual testament to the fusion of Eastern and Western artistic cultures along the Silk Road.

The Maritime Silk Road's propulsion of "western art moving eastward" and the specificity of the late Qing to early Republic era in this study necessitate elucidation. Export paintings, as unique art commodities, served as tangible extensions of 18th-century Baroque and Rococo styles into Chinese art [5]. With the opening of new maritime routes in the late fifteenth century, Portugal increasingly monopolized trade between Europe and the Far East [6], leading to a scenario of "eastern artifacts to the west" and "western technology to the east." By the late seventeenth century, Chinese export paintings had already been disseminated to Spain, the Netherlands, and Britain [7], introducing Eastern cultural philosophies to European art circles. As a pivotal hub of the Maritime Silk Road, the art of export paintings in the Guangzhou region peaked during the Qing dynasty [8]. However, with the introduction of camera technology in the late Qing to early Republic era, the art of Guangzhou export paintings began to wane.

Currently, with the rise of heritage economy [9], export paintings with merely social attributes are increasingly marginalized. This is evident in the limited scope of their artistic feature categorization, insufficient depth in exploring their historical value, lack of commitment in heritage conservation, and a lack of innovation in element design and application. Such trends suggest that contemporary art recreations based on these export paintings are superficial, reflecting a certain loss of Guangzhou's unique export culture. The 2022 Guangdong Provincial Museum's exhibition on "Visual Art Adjustments between China and the West during the 18–19th Centuries" was primarily aimed at disseminating cultural values and emphasizing its role as a visual template to experience past cultural ambiances [10]. The China Interior Decoration Association underscores that cultural exploration is the foundation for enriching the essence and cultural heritage in recreations [11]. While the protection, inheritance, and restoration of cultural heritage have been strengthened in the latest "Fourteenth Five-Year" cultural development plan [12], efforts in the preservation and cultural inheritance of export artifacts remain insufficient [13]. The essence of modern cultural restoration has elevated to protect superior cultural phenomena, emphasizing the extraction and propagation of elite cultural genes to adapt to contemporary demands and rejuvenate their significance.

Historically, export paintings catered to the Western fascination with Eastern culture, aligning with their imagined and aesthetic appreciation of the "Oriental Civilization." Presently, export paintings serve as evidence of Guangzhou's foreign trade and the evolution and integration of Chinese and Western cultures. With the enforcement of the sea ban policy from 1757–1842, the Guangzhou Thirteen-houses were designated monopolies for foreign trade [14]. The emergence of Guangzhou export paintings can be traced back to numerous art studios within the commercial streets of Guangzhou Thirteen-houses. Given that the clientele was predominantly foreigners, the color schemes of Guangzhou export paintings merged Western aesthetics while retaining some traditional elements. Yet, due to their commercial nature, their artistic value garnered extensive attention.

Both Wappenschmidt [15] and Qian [16] explored the relationship between the production of export wallpapers and their economic characteristics, suggesting that these Chinese wallpaper designs popular in Europe reflected class differences and integrated Western aesthetics. De Bruijn [17] noted that advancements in 18th-century wallpaper production technology led to its secularization, with Chinese wallpapers initially popular in Britain and Ireland no longer being a privilege of the nobility. Changes in wallpaper production costs and its popularization further influenced its artistic application in interior design. De Bruijn [18] discovered the significant economic impact on the artistic creation of Chinese export wallpapers. Although these wallpapers retained Oriental characteristics, their primary purpose for production was economic gain rather than cultural dissemination. Sevänen [19] believes that the evolution of European painting art in the eighteenth century towards a more independent and purer direction resulted from the industrial production and extensive application of wallpapers. In contrast, Chinese wallpapers had a minimal influence on traditional art during this period, with traditional Chinese painting maintaining its prestige and continuing to evolve.

Wu [20] discerned that Chinese export wallpapers, to some extent, mirror colonial economic control and hegemonic politics. They bear political connotations, serving as a foundation for Westerners to construct visual experiences of Eastern culture. Rostislav [21] observed that some Qing Dynasty export wallpapers exhibit urban marketplace styles, targeting not the aristocracy or elite but the common populace. The artists too were ordinary people, and as a result, the content reflects a genuine and vivid urban ambiance. Jiang [22] identified that, compared to painting techniques, wallpapers from Sino-British exchanges prior to the Opium War prioritized color application and pattern diversity. This likely

stems from the varying market demands and aesthetic values between the two nations. Bevan et al. [23] noted that 18th-century British Chinoiserie wallpapers catered to European fantasies of the Orient while also mirroring the class and status distinctions within British society. McClintock et al. [24] emphasized that the popularity of Chinese export wallpapers in international outreach wasn't purely commercially motivated; there was a genuine longing and demand for foreign cultures, thus reflecting socio-cultural transitions.

The trajectory of related research shifted from focusing on artistic form to content and then cultural connotations, ultimately reaching the dimension of national identity in decorative arts and cross-cultural exchanges. Studies on the colors in export paintings offer two perspectives: (1) economic attributes—an amalgamation of capital, aesthetics, and cultural collisions due to Sino-Western trade. This unravels the emergence of a commercial art market in Qing-era Guangzhou, where Eastern and Western cultures intertwined; (2) social attributes—a material representation of societal progression, symbolizing societal hierarchies, status differentiations, aesthetic preferences, and a spectrum of life experiences. Presently, few scholars employ quantitative methods to dissect the color composition of Guangzhou's export paintings or investigate their chromatic differences from traditional and Western paintings, and there's a scarcity of studies probing the deeper societal relations underpinning these color patterns.

Researching the color composition of Qing-era Guangzhou export paintings assists in elucidating their distinctive coloristic attributes, uncovering the cultural implications and artistic values they embody, and the historical confluence of Eastern and Western traditions. Throughout the mutual appreciation between Eastern and Western civilizations, export paintings play a pivotal role, serving as historical testimonies through visual representations. A plethora of series, museum collections, and archival resources have consolidated most of the information on Qing-era export paintings, forming the foundation for this paper.

This study initially involved the collection and statistical analysis of 35 sample data sets. Utilizing the HSV (Hue, Saturation, Value) color model, combined with the k-means clustering algorithm, the research extracted and analyzed the color information of these samples. This approach facilitated the identification of overarching color compositions and patterns. Subsequently, a focused color clustering was conducted on the architectural, commercial, and natural elements within the samples to unveil the color characteristics inherent in these micro-themes and scenarios. Furthermore, the research integrated color quantification data to draw comparisons between the color applications in the samples and those found in traditional Chinese and Western paintings. This comparative analysis aimed to elucidate the distinctive differences in color utilization between these artistic traditions.

Methodology

Definition of export painting and clarification of the scope of the study

Early export paintings were referred to by artists as "Western paintings (洋画)" and termed as "Chinese paintings" by overseas buyers. By the mid-twentieth century, they were identified in Western art history as "Chinese export paintings (中国外销画)" or "Chinese trade paintings (中国贸易画)." Presently, the term "export paintings" has gained a clear definition and widespread acceptance: artworks created primarily for foreign merchants and tourists in places like Guangzhou from the eighteenth century to the early twentieth century [25]. Paintings collected abroad that were not intended for export are not categorized as export paintings [26]. These paintings, as diverse as nine categories, covered themes reflecting China's political, economic, military, religious, societal, cultural, and biological domains during that period [27].

Since the establishment of the Cantonese Thirteenhongs in 1757, an entity designated by authorities to monopolize foreign trade, Guangzhou emerged as the sole port of international commerce in China [28]. As a hub of commercial trade and multicultural integration, Guangzhou's unique context in the eighteenth century provided a pivotal social and material foundation for the genesis and evolution of export paintings. These artworks, enriched by their economic implications, stood in stark contrast to traditional Chinese painting. Poel [29] categorizes export paintings as "commodity art," noting that their economic attributes are profoundly reflected in their artistic characteristics, distinctively differing from traditional Chinese painting (Table 1). This shift not only reveals the historical context of Qing Dynasty China's foreign trade and cultural exchanges but also illustrates the adaptation and transformation of Chinese art in a globalized context. The focus of this study on the post-18th-century scenario stems from the significance and value embedded in this historical backdrop.

k-Means clustering method

In 1967, Macqueen [30] from the University of California first elucidated the term "k-means," defining it as an iterative clustering analysis method. The milestone contributions of Macqueen's research work are outlined as follows [31–36]: (1) formalization and standardization of the algorithm: the study meticulously described and defined the KMA, laying a solid foundation for

Table 1 Comparison of the artistic styles of Guangzhou export paintings and traditional murals

Types	Characterstics	Pictures	
Exported Paintings	Convergence of character images. The standardized mode of production leads to the homogenization of character images and expressions, showing a commercialized and popular aesthetics		
	The richness of the painting colors. To meet the demands of the Western market, the artist has adopted a wider range of colors, moving from traditional Chinese orthochromatic colors to Western-style intertone and mixed colors		
	Diversity of painting themes. No longer dominated by courtly themes, more simple themes of local life were depicted, catering to the Western curiosity about Chinese culture		
Murals	Characters have a large proportion in the painting to highlight the story of the characters, while the landscape and other elements of the painting mainly serve as a backdrop		
	The painting colors are dominated by orthochromatic colors (solid colors that are not coordinated), and there is a lack of coordination of color transitions from element to element		
	The thematic content is mainly divided into two categories: character scenes and landscapes, while the content description is abstract and partially exaggerated, expressing more allegorical and cultural symbols		

subsequent advancements and applications in this domain. This formalization process included not only a mathematical representation of the algorithm but also encompassed guidelines and constraints for its application across diverse datasets. This comprehensive approach significantly contributed to the algorithm's widespread adoption and standardization; (2) enhanced computational efficiency: Macqueen's work significantly improved the computational efficiency of the KMA, enabling it to process large datasets more effectively. This enhancement has been instrumental in facilitating the handling of increasingly voluminous and complex data in various fields; (3) promotion of data mining and pattern recognition: through applied research on the KMA, Macqueen's work fostered the broad application of the algorithm, particularly in areas such as customer segmentation, image processing, and market analysis. This promotion has played a pivotal role in advancing the fields of data mining and pattern recognition by demonstrating the practical utility and versatility of the KMA in real-world scenarios.

The operational mechanism of KMA is mainly based on the approximate analysis of the sample distribution of data points for data segmentation. Its objective is to aggregate n data points into k clusters, optimizing each cluster's centroid through iteration, thus minimizing

intragroup variance and ensuring data homogeneity within clusters. Clustered data point averages predominantly influence similarity calculations. For identifying inherent clustering centers in data, KMA exhibits parallels with the expectation–maximization algorithm designed explicitly for Gaussian mixtures [37]. However, KMA presents evident advantages in data processing speed and computational precision, especially when handling extensive sample data.

KMA has been widely utilized in color analysis. Thompson et al. [38] proposed a novel color quantization (CQ) method based on the online k-means formula, using adaptive and efficient cluster center initialization and quasi-random sampling to achieve deterministic, rapid, and high-quality quantization [39]. By integrating the Analytic Hierarchy Process (AHP), Zhao et al. [40] introduced the GRA-TOPSIS evaluation method to rank and rate ethnic minority costume color schemes, finding KMA beneficial for refining color scheme designs. Based on KMA, Basar et al. [41] introduced an innovative adaptive initialization technique in RGB histogram analysis to determine the number of clusters and locate initial cluster centroids, assisting the standard k-means algorithm in tackling color image segmentation challenges.

The K-Means Algorithm (KMA) is a distance-based clustering technique, whose core mechanism involves determining a preset number of clusters (the K value) and iteratively assigning data points to these clusters, followed by recalculating the centroids [42]. In this method, initial cluster centers are randomly selected, and data points are assigned to these centers based on the distance to each. Subsequently, the centroid of each cluster is updated to be the mean of all points assigned to that cluster. This process is repeated until specific iteration termination criteria are met.

In the application of the K-Means Algorithm (KMA) to image color analysis, the initial step involves setting the target number of clusters, denoted as K (the number of cluster centers). Subsequently, for each pixel, its color value distance to each cluster center is calculated as D (Eq. 1), and the pixel is assigned to the nearest cluster center. Thereafter, the color values of all pixels within each cluster are averaged to update the cluster centers. This computational process is continued until the predetermined iteration termination criteria are met, typically using the mean squared error, a (Eq. 2), as this criterion. The algorithm concludes when the differences between results of consecutive iterations are less than 1, at which point the output cluster center values represent the extracted target color values. This method optimizes the clustering results through successive updates of the centroids during each iteration, ultimately achieving the convergence criteria of the algorithm.

$$D = \sqrt{\left(r - r_{i)-(}g - g_i\right) - \left(b - b_i\right)^2} \tag{1}$$

In this equation, D is the distance from the pixel point to the center of the cluster; r,g, b is the color value of the center of the cluster; and r_i,g_i,b_i is the color value of the other pixels.

$$a = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)^2} \tag{2}$$

In this equation. a is the mean square error; n is the number of pixel points in the cluster; x_i is the pixel points in the cluster; and μ is the arithmetic mean of all pixel points in the cluster.

HSV (hue, saturation, value) color model

In the application of the K-Means Algorithm (KMA) for clustering in image color analysis, several color space models such as Lab, RGB, HIS, and HSV are commonly utilized. The Lab color space is a uniformly distributed color space. Although its conversion process is complex, and the resulting data format is more suitable for determining color segmentation criteria, its direct application in KMA analysis is somewhat limited [43]. The RGB color space, comprising three independent dimensions of R, G, and B, presents a cubic form, effectively and intuitively reflecting data. However, the interrelated nature of the R, G, and B colors creates a strong correlation among these dimensions, making it challenging to express color change patterns through variations in these three values [41].

In clustering algorithm applications, HIS (Hue, Intensity, Saturation) and HSV (Hue, Saturation, Value) color space models often require specific spatial transformations, as their original compositions are not ideally suited for direct use in clustering analysis due to the complexity involved in their computations [44]. Nevertheless, these color space models demonstrate significant capabilities in color difference recognition, particularly in assessing the density of clustering results [28]. This characteristic gives them a unique advantage in processing color-related data. Compared to HIS, the HSV color space model is more advantageous in distinguishing and expressing the vividness and brightness of colors. The core strength of the HSV model lies in its intuitive and effective representation of color's visual properties, especially when dealing with Hue and Saturation [45]. Therefore, this study employs the HSV color space model for analysis, aiming to leverage its advantages in color recognition and expression, thereby enhancing the accuracy and efficiency of clustering analysis.

In 1978, Smith [46] presented the Hexcone Model based on the intuitive properties of color, introducing the HSV (hue, saturation, value) color space (Fig. 1). The HSV model mirrors human visual perception effectively. The three dimensions of this color space are: hue, saturation, and value. Hue is represented by angles, such as red (0°), green (120°), blue (240°), and their complementary colors like yellow (60°), cyan (180°), and magenta (300°). Saturation indicates the color's proximity to spectral colors, ranging from 0 to 100%—the higher the value, the more saturated the color. The value quantifies the lightness or darkness of a color, ranging from 0% (absolute black) to 100% (absolute white). Owing to its ability to represent the three distinct attributes of color, this model is invaluable in quantitative color analysis.

Data source and processing

During the Qing Dynasty, the production of Chinese export paintings reached tens of thousands [47]. The Victoria and Albert Museum in the United Kingdom holds a collection of over 3000 of these works, while The British Library's collection exceeds 5000 pieces. Additionally, the Cantonese Thirteen-hongs museums house 1412 such paintings. The data for this study are derived from 35 Guangzhou landscape export paintings, with Table 2 presenting basic information about these samples. Although the sample size chosen for this study is not extensive, it possesses significant representativeness for several reasons: (1) the subjects of export paintings include figures, plants, animals, etc., and all 35 of these works primarily depict the urban landscape of Guangzhou, effectively reflecting the city's landscape, folk life, and historical scenes; (2) the production period of these paintings spans from 1750 to 1896, clearly exhibiting the temporal evolution of artistic characteristics of Qing Dynasty Guangzhou export paintings; (3) the elements in these paintings encompass both macroscopic scene descriptions and microscopic depictions of architecture, streets, and human figures; (4) the paintings employ various media and techniques, such as watercolor on paper (纸本水彩), oil painting (油画), copperplate painting (铜版画), and watercolor on rice paper (通草纸水彩), reflecting a diversity of artistic innovation and the fusion of Eastern and Western cultures; (5) the artists of these works include several of Guangzhou's most famous studios at the time, such as Tingqua (廷呱), Youqua (煜呱), Sunqua (顺呱), and Lamqua (林呱), with five pieces (samples 11–14,16) created by foreign artists, deeply reflecting the intermingling of Chinese and Western art.

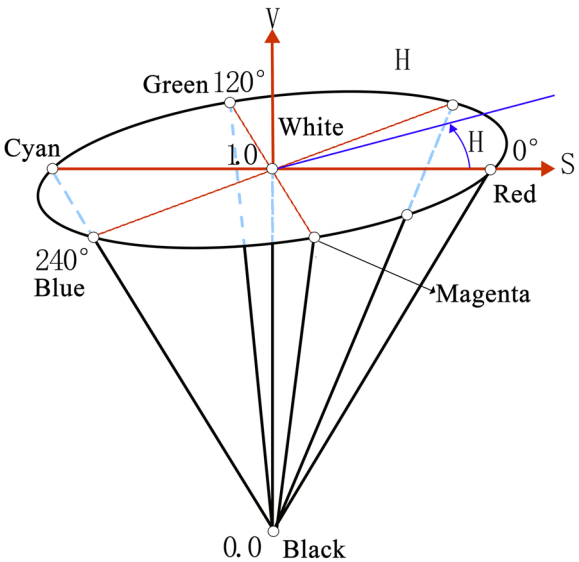


Fig. 1 Color space model proposed by Smith (Sourced from: https://blog.51cto.com/u_15057841/3784699)

The data processing in this paper consists of three processes;

The first step in this analysis involves graphic preprocessing and the initial selection of cluster centers. Given that natural elements in export paintings, such as skies and landscapes, often employ low-luminance dark hues, direct application of clustering algorithms might bias the analysis towards these dominant background colors. To address this, image segmentation techniques were employed to distinguish the image based on natural elements and human subjects, extracting the hues of these respective parts separately. Additionally, parts of the images affected by historical wear were desaturated and replaced with pure white to eliminate noise. Based on this preprocessing, clustering algorithms were applied to the segmented sections of the image for color analysis. Considering the complexity of color distribution in export paintings, direct application of the KMA might lead to significant differences in color clustering, such as categorizing bright but unsaturated color pixels under the same cluster, despite potentially large hue variances.

To overcome this issue, optimization of the initial cluster center selection was undertaken. In traditional clustering algorithms, the selection of initial cluster centers is typically based on hue or grayscale modes, but these methods do not adequately consider the diversity of image pixel composition [48]. Therefore, the max–min criterion method was utilized to optimize the initial cluster center selection, determining subsequent centers based on the maximum distance from the already chosen points, until all centers are selected [42]. The initialization method for KMA is as follows: a point is randomly selected as the first cluster center, and new cluster centers are iteratively chosen based on the farthest distance from the existing cluster centers, until

Table 2 Sample information sheet

Sample					
Coding	1	2	3	4	5
Name	Guangzhou Qujiang elegance building (广州曲江风度楼)	Guangzhou city scenery-1 (广州城风光)	Guangzhou city scenery-2 (广州城风光)	Guangzhou city scenery-3 (广州城风光)	Guangzhou city scenery-4 (广州城风光)
Drawer	Anonymous				
Time	1800	1860			
Types	Watercolor on paper (纸本水彩)				
Sample					
Coding	6	7	8	9	10
Name	Overlooking Guangzhou from commercial zone (从商馆区眺望广州景色)	Thirteen-houses commercial zone-1 (十三行商馆区-1)	Overview of Guangzhou city (广州城一览)	Guangzhou commercial zone-1 (广州行馆)	Huangpu port scenery (黄埔港风光)
Drawer	Anonymous				
Time	Nineteenth century		1750–1800	1827	Mid-nineteenth century
Types	Watercolor on paper (纸本水彩)				
Sample					
Coding	11	12	13	14	15
Name	Thirteen-houses commercial zone-2 (十三行商馆区-2)	Guangzhou street view -1 (广州街景-1)	Haizhu battery-1 (海珠炮台-1)	Guangzhou boatman fighting quails (斗鹌鹑的广州船夫)	Scenery of the northern bank of the pearl river in Guangzhou (广州珠江北岸风景)
Drawer	Bista		Modent Shipley, Conway	Fromm	anonymous
Time	1855	1826–1896	1854	Nineteenth century	
Types	Watercolor on paper (纸本水彩)			Oil painting (油画)	Oil painting (油画)
Sample					
Coding	16	17	18	19	

Table 2 (continued)

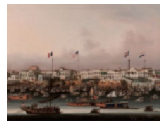
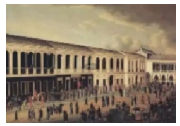
Name	Guangzhou street view-2 (广州街景-2)	Thirteen-houses scenery (十三行风光)	Tea transportation on the south bank of the pearl river (珠江南岸 运茶图)	Map of Guangzhou port and Guangzhou prefecture city (广州港和广州府城图)	
Drawer	Fromm	Anonymous	Tingqua (廷呱)	Anonymous	
Time	Nineteenth century		1855	1760	
Types	Copperplate picture (铜版画)	Woodblock print (木版画)	Watercolor on rice paper (通草纸水彩)	Gouache on silk mounted scroll (绢裱卷轴水粉画)	
Sample					
Coding	20	21		22	23
Name	Merchant warehouse and general inspection tax office (行商货栈与总巡税馆)	Panoramic View of Guangzhou Port (广州港全景图)		Thirteen-houses commercial zone -3 (十三行商馆区-3)	Guangzhou commercial zone-2 (广州行馆)
Drawer	Anonymous	Youqua (煜呱)		Sunqua (顺呱)	lamqua (林呱)
Time	1770	1845		nineteenth century	1830–1835
Types	Gouache on silk (绢本水粉)	Oil painting on canvas (布本油画)			Cloth-based oil paint (布本油彩)
Sample					
Coding	24	25	26	27	28
Name	Western painting—Qing dynasty Thirteen-houses (西洋画-清朝十三行)	Haizhu battery-2 (海珠炮台-2)	Painting of the dock in front of Haichuang temple (海幢寺门前码头画)	Pearl river (珠江)	Thirteen-houses commercial zone-4 (十三行商馆区-4)
Drawer	Anonymous				
Time	Nineteenth century				
Types	Unknown				
Sample					
Coding	29	30	31	32	

Table 2 (continued)

Name	Guangzhou Waterfront (广州水滨)	Pearl River scenery (珠江景色)	Guangzhou Haopan scenery (广州濠畔风光)	Distant view of Guangzhou city (远眺广州城)
Drawer	林呱 (lamqua)		Anonymous	Anonymous
Time	1835	unknown	Mid-nineteenth century	1800
Types	Unknown			
Sample				
Coding	33	34	35	
Name	Pazhou tower (琶洲塔)	Scenery of the north gate of Guangzhou city (广州城北门风光)	Corner of Thirteen-houses commercial zone in Guangzhou (广州十三行商馆区一角	
Drawer	Anonymous	Anonymous	Anonymous	
Time	1850	1860	1807	
Types	Paper-based pencil (纸本铅笔)	Unknown	Oil painting on canvas (布本油画)	

all k centers are selected. Forgy' s method of random data point initialization starts with randomly chosen k points, assigns each point to the nearest center, recalculates each center based on the average of the assigned points, and repeats this process until a predefined termination criterion is reached [49].

The second step involves determining the k value. In the application of the KMA, the k value represents the number of initial cluster centers and also determines the number of color categories in the final output. Considering the color extraction for export paintings, which serve as a reflection of native Chinese subjects, there is a correlation with the traditional Chinese "Five-Color" theory. This theory considers five basic hues as central to painting. Based on this concept, this study ensures the inclusion of at least five different hues and no fewer than five color types in color extraction [42]. However, traditional clustering algorithms typically rely on experiential judgment to preset the number of clusters (k), a method more applicable when the sample size is limited.

To reduce the influence of subjective presets and determine the optimal number of clusters, this study employs the elbow method to estimate cluster quantity [48]. This method evaluates clustering effectiveness by calculating the sum of squared errors *SSE* (Eq. 3) for sample points relative to their cluster centers across different cluster quantities. As per the definition of within-cluster distance, smaller k values lead to larger within-cluster distances, which gradually decrease as the k value increases. However, once the optimum k value is reached, the reduction in within-cluster distance becomes significantly less pronounced. By plotting the k value versus *SSE* and observing the downward trend, the optimal k value can be better determined at the inflection point of the curve. In this study, a potential maximum number of class clusters i was first randomly set, and then the corresponding *SSE* values were calculated by incrementing from 1 to i. By analyzing the relationship between k and *SSE*, the study identifies the inflection point where SSE decreases rapidly, thus determining the appropriate k value. This method aids decision-making in a visual manner, enhancing the precision and efficiency of cluster analysis.

$$SSE = \sum_{i=1}^{k} \sum_{p \in L_i} ||p - q_i||^2 \tag{3}$$

In this equation, p denotes the data objects in the ith class group L_i; q_i denotes the mean value of all data objects in a given class group; k denotes the number of classification groups.

Results

Dominant hue information extraction

The third step is the information extraction of dominant hue. Utilizing the KMA image processing program developed by Krzywinski [50] in 1999, each sample from Table 2 underwent color information clustering and data translation, producing 35 datasets. The platform integrates multiple functionalities, including color segmentation, color measurement, and color clustering, with the color conversion between HSV and CIE based on the CIE 1976 standard. The CIE (Commission Internationale de l'Éclairage) color system is a globally recognized set of color standards established to ensure color consistency and accuracy [51]. The CIE 1931 colorimetric system is foundational in colorimetry, employing X, Y, Z coordinates to denote color. These three coordinates represent the brightness and color distribution as perceived by the human eye [52]. The CIE 1976 L*a*b* uniform color space, built on the X, Y, Z system of CIE 1931, operates on the principle of non-linear adjustment of the color space, making color differences more visually uniform and intuitive. In terms of color analysis, the CIE 1976 color system is more meaningful as it more scientifically reflects the human eye's perception of camouflage patterns and offers better universality. It provides a more precise framework for analyzing color differences, enhancing the accuracy of color representation in various applications.

Utilizing the image color summarizer function of this platform, descriptive color statistical data are generated. The system's color clustering is accomplished using the KMA. During the clustering of colors, similarity is not solely based on hue but also considers the value and saturation of colors. The process begins by randomly assigning image pixels to k clusters, then calculating a cluster center for each, and reassigning pixels to the cluster whose color center most closely matches the pixel's color. This process is repeated multiple times until the color distance between pixels and their corresponding clusters is sufficiently low. For individual samples, the image colors are clustered into the optimal number of groups as determined by the elbow method, presenting the median color of each cluster. Color distance is denoted by ΔE, with colors having a $\Delta E \leq 5$ being clustered into groups. After several rounds of iterative clustering, the dominant hue composition of each image and its proportion are derived.

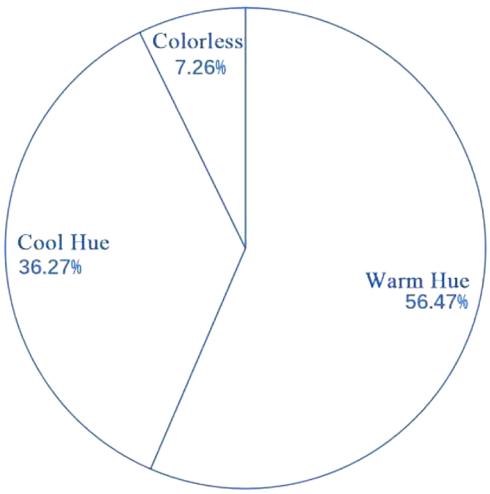
The KMA is typically suitable for data in "linear" or "Euclidean" spaces, implying that it assumes data points are positioned on a line or plane when calculating distances between them. Therefore, when employing KMA in the HSV space, it is necessary to overcome or adapt to the cyclical nature of the HSV space to effectively utilize the algorithm. The platform achieves this by calculating the HSV data through an angle-based mean of a periodic quantity. In the generated data of 35 export paintings, statistical measures are included for each component of RGB, HSV, and Lab (CIE LAB, $L^*a^*b^*$), encompassing average values, medians, maximums, and minimums. Additionally, the data comprises representative colors of the images, their distribution, and numerical values for the average hue, saturation, and brightness of the images, as well as histograms for RGB, HSV, LCH, and Lab. This comprehensive approach ensures a detailed and nuanced analysis of the color properties inherent in these export paintings.

Figure 2 summarizes the color information extraction results from the 35 export painting samples. Each color block represents the dominant hue extracted from a single sample. With consistent block lengths, block width indicates its proportion in the image. Figure 3a showcases a collation of dominant hue information from the 35 samples, whereas Fig. 3b captures the proportional relationships between cool hues, warm hues, and value.

Fig. 2 A summary of the dominant hue of 35 samples of foreign paintings

Subsequently, color data from the initial clustering was translated into the HSV color space. Colors were statistically analyzed based on hue, saturation, and value, then translated into the HSV histogram of color space. Figure 4a displays the hue histogram of color space, revealing a predominant transition from red to yellow-green, indicating widespread use of natural elements like vegetation and land. Apart from specific peak values, regional hue values are relatively uniform. The prominence of red, combined with the extensive use of orange and yellow-green, correlates with the depiction of traditional buildings, attire, and specific cultural activities in the paintings. Figure 4b depicts the saturation and value histogram of color space, revealing that many export paintings primarily employ colors with lower saturation (nearing grayscale or transitional colors), yet some vivid image colors (S = 690) are present. Value distribution is relatively even, with distinct fluctuations in certain regions, reflecting the treatment of shadows and dark details in the paintings. In summary, the HSV histogram of color space showcases richness and diversity in the sample image color information, dominated by low saturation (using soft and neutral background colors), with vivid colors serving as embellishments.

a. Honeycomb map visualization of primary hue information



b. Percentage relationship between cool hue, warm hue, and value

Fig. 3 Color information extraction from 35 samples

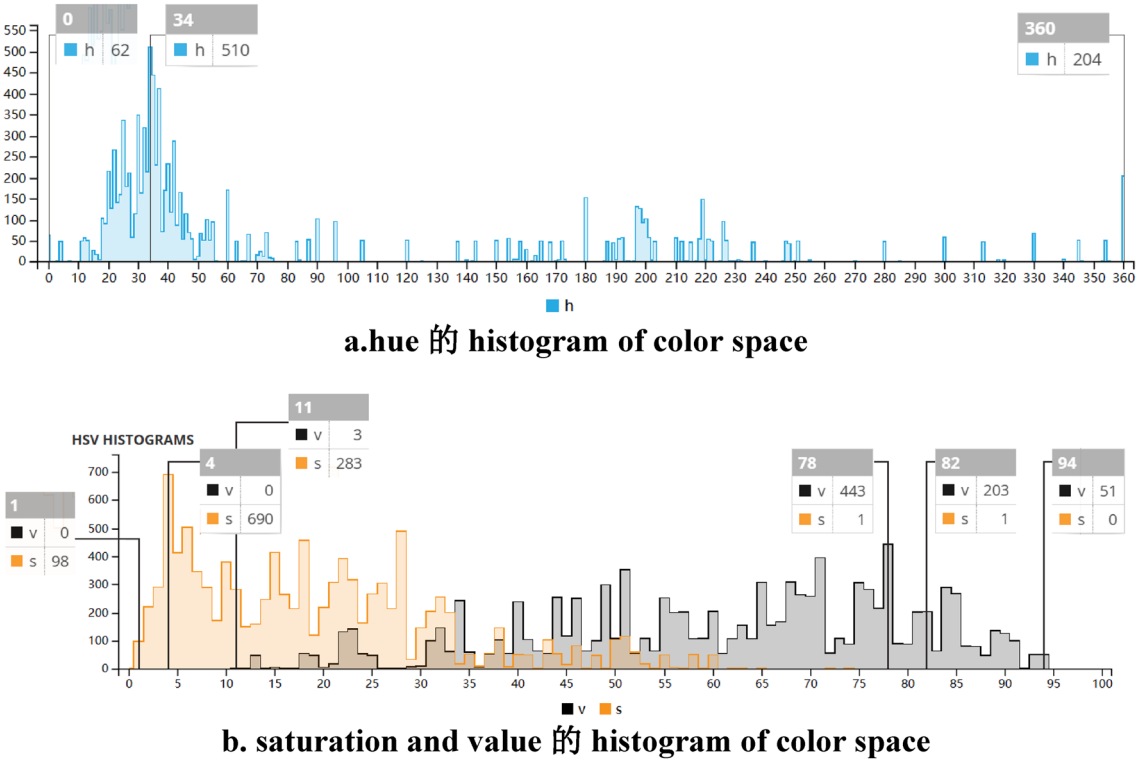


Fig. 4 Histogram of color space of HSV of 35 sample colors

Color analysis of architectural elements

Next, the architectural color elements are extracted. The second step focuses on the color analysis of architectural elements. Building on the procedures from Sect. "Dominant hue information extraction", architectural elements from selected samples were extracted for analysis. Table 3 presents the HSV color analysis results for these architectural elements. Native Thirteen-houses commercial architecture primarily features warm hues, accentuated with select cool hues, characterized by medium saturation and value. In contrast, foreign commercial buildings primarily gravitate towards gray hues, characterized by medium saturation and a more subdued value. Defense structures predominantly employ deep brown-green hues, characterized by medium saturation and a darker value.

Color analysis of business scene elements

Then, the commerce scene color elements are extracted. Based on the previous analysis, Table 4 displays the HSV color analysis results of trade scene components. The color scheme for merchant ships predominantly features reddish-brown and cyan hues characterized by low saturation and medium to dark values. The portrayal of human figures is diverse, encompassing red, yellow, and blue shades. The saturation of these colors varies significantly, combining both high saturation and muted hues, with the value generally being medium to high. For decorative elements in the scenes, red and green hues prevail with considerable variation in value but less so in saturation. Vibrant colors used for human figures might suggest their prominent status, while more subdued colors are typically used for ordinary citizens.

Natural elements color analysis

Finally, the colors of the natural elements of the scene are extracted. Figure 5 presents a comparison of the HSV color analysis results for various natural elements across 35 export paintings. Elements like the sky, rivers, vegetation, and land dominate these paintings. Although each painting has its unique hue, the color characteristics are generally consistent, with only a few exhibiting more pronounced color variations. During Guangzhou's trading boom, its landscapes depicted lush greenery, occasionally punctuated by patches of exposed yellow soil, creating a striking contrast. Simultaneously, forests and water bodies in export paintings were often portrayed in harmonious shades of grayish-green and grayish-yellow. This choice and combination of colors not only showcase the artists' adept capturing of Guangzhou's natural beauty but also hint at the traditional concept of societal harmony and coexistence. The consistency and continuity of

Table 3 Color extraction and analysis of architectural elements at Thirteen houses block in Guangzhou export paintings

Types	Architectural style	Architectural elements	HSV Color Information			
			Color	H	S	V
Local Commercial Building				195°	56%	40%
				223°	28%	63%
				15°	12%	65%
				21°	53%	78%
				36°	64%	87%
Foreign Commercial Building				253°	18%	41%
				260°	8%	59%
				326°	18%	47%
				22°	14%	76%
				28°	9%	84%
Defensive Building				12°	11%	36%
				349°	21%	42%
				18°	23%	58%
				252°	4%	48%
				345°	2%	65%

Table 4 Color extraction and analysis of commercial scene elements at Thirteen-houses block in Guangzhou export paintings

Types	Elements	HSV Color Information			
		Color	H	S	V
Merchant Ship			1	52	41
			159	16	42
			213	41	50
			26	35	73
			27	8	57
Character			214	98	36
			190	55	35
			15	64	67
			32	26	82
			165	2	83
Scene Decoration			231	34	44
			155	20	52
			9	52	66
			34	43	95
			204	12	90

H	S	V	H	S	V	H	S	V	H	S	V	H	S	V	H	S	V
156	21	56	115	8	52	147	12	30	57	44	64	160	18	46	186	21	53
25	11	75	6	9	87	36	35	78	34	51	80	12	12	58	189	15	72
			224	15	56	194	21	80	240	2	72	203	15	76	20	18	95

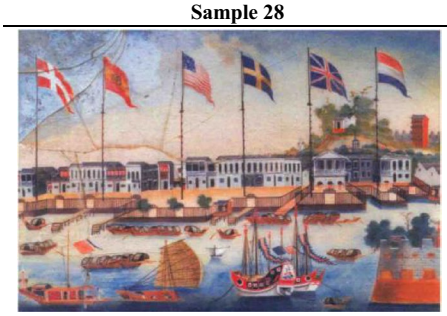
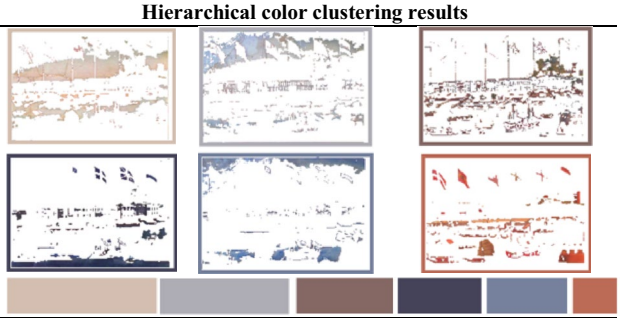
Fig. 5 Color extraction and analysis of natural elements at Thirteen-houses block in Guangzhou export paintings

colors also reflect the openness and diversity of Guangzhou's commercial and cultural exchanges of that period.

Case study: the color analysis of Thirteen-houses commercial zone export painting (sample 28)

To compare the color clustering of individual export paintings with the clustering results of the 35 samples and to explore the unique color themes and underlying cultural and historical significance of specific export paintings, this study selected the "Thirteen-houses commercial zone (十三行商馆区)" export painting (sample 28) for an HSV color analysis comparison. This painting stands out in two main aspects: first, in terms of color application, it showcases vibrant hues and saturation, reflecting the color aesthetic trends of the period; second, content-wise, the depiction of six different national flags and merchant ships from various countries provides an authentic representation of the bustling international trade scene at the Guangzhou port during the nineteenth century, indicating the close trade and cultural exchanges between China and other nations. The color clustering process utilized cutting-edge hierarchical image segmentation techniques, determining colors by calculating the average pixel value within clusters. Table 5 provides a comprehensive list of the image analysis results, with the

Table 5 Image color segmentation and cluster analysis results for sample 28

Sample 28		Hierarchical color clustering results					
							
Results	**Percentage**	**Color Name**	**Color Distance / ΔE**	**Color HEX**	**H**	**S**	**V**
	24.37%	Wafer	2.5	#D4BEB0	24	17	83
	20.91%	Bombay	1.8	#AEACB4	252	4	70
	16.17%	Pharlap	1.0	#856864	7	25	52
	13.83%	Dark Grayish Blue	0.8	#444259	244	26	35
	12.85%	Grayish Sapphire	3.5	#76819D	223	25	62
	11.88%	Clay	3.6	#BC6B57	12	54	74

color proportions adjusted based on pixel count after thorough research to ensure scientific and accurate outcomes.

Figure 6 displays the HSV color space histogram for sample 28. The artwork contrasts blue hues with orange, where the orange shades account for 52.42%, and the grayish-blue hues make up 47.59%. The relatively close proportions of these colors result in a strong visual contrast. For saturation, the pixel distribution mainly falls within the 0–60% range. Specifically, in the 4–25% interval, every percentage unit surpasses 500 pixel values. In the 25–60% range, an average percentage increase corresponds to over 200 pixel values. This analysis reveals that the painting predominantly features low-saturation grayscale hues, while high-saturation colors, exemplified by orange-red, are rarer, constituting 11.88%. Concerning value, the distribution spans from 9 to 99%. Notably, the 50–89% range has the densest pixel values, indicating a prevalent high-value characteristic in the painting, although almost 30% of values are below 50%, forming a harmonious contrast with the high values.

Discussions

From idealism to realistic portrait: color imagery of Guangzhou City under the interaction of Chinese and western cultures

In the transition from pure color (正色) to inter-color (间色) applications, Qing Dynasty Guangzhou export paintings not only transcended the color norms of traditional Chinese painting but shifted from idealistic color narratives to detailed depictions of real life. This shift vividly portrayed the daily customs of the bourgeoisie, the social activities of the middle class, and the trivialities and bustle of urban life, offering viewers a complex and bustling cityscape. Historically, pure colors, including blue, red, yellow, white, black, and other undiluted hues, were revered by ancient Chinese rituals [53]. In contrast, inter-colors are produced by blending multiple pure colors. In ancient China, the use of color was rigorously governed by ritualistic constraints [54], where pure and inter-colors not only distinguished rank and class but also symbolized power and status [55]. For instance, purple, an inter-color, was once deemed as inferior. Traditional Chinese paintings predominantly featured the elite, hence the prevalent use of pure colors.

However, the harmonious and soft inter-colors used in Qing Dynasty's Guangzhou export paintings made the characters and their outfits in the paintings vibrant and lively. This contrasted sharply with the characters depicted in Guangzhou's traditional murals, which showcased them in pure colors, often appearing subdued and solemn. Nowadays, related scholars have been quite rich in color studies of traditional murals and Western-style paintings. Due to the limited space, this paper does not analyze the color clustering of frescoes and Western-style

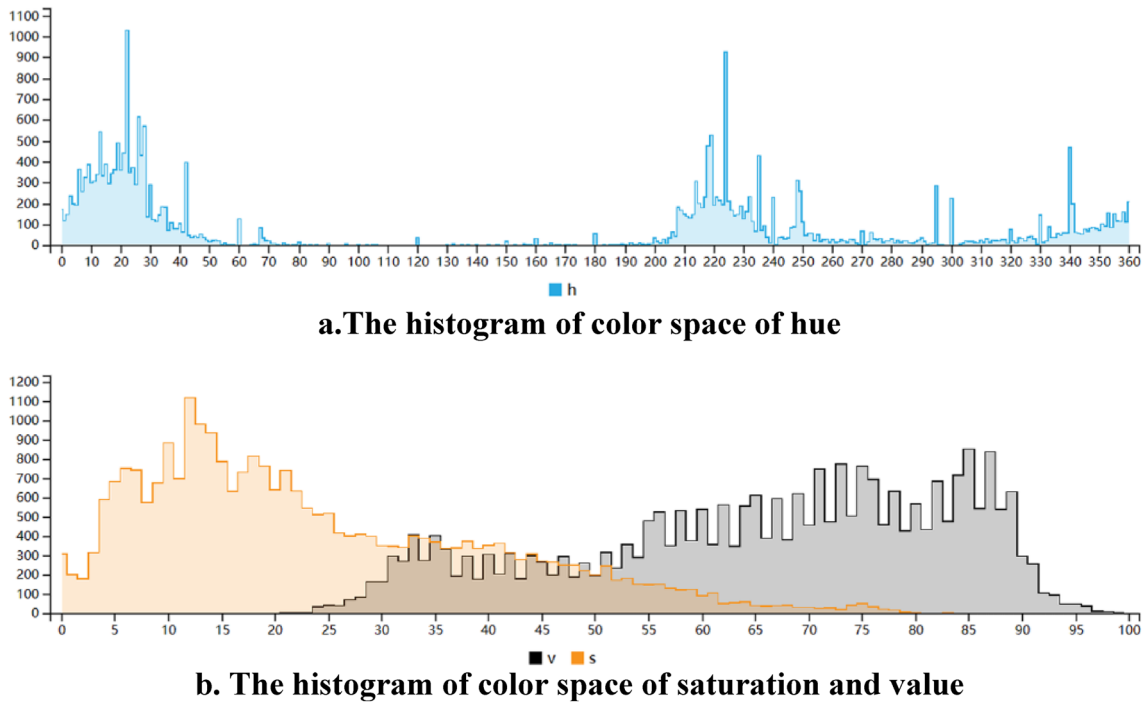


Fig. 6 Histogram of color space of HSV of sample 28

paintings, but adopts the way of combing and summarizing the results of related studies and comparing with them to highlight the differences.

Li et al. [56] conducted a quantitative study that analyzed the color usage in traditional Guangzhou murals and summarized their color application patterns (Fig. 7). Therefore, instead of conducting a color clustering analysis on these murals, this paper compares its findings with their results. They discovered that: (1) nost murals narrated themes and conveyed moral messages that predominantly offered positive content. The depictions of people, objects, flora, and other decorative artistic references in the murals expressed idealistic goals of material life and spiritual pursuits; (2) in the analysis of 181 murals, colors such as blue, white, yellow, and black were extensively used to portray thematic content and characters, adhering to the traditional Chinese hierarchical color system. In contrast, Qing Dynasty Guangzhou export paintings employed bright, subtle intercolors (multicolored, harmonious, and soft) to depict landscapes and figures, starkly contrasting with the monochromatic and expressionless characters in the murals. The color characteristics displayed in Guangzhou export paintings evidently do not conform to the Ming Dynasty's clothing color standards. This divergence highlights the distinct aesthetic and cultural contexts between the two art forms.

The use of red and yellow in the murals, rendered in multicolored, harmonious, and soft intercolors, subtly glows, forming a contrast with the dim, solemn, and restrained characters depicted in solid colors. This intercolor portrayal of the mural figures reflects that the artists of the time were not heavily influenced by class-based feudalism. The rounded depiction of the figures embodies a people-centered core philosophy, affirming human value and dignity, signifying a societal transformation of traditional thought. In an era marked by social change, driven by market demands and the blending of Chinese and Western cultures, the color application in export paintings exhibits a new aesthetic orientation. The choice of colors with low saturation and medium value further substantiates that the artisans had liberated themselves from the shackles of traditional feudal ideology during the creative process. The delicate portrayal of everyday life not only highlights respect for the lives of ordinary people but also emphasizes the recognition of human value and dignity, exhibiting distinct humanistic characteristics.

Fig. 7 Guangzhou traditional mural color system

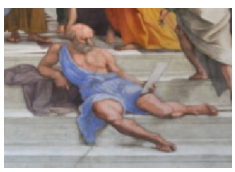
Research findings indicate that Western painting color artistry is characterized by the following features [57–60]: (1) emphasis on contrast in light and dark, as well as shadow representation. This is achieved by enhancing the three-dimensionality and depth of the color palette in the artwork, creating a visual illusion of depth that intensifies the viewer's sense of immersion and spatial perception; (2) fractal nature based on color dimensions. This aspect demonstrates an exploration and application of a complex color system, involving the integration of hue, saturation, and brightness, resulting in a rich, multicolored, and layered visual experience; (3) predominantly focusing on themes such as royalty, knighthood, or religious content, these attributes reflect Western societal cultural backgrounds and values.

In an analysis of 35 export paintings, as many as 22 samples exhibit a color style highly similar to Western paintings, including samples 1–4, 12–18, 23–29, 31, and 33–35. Some of these works are characterized by bold use of color, vibrant and full saturation, and dynamic compositions. In terms of painting techniques, they commonly employ darkened corners, a mix of perspective, line drawing, and sketching, all aimed at emphasizing the subject of the image. This approach is similar to the Western painting color representations outlined in Table 6. However, in terms of thematic content, these paintings primarily depict everyday folk life, differentiating them from Western painting themes and thus fully demonstrating the fusion of Chinese and Western art.

Interpretation of results

Regarding the hue, the color pixels of the 35 export painting samples primarily fall within 10°–60° (from red to yellow hue) and secondarily within 120°–250° (from green to blue hue). Predominantly, the hues are warm, with red, orange, and yellow being the most prominent. Among the cooler hues, teal and blue are the most frequent. In terms of saturation, the pixel values mainly range between 1 and 82%. The most abundant pixel values lie within the 1 to 35% range, followed by the 35–60% range, with values above 60% being the least frequent. As for value, the values primarily range between 11 and 94%, with 31–91% having the most pixel values and 11–30% following. In summary, the saturation of the 35 samples is predominantly low to medium, with low saturation dominating the majority of the area. Some samples also use a moderate amount of low-saturation colors to embellish the artwork, emphasizing a rich grayscale contrast. In value, there's a significant difference in brightness, which is distinct from traditional Chinese painting and clearly influenced by Western painting techniques. These export

Table 6 A comparison of Guangzhou export paintings with traditional mural paintings in Guangzhou and the colors of western paintings

	Qing Dynasty Guangzhou landscape export painting			
Painting				
Sample	15	18	24	29
Name	Scenery of the northern bank of the pearl river in Guangzhou (广州珠江北岸风景)	Tea transportation on the south bank of the pearl river (珠江南岸迓茶图)	Western painting—Qing dynasty Thirteen-houses (西洋画-清朝十三行)	Guangzhou waterfront (广州水滨)
	Chinese traditional mural painting			
Painting				
Name	Resident in the drunken country (醉乡常驻)	Eight immortals drunk (八仙醉酒)	Painting of banished immortal getting drunk (谪仙醉酒图)	Universe picture in pot (壶里乾坤图)
Collector	花山镇龙口村范氏宗祠	广州花山镇东湖村翔斋何公祠	广州花东镇杨三村志清高公祠	广州花山镇五星村欧阳氏宗祠
	Western Paintings			
Painting				
Name	The School of Athens (雅典学院)	The Alba Madonna (阿尔巴圣母)	Allegory-Vision of a Knight (寓言-骑士的愿景)	The Madonna of Pinks (圣母)
Collector	The Vatican Museum	National Gallery of Art in USA	The National Gallery in UK	The National Gallery in UK

paintings have begun to delicately handle shadows, dark areas, and use vignettes to highlight light sources, accentuating the focal point.

Wang [61] posits that the clothing and color styles in export paintings were influenced by traditional rituals, a viewpoint that diverges from this paper's assertion that the use of inter-colors deviates from traditional Chinese painting styles to some extent. Vermeylen [62] discerns that market-oriented demands shaped the decorative art of export paintings due to their commercial nature; this paper supports this claim by comparing the color expressions in Guangzhou export paintings with those in Western art. This study contends that while market demands steered Guangzhou export paintings towards a Westernized color palette, influences from feudal rituals and local culture ensured some traditional elements remained. Viktorovna [63] highlights that the styles in Guangzhou export paintings depicting landscapes, flora, fauna, and water, catered to Western consumers' curiosity about the exotic Far East, especially artworks by Western artists. These works often brimmed with imaginative depictions of Guangzhou's bustling trade scenes, thus natural elements like landscapes were auxiliary, enhancing the diverse ships along the harbor. This study corroborates Viktorovna's findings through a quantitative color analysis. Despite red and green being predominant, natural elements' colors still covered a significant portion of the paintings, without detracting from the central theme.

As a form of commodity art, export paintings also serve educational and social functions. Table 7 illustrates the general consensus of related studies: (1) export paintings are an effective medium for exploring Eastern and Western philosophies, industrial technologies, and the history of cultural arts. They provide researchers with a profound window into cross-cultural exchanges and knowledge transfer; (2) these paintings reflect the relationships

Table 7 Educationality and sociability of export drawings

Functions	Year	Authors	Findings
Educationality	2021	Viktorovna [63]	The author argues that the prosperity portrayed in late Qing dynasty export paintings was an artistic way of portraying China's heavenly empire. In terms of historical examination, these visual works are sometimes more appealing than written descriptions
	2021	Zhang et al. [9]	The carriers, pigments and painting techniques used in Guangzhou export paintings of the Qing Dynasty. It fully demonstrates the exchange and fusion of Chinese and Western art in painting ideas, methods and aesthetics
	2022	Wong [64]	The diverse colonial architectural styles and ship types in Guangzhou export paintings fully reflect the changing aesthetics and aesthetic needs of the material forms of the time, and are an important medium for tracing the influence of Western art on the East
	2022	Zhang [8]	The portrayal of scene content in export paintings (in which occupations are portrayed, characters' expressions, trade content, and colors are reflected) is considered to be based on traditional Chinese law. The examination of the content of these paintings is an effective way to learn and understand the differences between early Chinese and Western legal culture
	2022	Koo [25]	The author argues that the commonality of artistic characteristics between Chinese and Korean export paintings has prompted a re-examination of the linear understanding of 'non-Western' art history. Their examination should not be distinguished from existing traditional schools of painting. These export paintings are both self-objectifying images instilled by Orientalist ideology and at the same time authentic reflections of indigenous art
	2013 2016	Wang and Liu [61, 65]	The author argues that the pattern of color usage in the costumes of the characters in the Guangzhou export paintings reflects the hierarchical concepts in traditional Chinese ritual education, while the shift in their color usage highlights the emphasis on the idea of humanistic texts
Sociability	2016	Park [66]	As a special commodity exported to Japan in the early days, Chinese export paintings were considered a tool that could enhance social capital
	2020	Hulme [67]	Through an examination of cheap Chinese export paintings, the author shows how these works are manufactured and remanufactured at different points in the production chain (waste dealers, wholesalers, shopkeepers and shoppers). He argues that the rise of these commodity arts reflects both the globalized relationship between production and consumption in material culture and socio-cultural change
	2019	Baetens and Lyna [68]	Export painting was seen as a tool for constructing and increasing national identity, but early commodity art did not play these roles with the formation of directly globalized trade networks and the expansion of transnational markets
	2014	Peite [28]	In the academic context of the study "In Guangzhou's Thirteen Hongs: Foreign Merchants in Chinese Export Paintings (1700–1900)," the author delineates the multifaceted interactions between foreign merchants in Guangzhou and the local Chinese context during the specified period. The author emphasizes the pivotal role of these export paintings as a window into the socio-economic and cultural exchanges between China and the West
	2014	Kleutghen [69]	The author argues that the eighteenth-century Chinese taste for things European was satisfied not so much by the importation of foreign goods as by the domestic production of Western art. The art of export painting both satisfied Western curiosity about China and reflected China's geopolitical position in the global trade network

within the global trade network of the eighteenth and nineteenth centuries, social and cultural shifts, and regional geopolitical dynamics, offering a unique perspective for analyzing international relations and cultural interactions during that period. These studies highlight the significant value of export paintings in terms of both educationality and sociability. As recorders of history and culture, export paintings offer a rich resource for educating modern society about past lifestyles and understandings, while also serving as visual aids in art education and history courses. Additionally, export paintings are often seen as tools for social interaction and cultural exchange. They not only reflect the customs and habits of the society of that time but also facilitate mutual understanding and respect between different cultures. By depicting everyday life scenes and significant social events, export paintings provide a mirror for audiences to gain insight into and reflect upon the evolution of social structures and behaviors.

Contemporary research on the K-means algorithm largely concentrates on optimizing the algorithm, enhancing data clustering efficiency, and expanding its application domains. This paper, however, introduces a multi-dimensional, layered analytical approach by segmenting and comparing various elements of imagery such as background, architecture, characters, and other components. In terms of the CIE color measurement and its conversion to the RGB color system, this study provides detailed processes and insights, serving as a reference for related research. Current literature

predominantly focuses on qualitative descriptions, such as content analysis, visual art image feature comparison, and text mining, and lacks quantitative descriptions. The incorporation of K-means analysis in this study not only addresses gaps in the research of color usage in export paintings but also provides case support for studies of other painting types. The paper, through case studies, effectively demonstrates the patterns of color usage in export paintings and, by contrasting these with traditional murals and Western paintings, reveals the epochal significance of the transformation in export art. This offers a diversified interpretative approach for heritage art studies.

In archaeology, the study's precise color analysis unveils the visual characteristics of ancient artifacts and sites, aiding in interpreting historical and cultural contexts and the original state of the artifacts. This analysis could also reveal interactions and influences between different civilizations, providing new perspectives for reconstructing historical events. In graphic design, KMA guides data-based color selection and image layout, enhancing visual communication. Designers can more efficiently determine color combinations and visual focal points using KMA. In industrial design, this research assists designers in finding a balance between visual aesthetics and functionality, offering more precise design decision-making bases. For environmental color analysis, especially in urban planning and historical cultural preservation areas, the study provides new perspectives through quantitative color analysis. This aids in maintaining the visual characteristics of urban cultural heritage while promoting the preservation and inheritance of cultural traits. In architecture and interior design, the paper's method helps analyze the impact of color configurations on spatial perception and emotional responses, providing a scientific basis for creating appealing and comfortable environments. Additionally, this methodology is highly valuable in the study of the psychology of interior environmental colors, aiding in understanding how colors affect human emotions and behaviors. In heritage art research, the paper not only enhances color analysis of historical artworks but also provides quantitative tools to understand the socio-cultural background behind the art, offering in-depth perspectives for art history and cultural heritage studies.

The limitations of this study lie in the sample selection and centralized and thematic analysis of export paintings. While the 35 artworks selected are all landscapes, encompassing diverse themes such as commercial districts, harbor views, character portraits, and various architectural styles, this broad thematic range establishes a foundation to discern general color application trends. However, the concentrated sample scope might hinder drawing representative and in-depth conclusions on the color characteristics of a specific theme. On the other hand, although the selection of export paintings in this paper covers a dynamic sample of multiple dimensions, scales and time, the sample size is slightly insufficient. In order to reflect more comprehensively the color diversity and characteristics of export paintings in Guangzhou during the Qing Dynasty. For a more comprehensive reflection of the color diversity and features in Qing Dynasty Guangzhou export paintings, future research should consider: (1) expanding the sample size to incorporate more varieties of export paintings, such as portraits, flora, fauna, and landscapes, to enhance the breadth and depth of the research; and (2) focusing on a specific theme for a detailed color analysis and comparison to derive more nuanced and precise findings.

Conclusions

The research process revealed that: (1) most of the Guangzhou export paintings have a pixel range of 10°–60° and 120°–250° (dominated by red and yellow-green), a saturation value of 1–82% (dominated by low saturation), and a value of 11–94% (with a wide range of extremes); (2) compared to traditional Chinese painting, the shift in painting from pure color (正色) → inter color (间色) → projected perspective and light source is reflected in the blending of Chinese and Western culture and art, as well as the dilution of traditional ritual and cultural constraints, and reflected in the emphasis on humanism; (3) compared with western paintings, the color construction of some Guangzhou export paintings shows a westernized trend (realism), which is reflected in the color activity and strong contrast between light and dark.

Viewed as tailored art commodities, export paintings extend beyond mere trade items, offering a nuanced reflection of Guangzhou's unique mercantile culture and power dynamics. This distinct art form can be considered a "societal text", presenting a lens into cultural symbols and offering a means to scrutinize the regional power structures, cultural logic, and ideologies. The prevalent use of inter-colors, the realist style, and the shift towards humanistic features in Guangzhou export paintings not only showcase the continuity of Chinese aesthetic traditions but also reveal the blending and dialogue of Chinese and Western cultures propelled by Guangzhou's trade culture. Extracting and analyzing the colors of Guangzhou export paintings aids in distilling the color spectrum under the Guangzhou Sino-Western trade culture. This can provide a regionally representative color palette for contemporary Guangzhou city's cultural and creative design endeavors. The color spectrum of Guangzhou export paintings mirrors the characteristics of

Guangzhou's trade integration, offering fresh perspectives in the study of Guangzhou's urban historical heritage. On another note, the development of a color model and the methods of color extraction and analysis can enhance the efficiency of color matching for designers. This approach not only contributes to a deeper understanding of historical aesthetics but also applies practical insights to modern design practices, bridging historical art with contemporary design applications.

Future research by the team aims to delve into the correlation between color features and aesthetic composition in export paintings, as well as how this correlation was constructed and disseminated in specific historical and cultural contexts.

Author contributions

Conceptualization, J.A. and W.L.; methodology, Z.Y. and W.L.; software, Z.Y. and W.L.; validation, J.A., Z.Y. and W.L.; formal analysis, W.L. and Z.Y.; investigation, Z.Y., W.L. and S.J.; resources, J.A., Z.Y. and S.J.; data curation, W.L. and Z.Y.; writing—original draft preparation, J.A., Z.Y. and W.L.; writing—review and editing, J.A. and W.L.; visualization, Z.Y. and W.L.; supervision, W.L. and J.A.; project administration, W.L. and J.A.; funding acquisition, J.A. All authors have read and agreed to the published version of the manuscript.

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Data availability

The data used to support the findings of this study are included within the article.

Declarations

Informed consent

Not applicable.

Competing interests

The authors declare no conflict of interest.

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