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Maritime silk road heritage: quantitative typological analysis of qing dynasty export porcelain bowls from Guangzhou from the perspective of social factors

Jinghui Ao[1], Weicong Li[2*], Shanshan Ji[3] and Simin Chen[1]

Abstract

The formation of decorative patterns on export porcelain has risen to the research dimension of cross-regional culture. The interplay between social elements and the formal evolution of export porcelain bowls from the Qing Dynasty in Guangzhou remains nebulous. This study elucidates these underlying cultural dynamics through the lenses of utility and societal implications, thus addressing how societal components contribute to the molding of tangible cultural heritage. Key findings include: (1) A dominance of the ring-foot design in the bases of Qing Dynasty export bowls; (2) The diameter and height of the Qing Dynasty export bowls show relatively concentrated characteristics, reflecting a systemic production trend and relative consistency in form; (3) Some of the Qing Dynasty bowls exceed the parameter range of typical tableware, reflecting the adaptability and innovation of production mechanisms in responding to special market demands. The morphological evolution of the Qing Dynasty export bowls is a true reflection of the interweaving of multiple factors such as comfort design and aesthetic preferences, while the uniformity in shape is a comprehensive reflection of meeting market demands and advances in production technology. This study extends the research dimension to the interaction between standardized production techniques and socio-cultural demands.

Keywords Guangzhou porcelain, Exported bowlware, Quantitative typology analysis, Formal art, Social factors, Commerce culture, Color analysis

Introduction

Currently, research on "export artifacts" has risen to the discussion of foreign cultural communication [1]. Western scholars believe that export artifacts are considered as a refraction mirror of cultural formation, showing cultural transmission and evolution, reflecting the mutual influence and adaptation process of regional cultures [2]. Chinese scholars believe that apart from commercial value, export artifacts are physical carriers to display the past social and humanistic customs, emphasizing the uniqueness and aesthetic value of artworks, involving patterns, designs, colors, and forms [3]. In summary, the research on decorative art of export artifacts has experienced a process from focusing on "cultural locality" to "cultural symbolism". This paper re-examines some exogenous factors influencing the formation of Guangzhou's export porcelain art, especially the influence of commercial culture.

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The culture of port exports has always been a hot topic worldwide [4–6]. Since the launch of the United Nations Convention on the Diversity of Cultural Expressions [7] and Cultural Contents and the Convention for the Safeguarding of the Intangible Cultural Heritage, cultural restoration [8] and preservation have become the subject of international consensus [9, 10]. It emphasizes the correct transmission of artistic value and provides insights into the protection and understanding of contemporary cultural heritage. Such protection contributes to emotional associations and awareness bonds for an independent region and nation, being the core mechanism for consolidating national power [11, 12].

The opening up of new shipping routes and the formation of global trade networks in the sixteenth century made the export of commodities an important medium of cross-cultural exchange [13]. According to T. Volker's book Porcelain and the Dutch East India Company, between 1602 and 1682, the Dutch alone trafficked more than 16 million pieces of Chinese porcelain [14]. In these porcelains, most of the shapes and decorative patterns were customized and designed according to the needs of foreign customers [15], which not only reflected the global consumption trend of the time but also revealed the depth of cultural intermingling. The Chinese landscape figures, Western myths, and religious elements decorated in Clark Porcelain are a testament to the combination of Chinese and Western decorative arts [16]. Many Chinese export porcelains are treasured in museums all over the world [17], and they satisfy the Westerner's desire to know more about the Oriental civilization and its curiosity. The unique shapes and patterns on these porcelain pieces have also become a source of inspiration for Western designers, such as the celadon dress designed by Mr. Dior in 1952 [18]. The restoration and preservation of cultural heritage transcends national boundaries and is the common responsibility of all mankind, the concept of contemporary preservation and restoration of cultural heritage was first proposed by the Italian restorer Cesare Brandi at the beginning of the twentieth century [19]. He argued that the act of intervention in a work of art must be based on an in-depth understanding of it and that restoration directed at its materiality aims to reconstruct the potential oneness of the work of art. This concept became the basic guideline for restoration, conservation, and intervention in the cultural and material heritage in the European region, with Italy at the forefront. Subsequently, the concept has been "territorialized" around the world [20, 21], providing theoretical support for the preservation of cultural heritage worldwide.

The growing literature on subjects related to the form, art, and culture of porcelain highlights its importance as a material vehicle in cross-cultural exchange and technological diffusion. Quantitative Typological Analysis is also beginning to be applied to the analysis of porcelain artifacts. In the field of art history, Moisieiev [22] employs a morphological typology to sort out artifacts from the heritage area of South West Crimea, arguing that this approach demonstrates the development and evolution of the medieval porcelain production process. With the help of typology, Anastasi et al. [23] found that ceramic flakes excavated underwater could be shipping goods from early North Tunisia and Sicily and that early trade in the Mediterranean provided evidence. Combining computer algorithms with typology, Pawlowicz, and Downum [24] demonstrate that deep learning models based on typology help to reorganize similar ceramic fragments, providing insights into ancient technology and evolution. Ness [25] argues that a classification system based on morphological typology could help archaeologists explore Spanish ceramics and user behavior at a deeper level, and suggests that the method has high value in terms of identifying trade patterns. Typological Analysis has been widely used in cultural studies in addition to its application to modern industrial design.

However, with cultural expansion, Guangzhou's export culture is gradually losing its uniqueness [26]. Cultural derivatives, sold with fast-selling culture, lead to the diffusion and formalization of cultural relics [27], and are seen as the result of economic development [28]. The current cultural and creative product development has the following problems: (1) excessive commercialization and lack of innovation; (2) neglect of cultural background and lack of artistic connotation. According to statistics, 53.6% of the interviewed youth believe that current cultural and creative products have a problem of homogenization [29].

Currently, research and discussion on China's "export porcelain" are mainly centered around the "artifact" itself: (1) Craft value, involving functional forms, casting skills, pattern designs, and compositional forms; (2) Cultural value, involving historical verification, foreign exchange communication, and cultural inheritance.

In focusing on the aesthetic craftsmanship of export ceramics, Li [30] found that the most common decorative elements in export ceramics are floral patterns, with a refreshing, delicate, and exquisite curve modeling. This is very similar to the Rococo style in Europe, and its decorative symbols have had a profound impact on the culture of countries along the Belt and Road. Zhang [31] found that the rabbit-shaped patterns on ceramics exported to Japan evolved from a single, vivid folk kiln style to a diverse, neat and dazzling Japanese flat drawing style. This discovery underscores the fusion characteristics of porcelain decoration with Japanese flat decorations,

revealing Japanese philosophical thoughts and aesthetic foundations. Huang [32] explored the export routes and regions of Guangzhou ceramics and found that firing marks are a unique style of Guangzhou export ceramics. Chen [33] found that the shape of Filipino ceramics is dignified and steady, the body is firm, with a glossy green glaze. The surface presents small ice cracks and is adorned with common patterns in Chinese ceramic decorations such as scroll flower patterns and lotus petal patterns, providing evidence for early maritime cultural exchanges between China and the Philippines. Jin [34] found that the shapes and decorations of porcelain exported to Japan are innovative, with a heavy body and a primitive simplicity. These characteristics were influenced by the Japanese tea ceremony, incense ceremony, and food culture in the early Edo period, indirectly affecting their morphological characteristics.

In terms of emphasizing the cultural history of export ceramics, Schottenhammer's [35] research found that the export activities of Guangzhou export ceramics at different stages were influenced by political changes, which indirectly influenced its decorative art. Li [36] pointed out that the consistency of the decorative style of Ming Dynasty export ceramics was enhanced to adapt to the development of the social economy and the needs of the citizen class. Hansman and Julfār's [37] research found that the decorative art of Ming Dynasty's export ceramics had spread to the Arab region. Wu [38] found that the export ceramics printed with scenes of the court and official women's life during the Ming and Qing Dynasties were quite popular overseas. This indirectly represents the content of the garden life of women in the Ming and Qing courts in China and formed special design styles according to the needs of the European market. Moreover, Wu [39] also found that late Ming Dynasty export ceramics type originated from traditional Chinese types and new types formed by overseas influence in trade, with significant changes in shapes. The design elements were still dominated by Chinese designs, but changes and developments occurred in the shapes due to overseas trade supply and demand. This reflects the gradual shift of the European consumer market for late Ming export ceramics from the nobility to the middle class.

Therefore, research around "export porcelain" in the past few decades has mainly focused on three core issues: (1) how its cultural value can be better inherited and developed in the future; (2) how its decorative aesthetics inspires contemporary cultural creative design; and (3) how the permeation of past external economy, politics, and culture played a role in the formation of Guangzhou export porcelain decorative art. Clearly, recent studies have incorporated geopolitics as a factor influencing the formation of the decorative style of export porcelain, rising to the research dimension of cross-regional culture [40]. However, few Chinese scholars explore the cultural logic behind the formation of export porcelain art based on macro social factors.

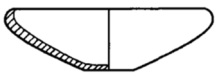
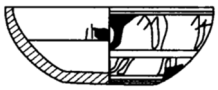
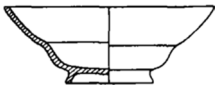
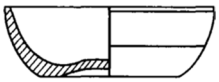
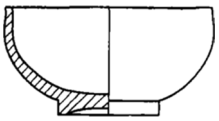
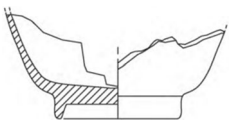
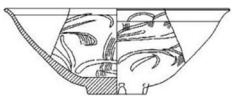
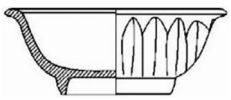
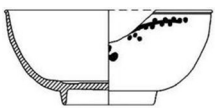
Research on the foreign dissemination of Guangzhou export porcelain decorative culture helps elucidate the influencing factors and extent of geopolitics within it, and simultaneously constructs a historical window for the cultural evolution of Guangzhou port under the geographical and temporal background. The Guangdong Provincial Museum has sorted out most of the information about export porcelain cases, which are important research materials for this paper [41]. The research steps of this paper are as follows: (1) firstly, the selected export porcelain is sorted out, counted, and summarized; (2) secondly, the samples are classified and coded according to their attribute characteristics, and then the contour lines of each group of samples are extracted and plotted on a unified coordinate axis; (3) next, the graph is divided into several types, and focus is placed on the perimeter, shape, and changes of the graphic contour lines in each type, as well as the application of decorative patterns and colors, to uncover the style characteristics of sample modeling evolution at different times; (4) finally, based on the geopolitical background of Guangzhou during the Qing Dynasty, combined with interpretive historical research, the influence of foreign cultures on the decorative art of export porcelain is explored and its underlying cultural formation relationships are deeply interpreted.

Methodology

Archaeological background of Chinese ceramic bowls

In the realm of archaeological research, the works of Feng [42], Guo [43], Yang et al. [44], and Chen et al. [45], as well as Li et al. [46], delineate a chronology of pivotal discoveries and events in Chinese pottery from the Paleolithic era through to the Qing dynasty, as cataloged in Table 1. Table 2 delineates the evolutionary trends in the design of various types of bowls. During the Tang dynasty, the flaring-rim bowl underwent continuous refinement, culminating in an artistic apex during the Qing dynasty. The high-footed bowls of the Yuan dynasty achieved perfection, with the Ming dynasty representing the zenith of this design, though a decline was observed in the Qing era. The constrained-rim bowls, widely celebrated during the Song dynasty for their distinctive shapes, reached a plateau in the Yuan dynasty before becoming more refined. The basic form of the open-rim bowl was established during the Song dynasty, experienced fluctuations in the Ming, and reached new heights in the Qing dynasty. The peaked design of the umbrella-style bowl during the Song dynasty gradually diminished, with the Qing era

Table 1 Archaeological events related to Chinese ceramic bowls

Year	Events/Characteristics	Typical Sample
More than 9,000 years old (Paleolithic)	Pottery Fragments from Cave Sites in the Southern Region	–
5000–6000 BC (Neolithic period)	Pottery bowl unearthed in 1975 at the Peiligang culture site (裴李岗文化遗址) in Xinzheng City, Henan Province	
4000–2000 B.C (Middle Neolithic-Yangshao Culture Period) (仰韶文化)	A group of pottery bowls were excavated in 1921 in the village of Yangshao, Mixed Chi County, Sanmenxia City, Henan Province. Characteristics include a clay large-mouthed, rim-bottomed or flat-bottomed bowl with a bulging belly or sloping-walled flat base	
2550–2195 B.C (Late Neolithic-Qujialing Culture) (屈家岭文化)	In 1954, a group of pottery bowls were unearthed at Qujialing, Jingshan City, Hubei Province, with features including a large open mouth, curved belly, rimmed foot, sloping wall, flat bottom, large open mouth, and curved belly bowl	
220–280 A.D (Han Dynasty, Three Kingdoms Period)	A group of ceramic bowls were unearthed in Hubei Province, with features including open mouths, curved walls, and flat or false rim bowls	
420–589 A.D (Northern and Southern Dynasties Period)	A number of porcelain bowls have been unearthed throughout China. Some of the bowls were excavated in blue and white porcelain, black porcelain and white porcelain. Characteristics include straight mouths, rounded lips, inner lower bellies, and round cake-shaped feet	
960–1127 AD (Northern Song Dynasty)	A group of Northern Song porcelain bowls were unearthed from kiln site No. 1 in Gongle County, Sanming City, Fujian Province, and their special features include an aoi mouth, a sloping curved belly, a slightly curved inner base, a rimmed foot, and an extremely shallow dug foot	
1127–1279 AD (Southern Song Dynasty)	A group of Southern Song dynasty blue and white porcelain bowls, characterized by a wide mouth with a rounded lip, a curved belly, and a rimmed foot, were unearthed in 2019 from the site of the old station where the Panfo Temple site (番佛寺遗址) is located in Quanzhou City, Fujian Province	
1271–1368 A.D (Yuan Dynasty period)	At Panfo Temple site, a group of Yuan dynasty celadon bowls were unearthed, characterized by a rounded lip, a wide mouth, a curved belly, and a rounded foot. The inner base is molded with a double-fish design, and the outer wall is incised with a petal design	
1368–1644 AD (Ming Dynasty period)	In 2007, a group of Ming dynasty blue-and-white porcelain bowls characterized by deep bellies, flared mouths, and slanting curved bellies were unearthed from the Mafankeng site (马饭坑窑址) in Longshan Town, Nanjing County, Zhangzhou City, Fujian Province	
1616–1912 AD (Qing Dynasty period)	A group of Qing dynasty porcelain bowls unearthed in 2019 from the Wandiedun No.1 site (碗碟墩一号窑址), Jiangle County, Sanming City, Fujian Province, China, with features including a rounded lip, an open mouth, a curved belly, and a rimmed foot. The inner and outer walls are covered with white glaze, and the inner bottom is covered with an astringent circle	

witnessing a trend towards standardization. In comparison to the Ming dynasty, both the Song and Qing dynasty's recumbent-foot bowls displayed a slight inferiority, with two predominant shapes: near-round and elongated oval. The design trajectory of the chicken-heart bowls mirrored that of the recumbent-foot bowls, with the Ming dynasty marking the pinnacle, followed by a decline in both the Song and Qing dynasties. The folded-rim bowls exhibited maturity in design by the Tang dynasty, with the Qing dynasty showcasing a diversity of designs albeit with an inconsistency in quality.

Quantitative typological analysis

Typological charting is a visualization method used to describe the interactions and correlations among different components within complex systems, revealing certain structures, rules, changes, and patterns in the system [47]. The basic principle of this method originates from the typological approach of archaeological studies on samples, based on the "sharp sense" classification

Table 2 Patterns of Development of Chinese Porcelain Bowl Shapes (618-1912)

Types	Maturity Period	Flourishing Period	Styling Trends
Flared-rim Bowl (撇口碗)	Tang	Qing	After the modeling matured in the Tang Dynasty, it gradually developed towards a more perfect state with the course of time. It entered its peak in the Qing Dynasty
Folded-rim Bowl (折沿碗)			This type of bowl type in the Qing Dynasty appeared most, but its shape in the Tang Dynasty already has a high level. By the Qing Dynasty, its form is rich but not uniform
High-footed Bowl (高足碗)	Yuan	Ming	Its modeling matured in the Yuan Dynasty, while the Ming Dynasty was the peak of its modeling. In the Qing Dynasty, the level of its modeling declined
Inward-rim Bowl (收口碗)		Song	The shape was prevalent in the Song Dynasty and was rich in forms. After entering a period of stabilization in the Yuan Dynasty, the art of modeling was further enhanced
Open-rim Bowl (敞口碗)	Song	Qing	Its shape matured in the Song Dynasty, but slightly deviated from its original features in the Ming Dynasty. In the Qing Dynasty, its modeling characteristics gradually returned and entered its peak
Umbrella-shaped Bowl (笠式碗)		Song	Its styling entered its peak in the Song Dynasty, but a certain amount of styling programmability appeared in the Qing Dynasty
Recumbent-foot Bowl (卧足碗)		Ming	The level of modeling in the Song and Qing dynasties was not as good as in the Ming dynasty. The Song Dynasty favored near-circularity, while the Qing Dynasty favored ovality
Chicken-heart Bowl (鸡心碗)	Ming		Its modeling maturity and peak appeared in the Ming Dynasty. The Song and Qing dynasties saw a slight decline in the art of modeling

principle. Firstly, it involves extracting the outline curves of the sample, then spectralizing the image, and after computation, selecting the ventral curve values of the sample group, thereby comparing and analyzing the data differences of the sample curve values, to establish a systematic and highly targeted charting system.

The method is widely used in several fields. In the field of design, Sholeh et al. [48] proposed four new product models of sedan class with high compatibility by using morphological analysis tools and believed that this method could deeply explore the potential innovation points of product design and provide innovative solutions for designers. In the field of archaeology, Bustos-Perez et al. [49] analyzed the morphological differences of Backed flakes from the Middle Paleolithic by using 3D geometric morphometric classification methods and machine learning models, providing a high-resolution identification method for lithic archaeology. In the field of sociology, Osipova et al. [50] used morphological typology to analyze hand axes excavated from the Aral Sea region and the Mugalzhar mountainous region, and found similarities and differences between them, providing evidence of early exchanges of cultural activities between the two regions.. In the field of urban studies, AlSadaty [51] classifies the morphological evolution of the historic port area of Bulaq Abul-Ela in Cairo, revealing the lack of spatial connections underneath it, and argues that the application of morphological typology can help in formulating development strategies. In the field of graphic design, Washburn [52] argues that a standardized classification system that focuses on the structure of the pattern parts rather than the pattern parts themselves can reveal a range of new insights about well-researched materials. Based on the principles of this approach, it has also been extended to the field of product-service systems and decision-making [53]. Tena et al. [54] proposed a theory of circular economy product development based on quantitative typology to explore the process of eco-product development. Based on the typology, Kalilu and Adeoti [55] categorized 135 lace textiles from South Nigeria between 1990 and 2016 into two categories, handmade lace, and mechanical lace, and further subdivided the latter into 11 categories to provide a systematic classification system for the locality.

In the past, time series [56], historical criticism [57], and social structure analysis [58] were the commonly used methods of historical interpretive research [59], and researchers often unconsciously injected a priori thinking into their research [60], which is avoided in historical research [61]. The quantitative analysis method of analytical mapping is based on archaeological methods [62], combined with scientific statistical data to justify differences in sample forms, and is particularly suitable for archaeology, art, phenomenology, and other research fields. The advantage of this method applied to art research lies in its objectivity, flexibility, and verifiability, which can transform the abstract, subjective, and difficult-to-outline diagrammatic aesthetics into figurative, fractalized, and quantitative forms, thus making art research more scientific, especially suitable for the excavation of the development trend and characteristics of things.

The four main steps of the typological charting quantification method are as follows: (1) Data source and processing. Data selection, cleaning, and preprocessing are performed on selected cases to eliminate invalid samples, thereby ensuring the accuracy and reliability of the data. A broad sample volume reflects the general trend of development, while the analysis of individual samples can reflect local features. (2) Sample classification and coding. Effective samples are divided into several types according to certain standards and coded into groups, which facilitates subsequent charting and quantitative analysis. Typing standards can be determined according to the structure and attribute features of the research object, such as shape, pattern, ornamentation, color, etc. (3) Curve extraction and typification. By fitting spline curves, the outer contour lines of the graphics are drawn, and then differences are compared based on morphological features. (4) Chart drawing and analysis. The contour curves of the same coding group are plotted on the same coordinate system to create typological charts, allowing for the quantitative calculation of the number, proportion, scale, and differences of each group of elements, thereby revealing certain characteristics.

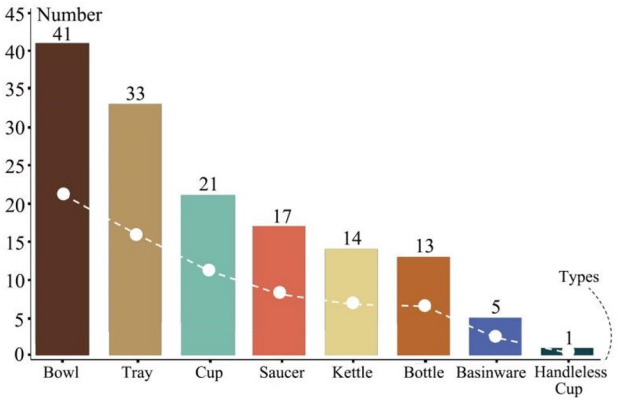


Fig. 1 Statistics on the number of porcelain vessels in the 145 valid sample groups

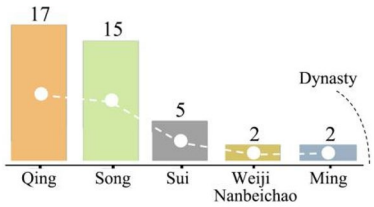


Fig. 2. 41 Bowls production times

Data sources and processing

The first step is data collection and processing. The data come from the collection library of the Guangdong Provincial Museum [41]. As of March 28, 2023, the museum has collected a total of 149,054 artifacts, including a rich array of types such as pottery, stone tools, paintings, sculptures, and coins. The museum has collected a total of 17,614 porcelain artifacts, but only 263 of them are available for public viewing on its official website, including 14 types: plates, bowls, pots, cups, bottles, pillows, pedestals, dishes, basins, cups, boxes, cylinders, covers, and porcelain boards. Not all the porcelain pieces (among the 263) have information on height, base diameter, morphological features, and physical pictures. After eliminating samples lacking the above information, 145 groups of valid analysis samples were obtained for subsequent typological charting (see Additional file 1).

Figure 1 shows the results of the effective sample screening process; unshown types of artifacts mean their quantity is zero after data cleaning. Due to the significant differences in shape, pattern, and decorative art among different types of artifacts, quantitative analysis focusing on the same type of artifact will be more credible and valuable [63]. Given that bowls have the highest number of valid samples, this article classifies images using ceramic bowls as an example. The shapes of porcelain and their decorative art forms show cultural integration and evolution over time, and artifacts from similar years better reflect these continuous artistic changes [64]. According to Fig. 2, among the 41 bowl samples (spanning from the third century to the end of the eighteenth century), the number of bowls produced during the Song Dynasty and the sea ban period of the Qing Dynasty accounted for the majority (15 and 17, respectively).

Table 3 compiles the colors used in 32 samples from the Song and Qing dynasties, while Fig. 3 elucidates the range and density of color distribution. The porcelain of the Song dynasty is characterized by a singularity and simplicity in color choice, with infrequent usage of blue, green, and white hues, possibly reflecting a restrained cultural expression of that period. A predilection for darker and natural tones such as black and tan indicates a profound appreciation for stability and the essence of nature, with the sparing use of vibrant colors subtly accentuating realism. The distribution of colors during the Song era was notably dispersed. Conversely, the porcelain of the Qing dynasty is distinguished by a richness and diversity of colors, with a reduced utilization of black, tan, and brown. The widespread application of red, blue, green, and white suggests a more open artistic expression and cultural diversification. The color distribution of the Qing dynasty shows a concentrated pattern, signifying a significant shift from simplicity to complexity, from dark to bright tones, and from dispersed to focused color arrangements, revealing an artistic transformation

Table 3 Color statistics of 32 porcelain bowl samples

Period	No	White	Blue	Yellow	Green	Red	Tan	Black	Brown	Embryo-color
Song	1	●		●		●	●	●		
	2			●				●		
	3			●		●		●		
	4						●	●		
	5							●	●	
	6						●			
	7		●				●			
	8									●
	9									●
	10									●
	11						●			
	12			●						
	13						●			
	14						●			
	15						●			
Qing	16	●	●		●	●				
	17	●	●		●	●				
	18					●		●		
	19	●				●				
	20					●				
	21	●			●	●				
	22	●	●		●	●				
	23	●	●							
	24	●				●				
	25	●		●						
	26	●				●				
	27		●	●		●				
	28	●	●		●	●				
	29	●	●	●				●		
	30	●	●		●	●				
	31	●	●	●	●	●				
	32	●	●			●				

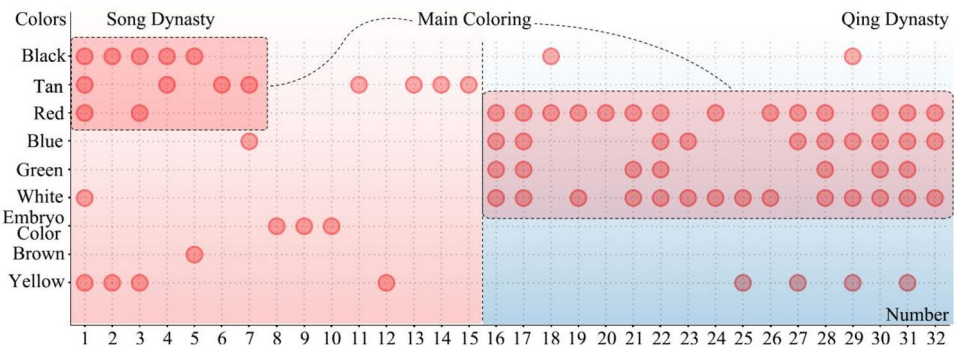


Fig. 3 Color Distribution of 32 Samples of Porcelain Bowls

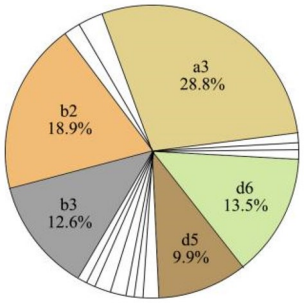


Fig. 4 Percentage of coded elements

of export porcelain under the influence of Sino-Western commercial and cultural exchanges.

Sample classification and coding

The second step is to classify samples with similar features based on their attributes, and to code each category or the elements under each category, to define several morphological variables for subsequent comparison of results. All of the 41 statistically analyzed samples are earless bowls, and only 4 have matching lids. Among them, the earliest produced is a Jin Dynasty greenish-yellow glazed dark flower small porcelain bowl (third century AD), and the most recent is a Small porcelain bowl with blue and white alum-red flower pattern produced at the end of the eighteenth century (during the Jiaqing period of the Qing Dynasty).

In terms of shape, these bowls display up to 17 design forms, among which ring foot, deep belly, arc belly, flared mouth, and wide mouth are quite common (Fig. 4). These design forms can be encoded into four groups: bowl bottom, bowl wall, bowl lid, and bowl mouth. Each form is assigned a number for subsequent typological comparison analysis (Table 4). Regarding decoration, the samples are rich in decorative patterns (up to 48 types), which can be coded into 10 categories. Plant (11 types) and texture patterns left during the casting process (10 types) are most common (Table 5). According to statistics (Fig. 5), bowls with plant patterns account for 48.7% (20), bowls with crests and font designs make up 29.7% (14), while those with craft texture patterns constitute 21.9% (9).

Table 4 Statistics, classification and coding of the design form of the sample

Coding group	Location	Elements and codes
A	Bowl bottom	Flat foot(a1), high foot(a2), ring foot(a3), round bottom(a4)
B	Bowl wall	Slant belly(b1), deep belly(b2), arc belly(b3)
C	Bowl lid	Arched(c1), knob-style(c2), cover-style(c3)
D	Bowl mouth	Petal-shaped(d1), flaring mouth(d2), lip mouth(d3), converging mouth(d4),flared mouth(d5), wide mouth(d6), rolled mouth(d7)

Table 5 Statistics, classification, and coding of Decorative patterns of the samples

Number	Types	Elements	No. of elements
①	Plant pattern	Gardenia, lotus, Blue and White Porcelain, Peony, Fish and Algae, Plum Blossom, Lotus Petal Pattern, Chrysanthemum, Scroll grass pattern, Petal, Entwined Branches	11
②	Cloud Pattern	Cloud Head Pattern, Cloud Dragon Pattern, Auspicious Cloud, Flame Cloud	4
③	Animal Pattern	Bird, Fish, Butterfly	3
④	Dragon and Phoenix Pattern	Round Phoenix Pattern, Purple Double Dragon Pattern, Cloud Dragon Pattern, Double Dragon Playing with a Pearl Pattern	4
⑤	Calligraphy Pattern	Inscription, Calligraphy Painting	2
⑥	Object Pattern	Sailboat, Eight Treasures, String of Pearls	3
⑦	Landscape and Flame Pattern	Ice Crack Pattern, Landscape, Flame	3
⑧	Polychrome Pattern	Pastel Color, Gold Color, Red Color, Blue Color	4
⑨	Craftsmanship Texture Pattern	Nail Marks, Cracking Marks, Knife Spin Marks, Tear Marks, Glaze Spots, Sand Grain, Swirl Pattern, Brown Eye, Adhesive Sand, Particle Marks	10
⑩	Theme Story	Western Figures, Sailing Ship Scene, Panoramic Landscape Painting	3

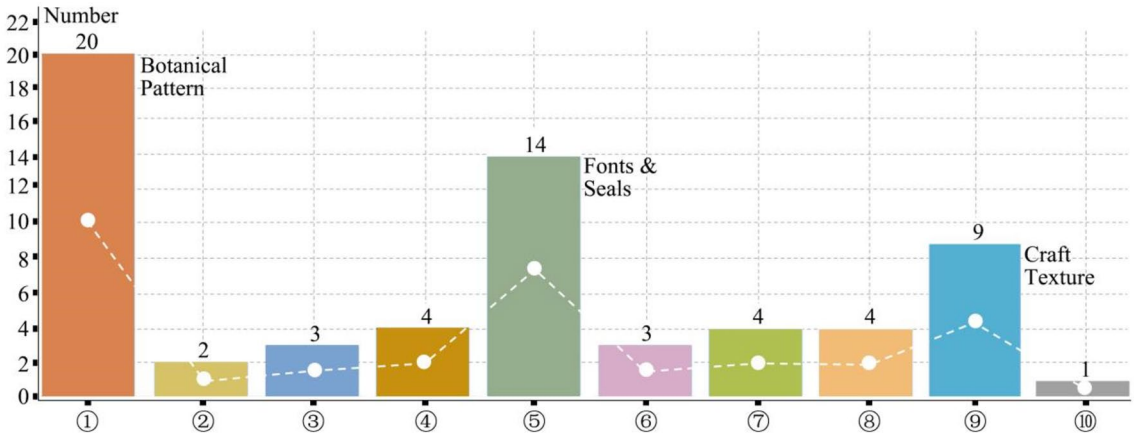


Fig. 5 The frequency of utilization for various decorative motifs in a collection of 41 bowl samples

Curve extraction and typing

The third step is to convert image samples into charts usable for quantitative analysis through the processes of edge detection and curve extraction. Firstly, referencing graphic samples, the initial outline of the image is obtained by drawing multiple short polylines in Autocad using the least squares method [65]. Then, the spline curve of the graphics is obtained using the Bayes corner point, and the edge curve is transformed into a series of data points for positioning in the chart coordinate system, quantifying morphological features. Figure 6 shows the basic steps of the typological charting quantification method.

An analysis of the shape of exported ceramic bowls from Guangzhou during the Qing dynasty based on quantitative typology

Minor differences in common bowl shapes reflect the impact of trade and cultural interaction

The artistic style of Qing Dynasty export porcelain bowls is, to a certain extent, a true reflection of the social style and commercial culture of Guangzhou. The extracted sample curves are displayed in the chart in proportion, and coded according to their shape features for subsequent typological comparison, thus discovering the inherent rules and characteristics. Due to space limitations, this article focuses on the study of Qing Dynasty bowl samples (Table 6).

In proportion, Table 7 presents the contour curve extraction and typology table of 17 Qing Dynasty bowl samples, highlighting the following features: (1) all 17 Qing Dynasty bowls adopt the ring foot form; (2) except for the typical sample 17, the proportion difference between the regular bowls and small bowls is small, showing consistency in the production process; (3) the shapes of bowl samples 11 to 13 are significant. The subsequent typological charting quantitative analysis will be carried out in two comparative groups. ● represents all groups, ▲ is the control group, and the grouping basis will be explained in the supplement.

Possibly for the sake of stability and ease of stacking [66], Qing Dynasty bowl samples adopt the ring foot design form, but there exist certain variations in the shape and tilt angle of the bowl edge among samples, which might reflect differences in usage functions or aesthetic preferences [67]. In terms of stability, the ring

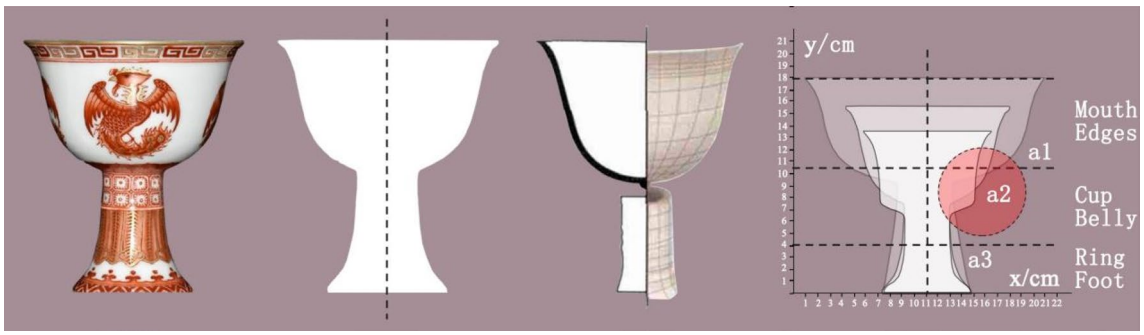


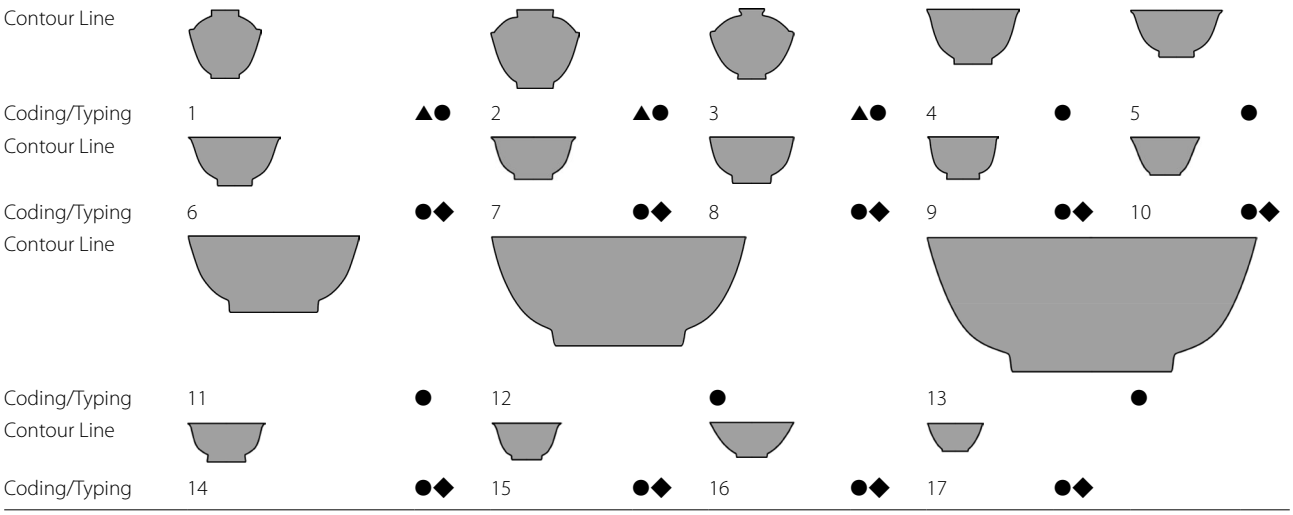
Fig. 6 Schematic diagram of the steps in the quantitative typology analysis

Table 6 Sample Data Information Sheet

Code	1	2	3	4	5
Samples					
Name	Polychrome Floral Porcelain Lidded Bowl (清五彩花卉瓷盖碗)	Famille Rose Porcelain Lidded Bowl (清晋磚唫馆款粉彩瓷盖碗)	Bean-red Porcelain Lidded Bowl (芸豆红瓷盖碗)	Yellow Ground Polychrome Cloud-Dragon Porcelain Bowl (黄地五彩云龙瓷碗)	Green Dragon Bowl (绿龙碗)
Scale/cm	H = 8 C = 8.4 BD = 3.3	H = 9.2 C = 10.3 BD = 4.2	H = 8.3 C = 9 BD = 3.3	H = 6.4 C = 11.2 BD = 4.5	H = 5.5 C = 11 BD = 4
Period	1616–1912 Qing Dynasty		(1678–1735) Qing Yongzheng	1662–1722) Qing Kangxi	
Codes	6	7	8	9	10
Samples					
Name	Yellow Glazed Cloud-Dragon with White Interior Small Porcelain Bowl (黄釉暗云龙白里小瓷碗)	Imitation Chenghua Coral Red Small Bowl (仿成化珊瑚红小碗)	Marked Purple Gold Glaze Small Porcelain Bowl (紫金釉小瓷碗)	Small glazed red porcelain bowl with phoenix (釉里红团凤小瓷碗)	Red and Gold Painted Plum Blossom Small Bowl (红彩描金折枝梅花小碗)
Scale/cm	H = 5.7 C = 11.1 BD = 4	H = 4.9 C = 9.8 BD = 4.4	H = 5.42 C = 9.9 BD = 4.4	H = 4.9 C = 9 BD = 3.9	H = 4.4 C = 7.4 BD = 3.5
Period	(1736–1796) Qing Qianlong	(1678–1735) Qing Yongzheng	(1662–1722) Qing Kangxi		(1678–1735) Qing Yongzheng
Codes	11	12	13	14	15
Samples					
Name	Guangcai Blue and Gold Painted Flower Large Bowl (广彩蓝彩描金折枝花大碗)	Guangcai Foreigners Returning Home Illustrated Large Porcelain Bowl(广彩洋人归航图大瓷碗)	Guangcai Openwork Character Pattern Large Porcelain Bowl(广彩开光人物纹大瓷碗)	Famille Rose Floral Small Porcelain Bowl (粉彩花卉小瓷碗)	Coral red and gold small porcelain bowl (珊瑚红描金小瓷碗)
Scale/cm	H = 9.1 C = 20.1 BD = 10.3	H = 13 C = 30 BD = 15	H = 16 C = 38.3 BD = 19	H = 4.5 C = 9.5 BD = 4.5	H = 4.3 C = 8.6 BD = 3.4
Period	(1736–1796) Qing Qianlong				
Codes	16	17			
Samples					
Name	Imitation Chenghua Blue and White Small Bowl (仿成化青花小碗)	Small porcelain bowl with blue and white alum-red flower pattern (青花矾红彩花卉小瓷碗)			
Scale/cm	H = 4 C = 10 BD = 3.5	H = 3.3 C = 8 BD = 3			
Period	(1662–1722) Qing Kangxi	(1796–1820) Qing Jiaqing			

H Height, *C* Caliber, *BD* Bottom Diameter

Table 7 Profile line extraction and typing table for bowlware samples



Group symbol explanation: ●All Groups ◆Control Group(Excluding samples 1–3 and 11–13)

foot of samples 4, 6, 7, 8, 11, 12, 13, 14 is characterized by being wide, flat, and thick, which increases the contact surface of the bowl and reduces the possibility of it overturning during use [68], especially as a shipped item or in other dynamic environments. Regarding stackability, the ring foot of samples 5, 10, 15, 16, 3 is narrow and rounded, demonstrating how effective stacking of bowls can be achieved through optimizing the ring foot design, providing convenience for storage and transportation, which is extremely practical for exported fragile goods.

The minute differences in the shape of regular bowls somewhat reflect the unique production and usage patterns in the Guangzhou region, indicating the influence of consistent, standardized production processes and techniques on product form [69]. Two aspects might be key reasons for these minor differences. Firstly, to cope with large order demands, the Thirteen Factories merchant district in Guangzhou during the Qing Dynasty adopted a relatively modernized assembly line production [70]. Secondly, to ensure product quality and consistency, the porcelain industry in Qing Dynasty Guangzhou established relatively strict production and quality inspection requirements, forming a standardized production model [71]. Compared to the Ming Dynasty, the production technology of Qing Dynasty potters was more mature and precise, which may be related to the political support given by the authorities [72].

Some Qing Dynasty bowls exceed the typical parameters of dinnerware, possibly reflecting some form or social symbolism [73], such as indicators of cultural customs, status, identity, or power [74]. For example, as a large bowl (H = 13 cm, Caliber = 30 cm, BD = 15 cm), Sample 12 might have been used by the affluent class, its intricate image decorations filled with rich cultural symbolism. This luxurious bowl depicts a scene of a sea-going ship returning from China and unloading heaps of goods at the dock, somewhat reflecting the Qing Dynasty's reverence for maritime culture and the power of the West in Eastern waters during the maritime prohibition period [75]. On the other hand, extra-large bowls (H = 16 cm, Caliber = 38.3 cm, BD = 19 cm) are typically viewed as vessels for serving a large amount of food on special occasions and are not mass-produced. However, Europeans in Guangzhou during the Qing Dynasty custom-ordered these large bowls in large quantities for mixing punch, calling them "punch bowls". This phenomenon reflects the profound impact of cultural differences on product form.

The morphology of the bowl bottom and bowl belly responds to the demands and functional adaptability of the export market

In the fourth step, samples from the same group in Table 7 are plotted in the same coordinate system to create a typological map (Fig. 7). This allows for a quantitative description of the differences in form, scale, and inclination among each group of samples, thereby identifying certain characteristics and providing insightful understanding of the formation process of their formal structure. Figure 7 shows the trend of contour line changes for 17 Qing Dynasty bowls under the same coordinate system. The average height and average bottom diameter of these bowls are 6.87 cm and 5.77 cm respectively. As typical reference samples, Bowl No. 13 (purple

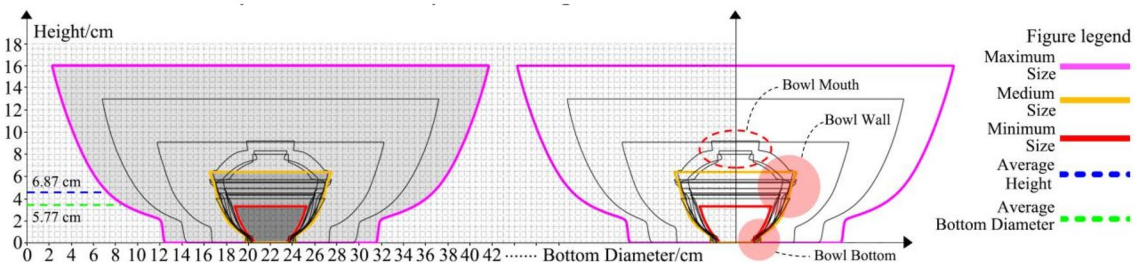


Fig. 7 Quantitative morphological map of all group samples

contour line), No. 4 (yellow contour line), and No. 17 (red contour line) represent the largest, medium, and smallest scales within these samples respectively. The curve centralization within 16 cm ≤ BH ≤ 27 cm, 5.7 cm ≤ H ≤ 4 cm and dispersion within 20 cm ≤ BH ≤ 24 cm, 12 cm ≤ H ≤ 32 cm are lateral reflections of the production patterns and usage customs of Qing Dynasty bowls. The centralized curves represent the popularization of bowl scales at the time, while the dispersion of the curves may reveal the diversity and flexibility in bowl production and use.

Given the limited samples highlighting the dispersion phenomenon, the generality of the analysis results is weak. Similarly, focusing on analysis results of the same type of utensils obviously has greater scientific validity. Next, samples 1–3 and 11–13 will be excluded. The Bowl Bottom and Bowl Wall of the control group bowls will be compared in a typological map to explore the association between the formal features of Qing Dynasty bowls and their production techniques, usage functions, and sociocultural significance.

Figure 8 describes the variation in contour line values of the control group samples. The sample with the Lowest Foot-side Junction Point Height is No. 17 (H = 1.9 cm). The Highest Foot-side Junction Point Height is No. 8 (H = 9 cm). More than half of the sample Foot-side Junction Point Heights are generally concentrated in the range of 6.1 ≤ H ≤ 9 cm, but the average height (H = 4.84 cm) is below this range. This may reflect an adaptive adjustment phenomenon between general demand and minority group preferences, revealing a systemic production trend, and that the production and export of Qing Dynasty export porcelain had a flexible response mechanism to environmental needs. In terms of the form of the ring foot wall, samples 4, 5, 6, 9, and 17 have a tendency towards a straight wall. This contributes to the enhancement of the bowl's structural stability and capacity, and also makes it easier to clean. Samples 7, 8, 15, 16 have outward-leaning characteristics, which aids in pouring out substances from the bowl, and may also facilitate grip and control [76]. The ring foot of samples 10 and 17 tend towards flatness, which reduces the possibility of the bowl tipping over during use [77]. Notably, the ring foot wall of sample 14 is inwardly concave, making it easier for substances at the bottom of the bowl to be collected towards the center of the bowl, adapting to the need to mix or stir contents [78].

Figure 9 displays the transition in shape from the bowl bottom to the bowl belly for the control group samples. Functionally, the bowl bellies of samples 10, 16, and 17 exhibit tendencies towards a straight wall, which is advantageous for storing and mixing substances [78]. In contrast, the other samples feature a significant outward bulge, providing conditions conducive for the bowl's carrying capacity and convenient hand operation [47]. Besides, except for samples 8, 10, 16, and 17, other samples' flared mouths display an outwardly curved, more expansive form [79], primarily to facilitate pouring of

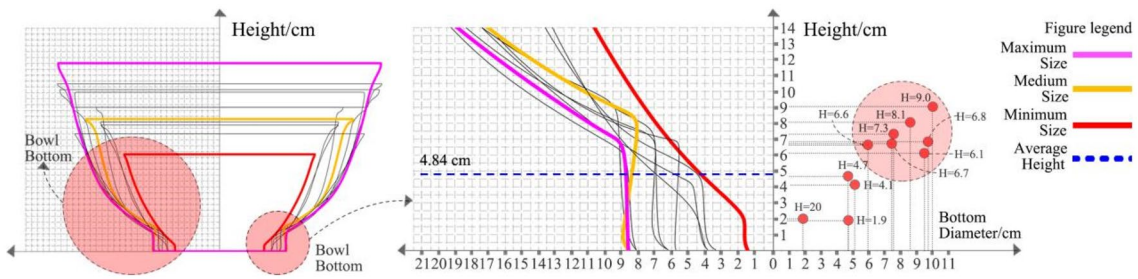


Fig. 8 Quantitative morphology map of bowl bottom in control group samples

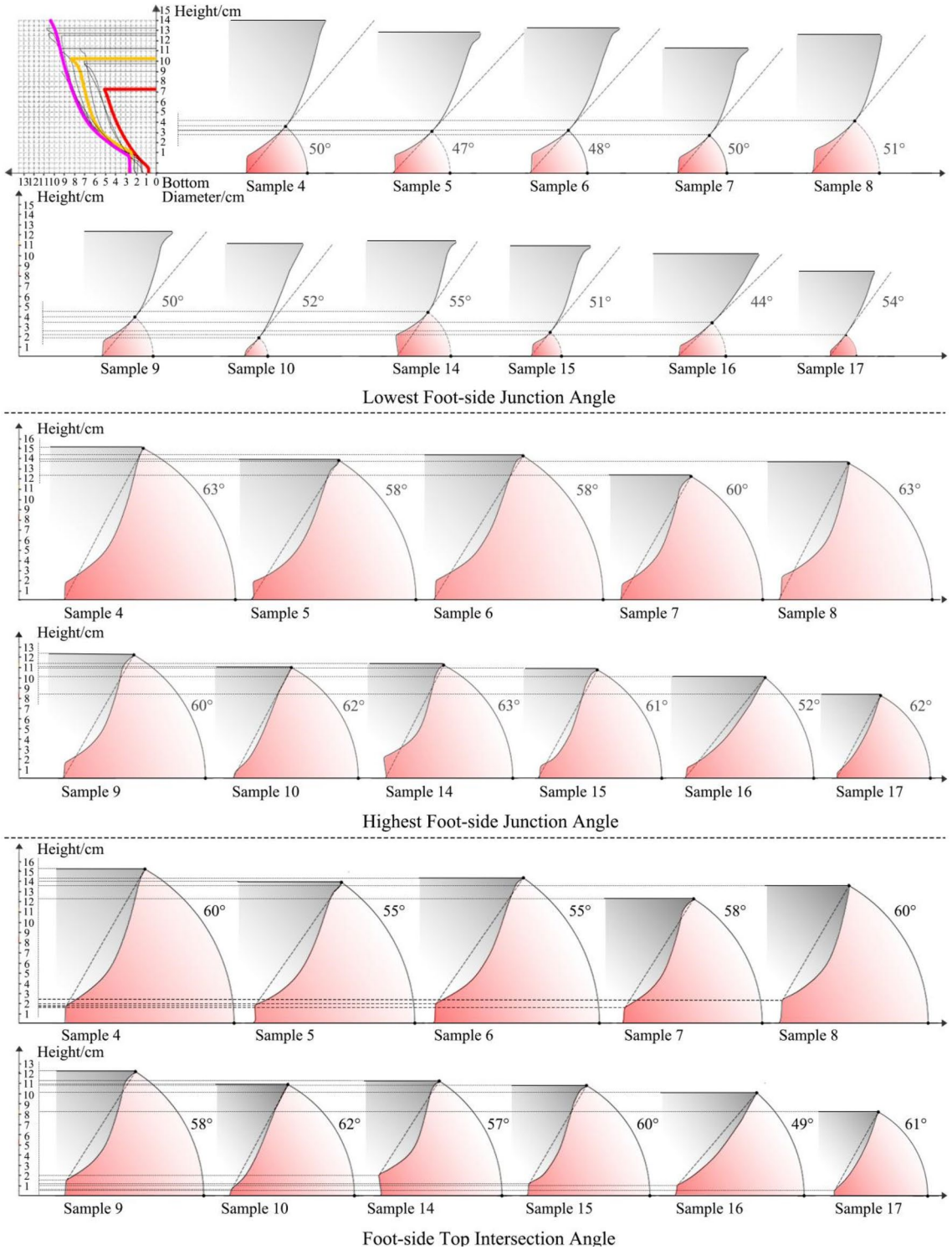


Fig. 9 Morphological Quantitative Map of the bowl wall of the Control Group Samples

soups or liquids and enable convenient use of tools like chopsticks or spoons to take food from the bowl [80]. Culturally, the product form might also vary due to differing user habits. As most of the Qing Dynasty export bowls were exported to Europe, the relative consistency in the control group samples' forms somewhat reflects the preferences and habits of Western users [81].

Table 8 Cut edge angles (∠), tangent heights (y), and their deviation from the central axis (x) between the bowl foot and bowl wall

Sample	Lowest Foot-side Junction Angle			Highest Foot-side Junction Angle			Foot-side Top Intersection Angle		
	Angle/∠	Y/cm	X/cm	Angle/∠	Y/cm	X/cm	Angle/∠	Y/cm	X/cm
4	50°	1.84	3.78	63°	5.95	5.50	60°	0.65	2.29
5	47°	1.64	3.53	58°	5.47	4.90	55°	0.67	2.10
6	48°	1.68	3.51	58°	5.65	5.52	55°	0.74	2.11
7	50°	1.48	3.45	60°	4.84	4.95	58°	0.59	2.28
8	51°	2.05	3.88	63°	5.36	5.43	60°	0.89	2.33
9	50°	1.54	3.24	60°	4.84	4.20	58°	0.60	1.94
10	52°	0.72	4.05	62°	4.35	4.05	62°	0.22	1.82
14	55°	1.72	3.45	63°	4.44	4.55	57°	0.83	2.20
15	51°	0.94	2.46	61°	4.26	4.04	60°	0.45	1.80
16	44°	1.31	4.92	52°	3.96	4.92	49°	0.41	1.85
17	54°	0.90	3.42	62°	3.25	3.24	61°	0.22	1.52
Average	50.18°	1.43	3.60	60.18°	4.76	4.66	57.72	0.57	2.02
Middle value	50°	1.54	3.51	61°	4.84	4.9	60	0.6	2.1
Difference value Δ	+0.18	− 0.11	+0.09	− 0.82	− 0.08	− 0.24	− 2.28	− 0.03	− 0.08

Table 8 records the angle change data between the bowl bottom and bowl wall reflected in Fig. 9. This paper defines the angle between the bowl foot edge point and the outermost cut edge of the bowl wall as the Lowest Foot-side Junction Angle, the angle between the bowl foot edge point and the highest point of the bowl wall as the Highest Foot-side Junction Angle, and the angle between the top point of the ring foot and the highest point of the bowl wall as the Foot-side Top Intersection Angle. ∠denotes angle, Y represents the cut-off height value, X denotes the distance from the cut-off point to the bowl's central axis. Δis used to represent the Difference value between the mean and the median. A larger absolute value ofΔindicates the presence of outliers or anomalous values in the dataset. AΔabsolute value closer to 0 indicates the dataset's distribution is approximating a normal distribution. The magnitude ofΔ reveals the uniformity or standardization degree of the control group samples' morphological features. Sample 16's morphological features differ significantly from other samples, reflected in its larger bowl belly inclination and larger difference between the mouth diameter and the bottom diameter. The body of this bowl is thin and light, its form characterized by a wide mouth and deep arc wall. As a typical sample, sample 16's Lowest Foot-side Junction Angle (44°), Highest Foot-side Junction Angle (52°), and Foot-side Top Intersection Angle (49°) are all the smallest values, while its X values are higher than the average. After excluding the typical sample 16, the average Lowest Foot-side Junction Angle of the control group samples is 50.8°, the average Highest Foot-side Junction Angle is the same as the median (61°), and the average Foot-side Top Intersection Angle is 58.6°. These angular measurements may reflect specific functional designs as well as considerations for hand comfort. In comparison to Asians, larger Foot-side Junction Angles and Top Intersection Angles may be required to accommodate Europeans' generally larger hands [82], and their grip and pinch force normal values are slightly lower [83]. The aforementioned values reveal the complex interactions and mutual influences between pottery craft and target market user demands.

Discussions

The typological features of Qing dynasty export porcelain bowls manifest their uniqueness as art commodities, encompassing: (1) a prevalent ring-foot base; (2) a relative consistency in overall form; and (3) anomalous dimensional disparities in some specimens. Section three of this paper has delved into the correlation between these morphological dimensions and their functional usage. However, as art commodities, the formation of Qing dynasty Guangzhou export porcelain bowl forms is closely connected not only to its unique mercantile culture and technological craftsmanship but also to market demand orientation [84]. The establishment of the Guangzhou Thirteen Hongs in 1757 not only signified the germination of the capitalist economic system in China but also heralded a pronounced commodification of export porcelain bowls. Their primary export targets were Western countries, hence the morphological art evolved in response to the aesthetic demands of the user groups.

The Opium War of 1840 marked the disintegration of China's traditional natural economy and prompted a significant shift in Guangzhou's trade model towards a technology-dependent economic paradigm. Emerging industrial technologies introduced into the porcelain production process [85] led to standardized production modes, which might explain the convergence and relative uniformity in porcelain bowl forms. Zhao [86] narrates the porcelain production process of the Qing dynasty through the "Porcelain Manufacturing Chart." Busto Zapico and García Porras [87] observed that the transformation to industrialized production technology greatly enhanced the productivity of potters, while the increasing market demand propelled the standardization of the ceramic genesis process. Busto-Zapico [88] also identified form convergence in the standardized production of early Spanish pottery. However, as exemplified by samples 11–13, the substantial size variation reveals the distinct symbolism and class identity of these porcelain bowls. On the one hand, the basin-sized design is evidently not oriented towards practical functionality but is likely intended to showcase the craftsmanship and cultural depth of the producing country. If intended as courtly decor, it may symbolize prestige and status [89]. Costin and Hagstrum's research [90] into the ceramic production methods of the pre-Spanish period in Peru revealed differences in the production of daily use products and luxury items under consumer markets. In the study, sample 12's Guangcai Westerner Returning Home motif large porcelain bowl, with its detailed rendering and choice of maritime theme, not only highlights the Western desire for maritime hegemony but also displays the curiosity for the Eastern power. Consequently, the emergence of such atypical porcelain bowls also reflects the market's response to special, niche custom-made products [91], exhibiting the Western nobility's preference for uniqueness and personalized products [92].

Changes in product form are not solely the result of functional needs, but the product of various cultural, social, and political factors interacting, emphasizing the tight connection between material culture and social life. Dong [93] found that the form of bowls was influenced by military conflicts and maritime trade systems, and this paper further reveals how the Qing Dynasty ceramic industry in Guangzhou adapted to these social changes by introducing assembly line production and quality inspection. Huang's [94] research also emphasized the policy orientation's impact on the form and patterns of bowls, while this paper reveals that the differentiation in forms and diversity in sizes of Qing Dynasty bowls could be to cater to market demands and cultural customs and aesthetic preferences, which aligns with the viewpoints of Zhang [95]. Similar to the research findings of Chen [96], this paper discovers that the minute differences in the regular form of Qing Dynasty bowls are related to the craftsmanship of potters, which could be politically supported. Liu et al. [97] believe that the evolution of bowl form follows the principle of functionality first, and this paper provides quantitative data to support the angle changes between the bowl bottom and bowl wall and functional analysis. Zhang and Han [98] emphasized the influence of users' sensory experience and cultural needs on the form of bowls. This paper takes into account the differences in aesthetic preferences and usage habits of Western users, extending the issue to the complex interaction and mutual influence between the art of Qing Dynasty bowl form and the demands of target market users.

Quantitative Typological Analysis, originating from the field of archaeology, has revealed its interdisciplinary importance in heritage science and design studies for morphological identification and symbol decoding. Despite variations in the depth and breadth of its application across disciplines, the research subjects and analytical methods used by Ashka and Ahmad [99] (architectural morphology), Waksman and Teslenko [100] (excavated vessel morphology), and Liu [101] exhibit similarities. Therefore, the research methodology of this paper also possesses a certain replicability. In the introduction's fourth paragraph and subsection 2.1, the paper elucidates examples of morphological typology's application in fields such as archaeology, art studies, design, architecture, and sociology. As an analogous method, the potential future applications of quantitative typological charts are foreseeable. For instance, the method could be applied to the ergonomic analysis of office swivel chair design or the analysis of columnar and morphological structures in historical buildings.

Regarding further possibilities for the application of this research method in heritage studies. Firstly, the method can precisely capture subtle morphological changes and historical evolutions in digital heritage reconstruction. Secondly, it can provide a more accurate morphological matching benchmark for the identification and restoration of artworks. Additionally, it can offer morphology-based assessments and recommendations for urban planning and heritage conservation.

This paper has slight deficiencies in terms of the quantity of sample analysis and the diversity of social factors considered. The target analysis samples of this paper are mostly regular and small-sized ceramic bowls, and there is a lack of in-depth exploration for samples 1–3 and 11–13. In terms of the cultural factors shaping the product form, it does not include contemporaneous religious philosophical thoughts as influencing factors like Zhang [95] did. In the analysis of form and functional use, it

lacks the extension to the relevance of bowl form with the hand size and gripping habits of different nationalities, like Feng [102] did. Moreover, the replicability of the method is contingent upon the specific research context and experimental conditions, which may be constrained by technology, data, and resources. Given the knowledge disparities between disciplines, the replication and widespread application of quantitative typological charting methods still require further attention.

Conclusions

The research process has revealed that: (1) The ring foot design was prevalent in the bottoms of bowls for export during the Qing Dynasty; (2) The average height and bottom diameter of these bowls tend towards 6.87 cm and 5.77 cm respectively, whereas 16 cm $\leq$ BH $\leq$ 27 cm, and 5.7 cm $\leq$ H $\leq$ 4 cm are common ranges for the diameter and height of Qing Dynasty bowls, displaying a relatively concentrated feature; (3) The Foot-side Junction Point Height of Qing Dynasty bowls typically falls within the range of 6.1 $\leq$ H $\leq$ 9 cm, yet the average height value (H = 4.84 cm) is lower than this range, revealing systematic production trends and relative consistency in form; (4) Some Qing Dynasty bowls exceed the parameter range of typical tableware, reflecting the adaptability and innovation of the production mechanism when responding to unique market demands.

To delve deeper into the causes of the forms of Guangzhou export ceramics, it is crucial to interpret not only their functional usage and artistic nature of decorative patterns, but more importantly, to present their social attributes as manifested in the production mechanism. The morphological evolution of Qing Dynasty bowls for export is a true reflection of intertwined factors such as comfortable design and aesthetic preferences, while the convergence in form is a comprehensive demonstration of meeting market demands and the advancement of production technology. This study responds to how social factors play a role in shaping the artistic form of material cultural products and extends the research dimension to the interaction between standardization in production processes and social-cultural demands. Future research will focus on the relevance between the form of Qing Dynasty bowls and the dimensions and gripping habits of hands.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40494-023-01103-2.

Additional file 1. Sample Information Sheet.

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Author contributions
Conceptualization, JA, WL and SJ; methodology, JA and WL; software, WL, JA and SJ; validation, WL, JA and SJ; formal analysis, WL, JA and SC; investigation, JA, WL and SC; resources, WL and JA; data curation, WL, JA and SJ; writing—original draft preparation, JA and WL; writing—review and editing, JA and WL; visualization, WL, and JA; supervision, WL and JA; project administration, JA and WL; funding acquisition, JA. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials
Some or all data, models, or code generated or used during the study are available from the corresponding author by request.

Declarations

Competing interests
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Publisher's Note

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