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# Quantitative typological analysis applied to the morphology of export mugs and their social factors in the Ming and Qing dynasties from the perspective of East–West trade

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## Abstract

The relationship between social factors and the formation of exported mug designs is blurred. This study addresses how they influence material design. Based on a quantitative typological analysis, this paper interprets the cultural relationships underlying the evolution of mug designs exported during the Ming and Qing dynasties. The study reveals: (1) the typology and handle styles of mugs can be categorized into six types, with a predominance of Cylindrical bodies and Ear-shaped handles. Notably, artistic emphasis is concentrated on Bulbous cup bodies and Tail outward curved handles; (2) the design of mugs in the eighteenth century exhibited diversity, morphological similarities, and feature continuity, evolving from representational (Ming Dynasty) to abstract and then to minimalistic styles (Qing Dynasty), particularly evident in the three-dimensional modeling of handles for ergonomic comfort (transitioning from a singular Outward curved form to Ear-shaped form, and then to Entwined branch form); (3) the body shape of mugs transformed from Arc-barrel bodies to Bulbous bodies (focusing on heat retention), and eventually to Cylindrical bodies (prioritizing heat retention, practicality, and cost-efficiency); (4) the volume of mugs steadily increased from the early eighteenth century, generally classified into large volume ( $\geq 500$  ml), medium volume (200–499 ml), and small volume ( $< 200$  ml); (5) considering the extreme range of volume (11090 ml) and height (25 cm), it indicates that these two variables do not necessarily have a direct positive correlation; (6) the low center of gravity in handle design (average width of 3.4 cm against an average height of 9.9 cm for the body) reflects considerations for the distribution of liquid weight and operational convenience. The volume of sample-10 (11127 ml) notably exceeds the typical range for tea-drinking utensils, revealing the mechanism of wealth and status symbolism. Market demand orientation emerged as the primary driver for the evolution of export mug designs during the Ming and Qing Dynasties, with adjustments in the merchant system playing a secondary role. The transformation in mug design reflects the interplay of multiple factors, with the trend toward minimalist design being a response to market demands.

**Keywords** Porcelain, Cantonese mugs, Quantitative typological analysis, Morphology, Evolution, Social factors, Trade culture, Ming and Qing dynasties, China, Guangzhou

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## Introduction

Research on “exported ceramics” has shifted from a focus on material forms to the realm of external cultural communication [1]. Western scholars approach the topic from the perspective of cultural change and fusion, emphasizing cultural fluidity and adaptability [2]. In contrast, Chinese scholars emphasize the exported ceramics as empirical records of historical society, focusing on their unique aesthetic value in patterns, colors, and shapes [3]. Hence, the research perspective has transformed from cultural regionalism to symbolism. To comprehensively decipher the formation of its decorative art, one must transcend the boundaries of individual disciplines and delve into the underlying cultural formation logic. This paper offers an in-depth examination of external factors behind the artistry of Guangzhou exported ceramics, particularly the influence of trade culture.

Since the United Nations introduced the “Convention for the Safeguarding of the Intangible Cultural Heritage” in 2003 [4], global awareness towards the restoration and protection of cultural heritage has intensified [5, 6]. This concerns not only the inheritance of artistic value but also the pivotal task of maintaining emotional and cultural identity across regions and nations [7]. The fourth chapter of the “Cultural Relics Protection Law of the People’s Republic of China” elaborates on the management, circulation, and restoration of exported relics, aiming to ensure their integrity and authenticity [8]. However, Guangzhou’s export culture seems to be losing its uniqueness in the face of cultural globalization [9]. Archaeological data indicates that the manufacturing history of Guangzhou’s exported ceramics can be traced back to the mid-late Ming dynasty and peaked during the Qing dynasty. However, current restoration policies seem to prioritize economic value, resulting in the marginalization of cultural inheritance to some extent [10–12]. In response to the needs for cultural identity and inheritance, numerous cultural derivatives related to relics have emerged. Presently, these derivative designs suffer from excessive commercialization and a lack of innovation [13].

Historically, exported ceramics were not just tools for economic exchange but also carriers of cultural interaction [14]. Today, they are seen more as vital witnesses to history, politics, and cultural geography [15]. Lu [16] utilized archaeological typology to systematically categorize and illustrate ancient artifacts, discovering that such artifacts from various periods reflected the combined influences of societal structures, cultural inheritance, and technological innovations. Sun and Qian [17] concentrated on the morphological evolution of ceramic drinking vessels from the Ming and Qing dynasties, contending that their designs were profoundly influenced

by the contemporary socio-economic context, technological advancements, and aesthetic values, mirroring the cultural backdrop and value orientations of their times. Yonan [18] delved into stylistic features of vessel shapes, meticulously documenting their forms, craftsmanship, and dynastic origins, revealing how ancient ceramic techniques and cultural elements merged, clashed, and gradually evolved into distinct cultural symbols over different historical epochs. Hu [19] compared Chinese and Western vessel shapes, patterns, and glaze colors, finding that Chinese vessels integrated Ming dynasty aesthetic trends while also incorporating elements from external cultures, reflecting the historical interactions and exchanges between the Ming dynasty and other civilizations.

In summary, it is particularly important to analyze how social structures and historical contexts shape material forms, as well as to explore their cultural heritage value and social significance. Currently, external factors have been recognized as key elements affecting the formation of the decorative art of exported ceramics, with a further shift towards cross-regional cultural studies [20]. Few Chinese scholars have explored the cultural logic behind the formation of exported ceramics decorative art from a broader societal perspective.

This study analyzes the transnational dissemination of export ware from Guangzhou, revealing socio-historical influences and reflecting the evolution of Guangzhou’s port culture. As a significant cultural heritage of Guangdong’s history and the Maritime Silk Road, Guangzhou’s export ware occupies a central position in the realm of exported artifacts. An analysis of the artistic characteristics of Qing Dynasty Cantonese mugs further reveals their impact on traditional production modes and related manufacturing industries.

The interplay between material form changes and social factors can be explored through several dimensions: (1) the continuity of form characteristics. This involves investigating how form characteristics are inherited, transformed, or discarded over different periods, and how these changes reflect societal values and technological advancements. Historic heritage is examined to understand how certain forms evolve; (2) the innovativeness of artistic design. This includes analyzing innovations in design elements and decorative techniques, and how these are influenced by contemporary technology, economics, and culture. The roles of artists, craftsmen, and designers are highlighted, along with their responses to and influence on societal trends; (3) the local relevance of product design. This focuses on how product designs reflect local cultural characteristics and societal needs. It analyzes how local design elements and functionalities are integrated into products, and how these designs meet or reflect the specific needs and preferences of

local communities; (4) the convergence and divergence in the commodification of products. This explores how products adapt to global market needs and find a balance between globalization and localization. The varying acceptance and usage of similar products across different regions or communities are analyzed, and how these differences impact marketing strategies and design.

The study initially categorizes, statistically analyzes, and synthesizes selected mug samples. Subsequently, it classifies and codes these samples based on their characteristic attributes, extracts contour curves of each sample group, and plots them on a unified coordinate axis. Furthermore, data on diameters, rim sizes, heights, and volumes of the mugs are visually analyzed to uncover stylistic trends in form evolution over different periods. Finally, grounded in the historical context of Qing Dynasty Guangzhou, interpretive historical research is employed to discuss the influence of trade culture on the decorative art of export porcelain.

## Methodology

### Cantonese mugs

Ancient Chinese tea and wine cups, predominantly handle-less [16], significantly differed in shape and size from mugs, indicating a lack of direct lineage [21]. The emergence of mugs was closely linked to Western trade expansion [22, 23]. Known as “mugs (马克杯),” these vessels, originating in mid-sixteenth century Europe, initially featured large handles, robust bodies, and intricate designs to signify the user’s status and wealth [24]. While the exact time of their introduction to the Chinese market is not documented, research by Ao et al. [25] and Kharchenkova [26] suggests their arrival post-1757 with the establishment of the Cantonese thirteen-hongs, the sole legal trading entity in Guangzhou from 1757 to 1840 [27]. Figure 1 presents a custom design blueprint of a mug circulated in the Qing Dynasty Guangzhou market by the West [28], exemplifying early trends in East–West

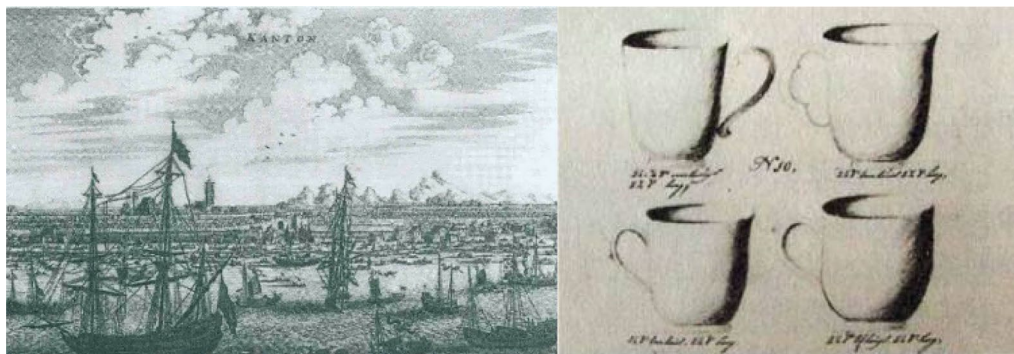
cultural exchange and product customization. Compared to typical mugs, Cantonese mugs, renowned for their unique local craftsmanship and trade background, demonstrate intricate design and craftsmanship, reflecting cross-cultural adaptation and innovation, thus furthering cultural integration and artistic innovation, and symbolizing Guangzhou’s flourishing foreign trade.

In 1784, Shaw, responsible for escorting the British Queen’s ships, noted: “There are many painters in Guangzhou, but as far as I know, none possesses a design genius... It’s commonly said that Chinese painters, while capable of imitating most fine arts, lack much original genius” [29]. This indicates that Cantonese mugs, to some extent, represented the economic attributes and production characteristics under the market demands of Qing-era Guangzhou, being the outcome of market demands intertwined with local production capabilities. In this context, they not only reflected the socio-economic conditions of the time but also served as vehicles for cultural fusion and innovation.

Socially, the evolution in the design of mugs mirrored the societal values and lifestyles of Ming and Qing China, as well as the relationship between craftsmen and consumers. Market and aesthetic demands drove innovation in mug decorations and forms, breaking free from traditional constraints and exemplifying a dual pursuit of functionality and aesthetics.

### Quantitative typological analysis

Archaeology is the study of human culture and behavior through its material evidence. Although archaeology sometimes works with the material evidence of contemporary societies (ethnoarchaeology) or historical societies (historical archaeology and classical archaeology), for most of our past, the archaeological record is the only source of information. What we can learn about that past must come from surviving artifacts and modifications of the earth’s surface produced by human activity.



**Fig. 1** Mugs customized design for market demand oriented designs [28, 30]

Quantitative archaeological data can be divided into four broad classes: shape, composition, age, and location. Compositional data can be further divided between object composition (e.g., elemental or isotopic composition) and assemblage composition (counts of particular types of artifacts from a site, grave, level, or grid square). Quantitative typological analysis in archaeology is a method of formal typological classification using an explicit quantitative approach to investigate patterns of cultural change [31–33].

Examples of this method include, e.g., Busto-Perez et al. [34] utilized 3D geometric morphometrics and machine learning to analyze the morphological differences of middle paleolithic backed flakes, offering a refined method for lithic analysis. Osipova et al. [35] applied morphological typology to examine hand axes from the Aral Sea and Mugalzhar regions, uncovering cultural exchange evidence. Ao et al. [25] categorized Qing Dynasty export porcelain bowls into ring-footed and non-ring-footed groups, comparing their bottom and belly curves through matrix grid analysis. They noted some bowls exceeding typical dining ware dimensions, highlighting the production system's adaptation to market demands. Han and Li [36] classified Yuan Dynasty stem cups into five types based on morphological differences, correlating handle comfort with belly curve angles, and found design variations revolving around functionality. Meng and Zhou [37] segmented Tang Dynasty ceramic pitchers into four styles based on chronological sequences, analyzing commercial drivers behind their form through metrics like the average center of gravity, handling space, and spout angle. Liu [38] analyzed Qing Dynasty ceramic bottles using symmetry elements, categorizing them by belly shape and encoding distinct morphological features, evidencing the influence of flourishing foreign trade on their evolution.

Data collection for artifact morphology includes methods like 3D modeling, 3D scanning, creating Autocad libraries, museum data collection, and historical archives. Ao et al. [25] gathered frontal images and dimensions from museum electronic displays, replicating them in Autocad and adjusting them through multiple calibrations. Di Angelo et al. [39] used 3D scanners to obtain point cloud data of ceramic fragments, identifying uniformity and building a 3D database. Guo [40], however, adopted a more traditional approach, collecting and constructing Excel databases from thesis appendices with similar themes.

This study will gather data from various museum digital collections, including measurements like radius, aperture, and base diameter. The process involves three-dimensional modeling in Rhino software, adjusted according to rotatable 3D images from digital collections,

and multi-point calibration based on dimensions. The models are standardized in Rhino for uniform elevation views and imported into Autocad 2022 for library creation. A unified X and Y axis is established with matrix grid lines for morphological data collection.

In our study, quantitative typological analysis follows these steps [36]: (1) Data collection and preprocessing for sample completeness and reliability; (2) Classification and coding of samples based on structural and attribute characteristics; (3) Extraction and comparison of contour curves based on morphological features; (4) Calculation of related morphological variables in Autocad 2022; (5) Grouping and charting of similarly coded outlines in a unified coordinate system to compare their proportions, scales, and variations.

#### Data sources and processing

The first step involves data collection and processing. The data for this study was sourced from 14 museums, including the Guangdong Province Museum, the National Museum of China, and the British Museum. The term “Mug” is also known as “handled cup” and “single-handled cup”. The research was conducted using these keywords, resulting in the acquisition of 23 valid samples of Ming and Qing dynasty ceramic mugs (Additional file 1: Appendix): 3 from the Ming dynasty and 20 from the Qing dynasty (of which 9 are Cantonese mugs). These three groups were respectively coded as A, B, and B' (Table 1).






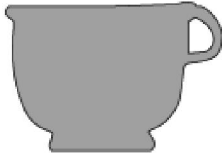



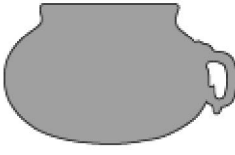

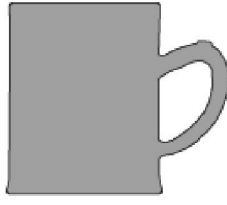




#### Sample typing and coding

The second step involved categorizing samples with similar characteristics and encoding each category or its elements to define morphological variables for subsequent comparative analysis. For the criteria of morphological classification, this paper refers to Lu's [16] “Dictionary of Ancient Chinese Artifacts. Volume of Ware” published in 2001 for morphological classification. This extensive work showcases a wide variety of wares, including bowls, bottles, pots, and dishes, and systematically delineates their common features and patterns in similar designs, as described in Table 2 of the book. This approach facilitated a structured and comprehensive analysis of the artifact morphology, providing a foundation for further detailed investigations into the specific characteristics and trends of these ancient artifacts.


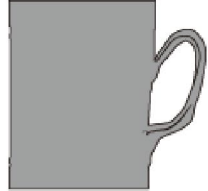





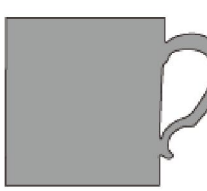

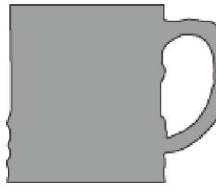






The coding results for 23 mugs have been presented in Table 1. The order of the coding naming is composed of dynasties, types, patterns, and codes. Mugs from the Ming dynasty, Qing dynasty, and Cantonese mugs are respectively coded as A, B, and B'. For instance, sample 16 is coded as B'a1-xx type. According to Table 2, this study divides the mug bodies in Table 1 into 6 types (Table 3):



**Table 1** Sample data information sheet

<b>Codes</b>	1		2	
<b>Samples</b>				
<b>Name</b>	Dehua Kiln White Porcelain Handled Cup (德化窑白瓷把杯)		Dehua Kiln White Porcelain Autumn Leaf-shaped Handled Cup (德化窑白瓷秋叶形把杯)	
<b>Collector</b>	Zhejiang Province Museum			
<b>Types</b>	AcIII-01	▽	AfII-02	▽
<b>Codes</b>	3		4	
<b>Samples</b>				
<b>Name</b>	Shiwan Kiln Light Green Glazed Ring-handled Cup (石湾窑浅绿釉环柄杯)		Green Ground Famille Rose Entwined Lotus and Bat Design Single-handled Cup (绿地粉彩缠枝莲蝠纹单柄杯)	
<b>Collector</b>	Chinese Palace Museum			
<b>Types</b>	AcVI-01	○	BcIV-01	●
<b>Codes</b>	5		6	
<b>Samples</b>				
<b>Name</b>	White Glazed Incised Spiral Design Single-handled Cup (白釉暗划回纹单柄杯)		Famille Rose English Cobbler Illustrated Mug (粉彩英国皮匠图马克杯)	
<b>Collector</b>	Chinese Palace Museum		British museum	
<b>Types</b>	BdII-01	●	B'aII-01	●
<b>Codes</b>	7		8	
<b>Samples</b>				
<b>Name</b>	Jingdezhen Kiln Aubergine Glazed Lingzhi Mushroom Handled Cup (景德镇窑茄皮紫灵芝柄把杯)		Dehua Kiln White Glazed Bamboo Joint Cup (德化窑白釉竹节杯)	
<b>Collector</b>	Zhejiang Province Museum		Beijing Capital Museum	
<b>Types</b>	BcII-01	●	BcI-01	▽

**Table 1** (continued)

<b>Codes</b>	9		10	
<b>Samples</b>				
<b>Name</b>	Jingdezhen Kiln Blue and White Pavilion Illustrated Handled Cup (景德镇窑青花亭台楼阁图把杯)		Celadon Mug (青花马克杯)	
<b>Collector</b>	Shanghai Museum		Shanghai Zhendan Museum	
<b>Types</b>	BaI-04	◆	BaI-03	◆
<b>Codes</b>	11		12	
<b>Samples</b>				
<b>Name</b>	Blue and White Landscape Illustrated Mug (青花山水风景图马克杯)		Western-style Porcelain Blue Ground Gilded Character Illustrated Handled Cup (洋瓷蓝地描金开光人物图带柄杯)	
<b>Collector</b>	Jingdezhen Museum		Chinese Palace Museum	
<b>Types</b>	BbI-02	▽	BaIII-01	▽
<b>Codes</b>	13		14	
<b>Samples</b>				
<b>Name</b>	Famille Rose Imitation Spotted Bamboo Floral Pattern Mug (粉彩仿斑竹花卉纹马克杯)		Zisha Single-eared Orchid Grass Inscribed Square-mouthed Cup (紫砂单耳兰草铭文方口杯)	
<b>Collector</b>	Beijing Guanfu Museum		Chengdu Dayi County Cultural Management Office in China	
<b>Types</b>	BfI-01	●	BeI-01	○
<b>Codes</b>	15		16	
<b>Samples</b>				
<b>Name</b>	Canton Enamel Human and Floral Bird Pattern Teaware (广彩人物花鸟纹茶具)		Canton Enamel Floral, Butterfly, and Human Pattern Mug (广彩花蝶人物纹马克杯)	
<b>Collector</b>	The First Customs Museum of Guangdong		Guangzhou Thirteen-hongs Museum	

**Table 1** (continued)

<b>Codes</b>	17		18	
<b>Samples</b>				
<b>Name</b>	Canton Enamel Blue and White Brocade Ground Landscape and Character Illustrated Mug (广彩青花锦地开光山水人物纹马克杯)		Canton Enamel Brocade Ground Ship and Character Illustrated Mug (广彩锦地开光船舶人物纹马克杯)	
<b>Collector</b>	Guangzhou Thirteen-hongs Museum			
<b>Types</b>	B'aII-02	▽	B'aIV-02	○
<b>Codes</b>	19		20	
<b>Samples</b>				
<b>Name</b>	Canton Enamel Ladies and Children Playing Pattern Mug (广彩仕女婴戏纹马克杯)		Canton Enamel Courtyard Human Pattern Cup with Saucer (广彩庭院人物纹带碟杯)	
<b>Collector</b>	Guangzhou Thirteen-hongs Museum			
<b>Types</b>	B'dI-01	○	B'cV-01	○
<b>Codes</b>	21		22	
<b>Samples</b>				
<b>Name</b>	Canton Enamel Floral, Butterfly, and Human Pattern Mug (广彩花蝶人物纹马克杯)		Canton Enamel Floral and Badge Pattern Barrel-shaped Mug (广彩花卉纹章纹筒形马克杯)	
<b>Collector</b>	Guangzhou Thirteen-hongs Museum		Guangdong Province Museum	
<b>Types</b>	B'al-01	◆	B'bl-01	▽
<b>Codes</b>	23			
<b>Samples</b>				
<b>Name</b>	Canton Enamel Gilded Floral and Badge Pattern Mug (广彩描金花卉纹章纹马克杯)			
<b>Collector</b>	Guangdong Province Museum			
<b>Types</b>	B'aIV-01	○		

**Symbol Description:** A- Ming dynasty; B- Qing Dynasty; B'- Cantonese mug

**Handle types:** ◆ Entwined Branch Handle (缠枝状); ● Bamboo Joint Handle (竹节状); ○ Ear-shaped Handle (耳廓状); ◇ Inward Convex Handle (内凸状); △ Inward Curved Handle (内弧状); ▽ Outward Curved Handle (外翘状)

**Table 2** Characteristics of the abdominal and handle shapes of the six types of ceramic vessels

Parts	Types	Morphological Characteristics
Vessel Bodies	Cylindrical (直筒形)	(1) Exhibits an upright cylindrical form, with sides parallel or slightly tapering inwards; (2) The base is generally flat, occasionally with a slight concave indentation; (3) The top rim may be upright or slightly flared outwards
	Barrel-shaped (桶形)	(1) Features a gentle curvature on the sides, resembling a barrel shape; (2) The base is wider than the top, yet both are proportionally balanced; (3) The top rim is usually thicker to augment structural stability
	Bulbous Cup Body (鼓腹形)	(1) The base is narrower, with the middle expanding into a bulbous form; (2) The top edge may be thinner, creating a contrast with the expanded body
	Gourd-shaped (葫芦形)	(1) Displays a two-tier structure, either narrow at the top and wide at the bottom or vice versa; (2) Often characterized by a distinct neck
	Square (方形)	The four sides are straight and angular
	Irregular-shaped (异形)	(1) An irregular shape, without a fixed geometric form; (2) May incorporate a combination of various design elements, such as a round base with a square mouth
Handles	Entwined Branch Handle (缠枝状)	(1) Mimics the form of naturally entwined branches, featuring complex curves; (2) Surface details may include textures resembling tree bark or small knots; (3) Structurally emphasizes a balance between aesthetics and practicality
	Bamboo Joint Handle (竹节状)	(1) Imitates the shape of bamboo nodes, with clear separation between sections; (2) The surface often has lines simulating bamboo patterns; (3) Design focuses on simplicity and naturalness; (4) Exhibits varying degrees of bending
	Ear-shaped Handle (耳廓状)	(1) Resembles the shape of human or animal ears, being semi-circular or oval; (2) May feature simple or decorative edges; (3) Aesthetically seeks harmony with the main body of the object; (4) Common in classic or traditional style items; (5) Carries significant symbolic meaning or decorative effect
	Inward Convex Handle (内凸状)	(1) Presents an inwardly convex design; (2) Balances ergonomics and functionality in its form; (3) Used in objects requiring a firm grip; (4) Visually more subtle or integrated into the overall design of the object
	Inward Curved Handle (内弧状)	(1) Characterized by an inwardly curving arc; (2) Structurally designed for comfortable gripping; (3) Often harmonizes with the overall curvature of the object; (4) May feature a streamlined aesthetic typical of modern design
	Outward Curved Handle (外翘状)	(1) Shaped with an outward flare or curve; (2) Emphasizes dynamism and visual impact in its form; (3) Used in objects with a strong personality, often in modern or abstract styles; (4) Functionally designed for ease of grasping and carrying

Cylindrical Cup Body-Type A (Sample 23), which is characterized by a vertical alignment of the cup's mouth and body, with equal diameters at the top and bottom; (2) Barrel-shaped Cup Body-Type B (Sample 22), where the body is barrel-like; (3) Bulbous Cup Body-Type C, with a mouth diameter larger than the base, and an outwardly convex curve near the bottom of the body; (4) Gourd-shaped Cup Body-Type D (Sample 19), where the body is gourd-shaped and the external contour exhibits a continuous double curve; (5) Square Cup Body-Type E (Sample 14), which has a square cross-section and a cuboid body with edges; (6) Irregular-shaped Cup Body-Type F, which displays an irregular form.

Table 3 is a combination typology table based on the morphology and handle types from Tables 1, 2. Handles are subdivided into six categories, including: (1) Entwined Branch Handle (◆), which displays a pattern reminiscent of intertwined tree branches. This might have been influenced by ancient plant decorative patterns, showcasing a traditional aesthetic appreciation of natural beauty; (2) Bamboo Joint Handle (●) emulates the natural characteristics of bamboo, reflecting the tenacity and grace found in Eastern philosophy; (3)

Ear-shaped Handle (○) resembles a human ear, possibly correlating with the socio-cultural customs and bodily aesthetics of the time; (4) Inward Convex Handle (◇) exhibits a concave design, providing users with a more stable grip; (5) Inward Curved Handle (△) extends in a gentle curve, mirroring ancient aesthetic pursuits of harmony and fluidity; (6) Outward Curved Handle (▽) adopts a dynamic, undulating design, enhancing the artistic expression of the mugs.

Table 4 classifies the 23 mugs based on their stylistic features. The cup body's characteristics are primarily focused on the Bulbous Cup Body and the Tail Outward Curved Handle. Within the Outward Curved Handle category, the c-I type combines Tail and Top Outward Curved Features. The c-V type handle has a local protrusion on its inner outline, classifying it as an inwardly convex shape. The c-IV type within the same group has a handle shape that forms a protrusion closing with the cup wall, hence classified as Inward Convex Handle. In the Irregular-shaped body's mugs category, the e-I type is a square body. Its cup edge has corners, and the handle's cross-section is square. This type's overall outer contour shifts upwards, making it a Top Outward Curved Handle.



**Table 3** Mugs body and handle fractal chart

Body Types	Pattern I: ◆			
a-Cylindrical (直筒形)				
	Pattern II: ●		Pattern III: ▽	
	Pattern IV: ○			
b-Barrel-shaped (桶形)				
	Pattern I: ▽	Pattern II: ●	Pattern III: ▽	Pattern IV: ●
c-Bulbous Cup Body (鼓腹形)				
	Pattern V: ○	Pattern VI: ○	Pattern VII: ▽	
d-Gourd-shaped (葫芦形)	Pattern I: ○	Pattern II: ○		
e-Square (方形)	Pattern I: ○			
		Pattern II: ▽		
f-Irregular-shaped (异形)				

Noted: The green outlined samples are Cantonese mugs, while the black outlined samples are non-Cantonese mugs.

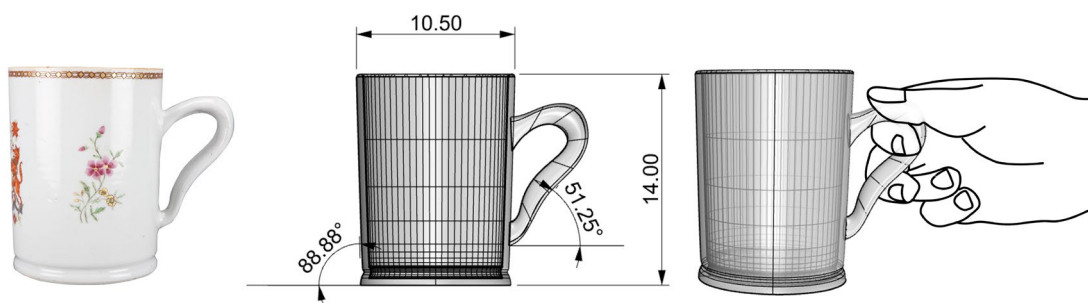
The handles are categorized into the following six types.,

◆ Entwined Branch Handle (缠枝状); ● Bamboo Joint Handle (竹节状); ○ Ear-shaped Handle (耳廓状);

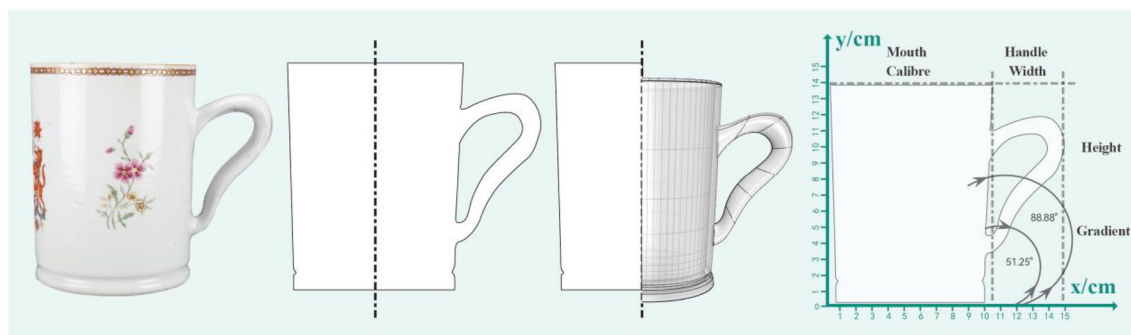
◇ Inward Convex Handle (内凸状); △ Inward Curved Handle (内弧状); ▽ Outward Curved Handle (外翘状)

**Table 4** Classification basis for stylistic features of 23 mugs

	Bamboo joint handle	Entwined branch handle	Tail outward curved handle	Top outward curved handle	Ear-shaped handle	Inward convex handle
A-Cylindrical	A-II	A-I	A-III	-	A-IV	-
B-Barrel-shaped	-	-	B-I	-	-	-
C-Bulbous Cup Body	C-II	-	C-I C-VII	C-I C-III	C-VI	C-IV C-V
D-Gourd-shaped	-	-	D-II	-	D-I	-
E-Square	-	-	-	E-I	-	-
F-Irregular-shaped	F-I	-	-	F-II	-	-



a Analysis of mug's scale and hand grip posture - 1:1 model reduction with sample 23



b Steps for curve extraction and map quantification

**Fig. 2** Step-by-step diagram of quantitative typological analysis

The f-II type combines an Irregular-shaped Body with a Top Outward Curved Handle, where the handle's outer contour also shifts upwards.

**3D modeling and curve extraction**

The third step in the study involved transforming image samples into a typological chart suitable for quantitative analysis through 3D modeling and curve extraction processes [36]. Initially, based on the

rotatable 3D images and data such as diameter, radius, and height from museum digital collections, proportionate three-dimensional models were created in Rhino software, enabling the measurement of related morphological variables (Fig. 2a). Subsequently, in Rhinoceros 6.0 version [41], all models were aligned with their bases on the same horizontal plane, and front elevation views were captured and imported into Autocad software for outline extraction. In Autocad

**Table 5** Dimensional data table of mugs

Types	Sample Code	Maximum Diameter (MD)/cm	Height (H)/cm	Inclination (I)/°	Volume(V)/ml
Bal-01	21	8.8	9	90°	547
B'al-02 <sup>a</sup>	16	8.7	11.5	88°	683
Bal-03	10	22.5	28	90°	11,127
B'al-04 <sup>a</sup>	9	8.3	9.5	90°	514
Ball-01	6	12	14.8	90°	1672
B'alll-01	12	8.7	9	90°	535
B'alll-02 <sup>a</sup>	17	8.6	11.1	90°	644
B'alV-01 <sup>a</sup>	23	10.5	14	88°	1153
B'alV-02 <sup>a</sup>	18	8.8	11	90°	668
B'bl-01 <sup>a</sup>	22	8	10	73°	502
Bbl-02	11	8.4	10.2	73°	558
Bcl-01	8	6.8	3.4	50°	74
Bcll-01	7	7	3.7	43°	85
AcIII-01	1	6.5	3.5	53°	132
BclV-01	4	7.1	6	61°	148
B'cV-01 <sup>a</sup>	20	7	5.5	68°	130
AcVI-01	3	6.9	6.5	60°	111
B'cVII-01 <sup>a</sup>	15	6.4	5.7	72°	101
B'dI-01 <sup>a</sup>	19	6.7	11	50°	387
BdII-01	5	4.2	4.5	26°	52
Bel-01	14	10.4	8.8	79°	518
Bfl-01	13	13.4	15.6	90°	2198
AflI-02	2	4.8	3	34°	37
Average		8.7	9.3	71.2°	981

<sup>a</sup> Represnt Cantonese mugs

2022, Bezier corner points were used to fit spline curves of the shapes, and pre-classified coded groups were assigned uniform X and Y axes. Finally, the corresponding parts of the spline curves were divided into several segments. Each segment referred to as a typology, was used to group and compare graphically samples with similar characteristics (Fig. 2b). Figure 2 illustrates the basic steps of quantitative typological analysis.

**Data measurement and mapping**

In the fourth step, the samples of Table 1 were placed in the same coordinate system to plot the data of shape proportion, scale, and inclination (I) of the measured samples (Table 5). Based on Autocad software, the basic data of mugs, their Volume (V) can be calculated by Eq. 1, while for samples with I < 90°, their V can be calculated by Eq. 2. The circumference π takes the value 3.14.

Figure 3 presents a three-dimensional scatter plot of the volume (V), height (H), and dynasty period of 23 mugs, revealing the following information: (1) most

mugs appeared in the mid-eighteenth century, with their H and V ranging between 3.4 and 11.5 cm and 74–683 ml, respectively; (2) 9 mugs with low V (37–148 ml) also appeared in the eighteenth century, but their H varied between 3 and 6.5 cm. In contrast, fourteen mugs with high V (387–11127 ml) emerged from the mid-18th to early nineteenth century, with H ranging from 8.8 to 28 cm; (3) in terms of H, the difference between the lowest and highest mugs was significant, up to 25 cm (sample-2 and sample-10), and their V also varied greatly, by up to 11090 ml. These data indicate several trends: 1) the size and shape of mugs from the eighteenth century displayed a diversity, for instance, AcIII-01 (V = 132 ml), Bbl-02 (V = 558 ml), Bfl-01 (V = 2198 ml); (2) the relationship between height (H) and volume (V) is not an absolute positive correlation, as evidenced by the comparison between B'dI-01 (H = 11 cm, V = 387 ml) and B'al-02 (H = 11.5 cm, V = 683 ml).

$$V = \pi r^2 h \tag{1}$$





**Table 6** Bottom and handle size data for mugs

Types	Samples	Bottom Sizes		Handle Sizes	
		Height (H)/cm	Diameter (D)	Wide(W)/ cm	Height (H)/cm
Bal-01	21	9	8.8	2.4	4.9
B'al-02 <sup>a</sup>	16	11.5	8.6	3.5	9.2
Bal-03	10	28	22.5	8.5	17.1
B'al-04 <sup>a</sup>	9	9.5	8.3	2.9	7.5
Ball-01	6	14.8	12.3	5.4	8.8
B'allI-01	12	9	8.7	3.2	6.6
B'allI-02 <sup>a</sup>	17	11.1	8.6	4.2	8.5
B'alV-01 <sup>a</sup>	23	14	7.5	4.9	9.1
B'alV-02 <sup>a</sup>	18	11	8.8	3.9	7.6
B'bl-01 <sup>a</sup>	22	10	6.5	3.5	6
Bbl-02	11	10.2	8.3	3.4	6
Bcl-01	8	3.4	3.6	1.8	2.8
BclI-01	7	3.7	3.7	2.1	2.7
AcIII-01	1	3.5	2.8	1.6	1.8
BcIV-01	4	6	4	1.6	1.8
B'cV-01 <sup>a</sup>	20	5.5	3.8	2.3	3.6
AcVI-01	3	6.5	2	1.7	3.3
B'cVII-01 <sup>a</sup>	15	5.7	2.9	2.5	3.8
B'dI-01 <sup>a</sup>	19	11	4.9	3.5	6.4
BdII-01	5	4.5	2	1	2
Bel-01	14	8.8	6.8	5.3	7.3
Bfl-01	13	15.6	13.4	5.8	11.8
AflI-02	2	3	2.5	1.2	2.1
Average		9.3	7	3.3	6.1

<sup>a</sup> Represent cantonese mugs

stability, and the handle size considers ease of grip and distribution of force; (2) for the nine Cantonese mugs, the average bottom sizes in H and D are 9.9 cm and 6.6 cm, respectively, with handle sizes in W and H averaging 3.4 cm and 6.8 cm. The taller base and larger handle size may cater to more delicate usage habits or specific social settings; (3) for the other 14 mugs, the average bottom sizes in H and D are 9 cm and 7.2 cm, respectively, with handle sizes in W and H averaging 3.2 cm and 5.6 cm. The broader base might be designed for stabilizing heavier liquids, while the relatively smaller handles could facilitate a quicker or more casual drinking experience.

In Table 7, the paper defines the handle-side junction angle (HJA) as the angle ( $\angle$ ) formed by the outer side of the handle with the horizontal line at the mug's base, and the wall-side junction angle (WJA) as the angle ( $\angle$ ) formed by the mug's inclined wall with the horizontal line. The values of x and y correspond to the intersection points on the coordinate axis. The data from Table 7 reveal [42–47]: (1) for the 23 mugs, the average values of  $\angle$ , y, x in HJA are 41°, 5.2 cm, and 3.3 cm, respectively, while the corresponding values in WJA are

71°, 7.4 cm, and 6.7 cm. The design of the mugs' handles tends to be more compact with a direct connection to the body, and the inclination of the mug body provides a larger space for drinking; (2) in the 9 Cantonese mugs, the average values of  $\angle$ , y, x in HJA are 41°, 4.9 cm, and 2.8 cm, and in WJA are 78°, 5 cm, and 3.9 cm. The steeper angles facilitate quick drinking or suit certain types of beverages; (3) in the other 14 mugs, the average values of  $\angle$ , y, x in HJA are 40°, 5.4 cm, and 3.5 cm, and in WJA are 66°, 9 cm, and 8.7 cm. The handles of these mugs are relatively more prominent, and the inclination of the mug body is less steep, accommodating a larger volume of beverage.

Based on the data from Tables 5, 6, 7, this study further compares the differences in their respective values within a unified grid system to reveal the variations in the proportions, scales, and inclination characteristics of the mugs. Figure 4 illustrates the changes in the shapes of the mugs' bottoms and handles, while Fig. 5 is drawn based on the data from Table 7.

Synthesizing all the previously gathered data [42–47]: (1) the WJA of 14 mugs exceeds 70°, while the average

**Table 7** The angle of the tangent between the handle and the cup wall ( $\angle$ ), the height of the tangent point (y) and its offset from the center axis (x)

Samples	Handle-side Junction Angle (HJA)			Wall-side Junction Angle (WJA)		
	Angle / $\angle$	Y/cm	X/cm	Angle / $\angle$	Y/cm	X/cm
1	32°	1.6	1.8	53°	3.5	6.5
2	39°	1.2	2.1	34°	3	4.8
3	54°	1.7	3.3	60°	6.5	6.9
4	41°	1.6	1.8	61°	6	7.1
5	28°	1	2	26°	4.5	4.2
6	53°	8.8	5.4	90°	14.8	12
7	30°	2.7	2.1	43°	3.7	7
8	23°	2.8	1.8	50°	3.4	6.8
9*	48°	7.5	2.9	90°	9.5	8.3
10	48°	17.1	8.5	90°	28	22.5
11	51°	6	3.4	73°	10.2	8.4
12	58°	6.6	3.2	90°	9	8.7
13	49°	11.8	5.8	90°	15.6	13.4
14	27°	7.3	5.3	79°	8.8	10.4
15 <sup>a</sup>	36°	3.4	1.8	72°	2	2.2
16 <sup>a</sup>	34°	5.4	2.6	88°	2.1	4.4
17 <sup>a</sup>	48°	6	3.1	90°	11.1	4.3
18 <sup>a</sup>	39°	6.4	4	90°	11	4.4
19 <sup>a</sup>	34°	3.9	2.7	50°	2.3	2.7
20 <sup>a</sup>	44°	2.9	1.6	68°	1.7	2.3
21	34°	5.3	3.3	90°	9	4.1
22 <sup>a</sup>	38°	4.1	3.6	73°	3.7	2.9
23 <sup>a</sup>	53°	5.2	3.5	88°	2.1	3.8
Average	41°	5.2	3.3	71°	7.4	6.7
Middle value	39°	5.2	3.1	73°	6	4.8

<sup>a</sup> Represent cantonese mugs

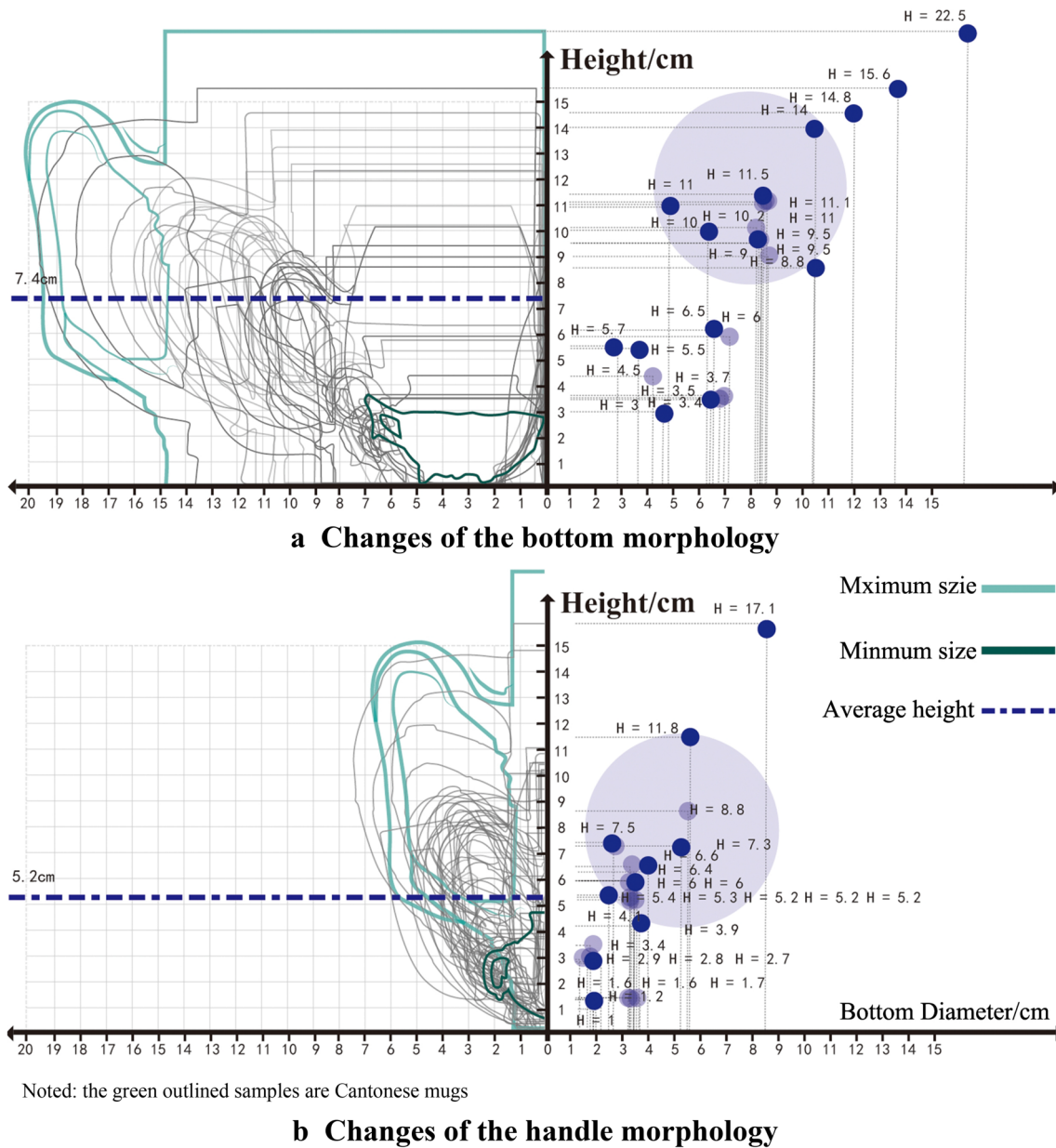
HJA is approximately 41°. This indicates a balance in mug design between stability and comfortable grip. A WJA greater than 70° aids in stability when placed on a flat surface, whereas  $\angle < 90^\circ$  increases liquid capacity at the expense of stability. Lower angles for both WJA and HJA, implying a body tilt towards 45°, help in distributing the liquid's weight, thereby easing the burden on the hand holding the mug; (2) the MD is 8.7 cm, with 10 mugs exceeding a H of 10 cm and 13 mugs having a V greater than 500 ml. This reveals that the functional and practical design of Qing dynasty Cantonese mugs, while pursuing large capacity, also considers comfort in handling and usage; (3) the average width of the handle is 3.4 cm, and the average H of the mug body is 9.9 cm. This reflects the design consideration of weight distribution and ease of operation, with the handle's position and center of gravity being lower. Such a low center of gravity design enhances operational stability and reduces hand fatigue during use, likely reflecting an adaptation to the customs of tea or other beverage consumption at the time; (4) the

range of HJA is between 23° and 54°. This variation may be associated with the cup-making techniques, aesthetic preferences, or functional requirements of the time. For instance, larger angles might indicate a more robust connection between the handle and the mug body or cater to a specific aesthetic trend; (5) the range of WJA is between 26° and 90°. A 90° angle suggests an almost vertical alignment of the mug body with its base, while smaller angles indicate a certain tilt of the mug body. Such tilting might relate to contemporary popular aesthetics, usage habits, or specific demands of the mug-making craft.

## Results and discussions

### Morphological variations of the belly and handle for mugs

In this study, some representative samples from different periods of the Qing Dynasty in China were selected for morphological comparison, revealing trends in two dimensions (Table 8). Beginning in the eighteenth century, the design of mugs exhibited trends of diversification, similarity in form, and continuation of features.

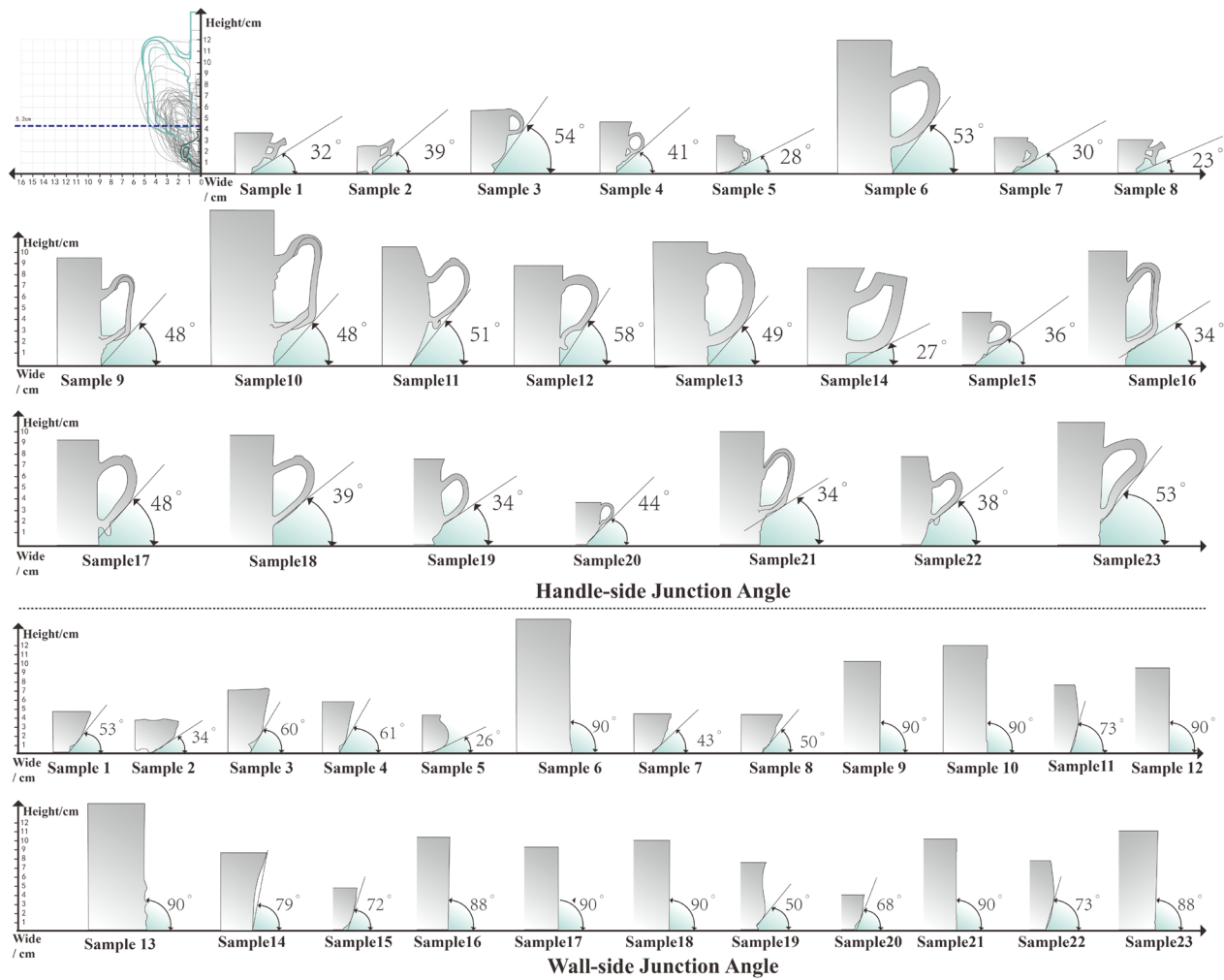


**Fig. 4** Comparison of bottom and handle morphological changes in 23 mugs. Noted: the green outlined samples are Cantonese mugs

Overall, the evolution of the mug’s body can be distinctly divided into three main stages: from the initial Arc Barrel shape, gradually transitioning to the Bulbous Cup Body, and eventually evolving into the Cylindrical Cup Body. This morphological change is likely linked to multiple factors, including users’ drinking habits, cultural aesthetic tendencies, and advancements in porcelain-making techniques. The design of the handle underwent a more complex evolutionary process: from a single Outward Curved Morphology → Ear-shaped Morphology → Entwined

Branch Morphology, showing a gradual interpenetration and fusion of different design elements.

In terms of functionality, the Arc Barrel and Bulbous Cup Body design in the early Qing Dynasty appear to prioritize thermal insulation and stability, meeting specific tea-drinking needs of the time. On the other hand, the Cylindrical Cup Body design may relate to emerging tea-drinking styles, favoring simplicity and practicality. The Outward Curved Handle design enhances grip stability and comfort, while the Ear-shaped Handle design adds decorative flair and denotes hierarchy. External cultural



**Fig. 5** Variation of handle-side junction angle and wall-side junction angle for 23 mugs

**Table 8** The changing patterns of body and handle morphology of mugs

Sample	11	20	18	15	23	6	19	10	17	16
Cup Body										
Pattern	B-I	C-V	A-IV	C-VII	A-IV	A-II	D-I	A-I	A-III	A-I
Handle										
Pattern	▽	◇	○	▽	○	●	○	◆	▽	◆
Period	1661- 1742 Kangxi to Yongzheng Emperor		1722-1735 Yongzheng Emperor		1735-1850 Qianlong to Jiaqing Emperor		1735-1875 Jiaqing Emperor		1740-1908 Guangxu Emperor	





### Historical contextual analysis of the morphological characteristics of mugs in the Ming and Qing dynasties

Zeng [48] categorizes the morphological changes of mugs during the Ming and Qing dynasties into four distinct phases: the initial period (Qing Kangxi to Yongzheng, 1681–1735), the boom period (Qing Qianlong, 1736–1795), the transition period (Qing Jiaqing to mid-Daoguang, 1796–1835), and the stabilization and continuation period (late Qing Daoguang to the present, post-1836). Drawing on the classification logic of porcelain forms by Lu [16] as delineated in Table 2, and in conjunction with the morphological analysis presented in Tables 1 and 3, as well as Fig. 4, this study delineates the evolutionary trends in the morphological characteristics of mugs during the Ming and Qing dynasties. Figure 7 illustrates the morphological transformation of mugs from 1600 to 1880, tracing a developmental trajectory from concrete → abstract → partially concrete → simplicity.

Among the 23 samples analyzed in this study, 12 exhibit morphological characteristics indicative of an initial phase. Of these, four samples display modernized features, while the remaining exhibit varying degrees of figuration and abstraction in their morphologies. Seven samples, attributed to a period of prosperity, demonstrate a trend towards minimalism in their morphological forms. Compared to the craftsmanship and aesthetic refinement observed in mugs from this period, the three samples from the transitional phase appear somewhat not enough. Only one sample-6 corresponds to a stable period, featuring a design that closely approximates contemporary mug forms.

One of the distinguishing features of the changes in mug morphology is reflected in the handles. During the Shang and Zhou dynasties, the handles of bronze Ding vessels were often representational, taking the form of dragons, and symbolizing status. Although the handles of Qing dynasty mugs have evolved towards a more modern design, they still retain a variety of styles, including human ear-like, representational, simplified, and other diverse forms. These handle styles, beyond their functional utility for gripping and use, carry auspicious symbolic meanings in traditional Chinese culture, such as the human ear-shaped handles symbolizing humility and attentiveness [49].

The evolution of mug design art is closely tied to the historical context and social dynamics of Guangzhou. During the late Ming Dynasty, with the rise of globalization in trade, European-style mugs first entered the Chinese market, characterized by a design that combined practicality with Renaissance aesthetic features. By the Kangxi period of the Qing Dynasty, deeper Sino-Western cultural exchanges led to the fusion and innovation

in artistic forms. During this time, mug designs, while retaining European styles, incorporated delicate elements of traditional Chinese art, such as exquisite blue and white porcelain paintings and symbolic dragon and phoenix patterns. In the Qianlong period, as mugs became popular among the common people, their design tended towards simplification and purity. The decorative aspects gradually adopted more abstract and geometric elements, reflecting exploration into new styles. The establishment of the Thirteen Factories in Guangzhou in 1757 made it the sole port for China's foreign trade [27], elevating Guangzhou's importance in China's commercial and cultural exchanges and expanding market demand. During the Jiaqing period, mug designs reflected a pursuit of diversity and novelty, with significant advancements in craftsmanship, showcasing the exquisite skills and innovative capabilities of the artisans of that time. Following the Opium Wars, as China further opened its foreign trade and new industrial production technologies were introduced, traditional handicrafts faced significant challenges [50]. In this period, mug design tended towards simplification, forming the basic shape of modern mugs, although somewhat lacking in artistic craftsmanship.

### Discussions

Eerkens and Lipo [51] highlight the dual evolution of material culture, encompassing both morphological and cultural dimensions, resonating with Sanz and Fiore [52] who explored material culture's role in cultural perceptions. This multidimensional analysis aims to decipher the genetic codes and cultural transmission mechanisms behind material form by identifying self-similarity and repetitive patterns in artifacts' color, size, texture, and volume. Binford [53] underscores the necessity of understanding the link between material form and cultural diversity, introducing technological form, design form, decoration techniques, and design as key variables to delineate primary and secondary functional differences—the former pertaining to the artifact's direct utility and the latter reflecting the socio-cultural context of production and usage. Eerkens and Lipo [51] also consider whether peculiar samples in material forms result from replication errors or a culmination of multiple decision-making factors, arguing the complexity of material evolution is influenced by a myriad of social factors including economic, political, cultural, and military backgrounds, manufacturer preferences, market demands, and individual choices. Their typological comparison of arrowhead morphologies across regions, integrating material and craftsmanship, unveils technological and historical cultural differences between Eastern California and Central Nevada. Aldenderfer [54] posits that typological measurements, while not intrinsically meaningful, are crucial

for understanding how these metrics reflect underlying cultural formation and relationships.

Hence, the study of mugs' forms transcends mere morphological changes, seeking to interpret the cultural significance of dematerialized attributes within a historical context. The ensuing discussion delves into the cultural backdrop behind mugs' forms from various perspectives, including economy, politics, market orientation, production techniques, and practical functionality.

Politically, during the mid-to-early Qing dynasty (1662–1795), the production of porcelain was profoundly influenced by the traditional ceramic crafts of the Song and Ming periods [55]. In this era, as cultural exchanges between China and the West increased, and interactions between the central government and the bordering ethnic minorities deepened, there was a significant integration of Han culture with those of the minorities and Manchu-Han cultures. This fusion fostered continuous innovation and enhancement in porcelain production techniques. However, from 1796 to 1821, during the Qing Jiaying period, the flourishing scene of China's foreign trade began to decline [56]. Political circumstances during this time constrained the innovation in porcelain shapes and decorations, leading producers to adopt a conservative approach to design, wary of deviating from traditional boundaries [57]. Following the Opium Wars (after 1840), as China gradually became a semi-colonial and semi-feudal society, the export of porcelain dramatically decreased [58]. Political and trade transformations necessitated adjustments in porcelain production techniques, thereby influencing the morphological characteristics of porcelain across different historical periods [57]. This background reveals how political dynamics and trade trends have been reflected in the evolution of porcelain forms through technological innovation and changes in production styles.

In terms of market impact, particularly since the establishment of the Thirteen Factories in Guangzhou in 1757, making it China's sole port for foreign trade [59], this historical event played a crucial role in the artistic evolution of mug forms. Market demand orientation emerged as the primary driver for the evolution of form art, while adjustments in the merchant system constituted a secondary force. Against the backdrop of economic and cultural exchange, the forms of mugs exhibited significant diversification. For instance, regional aesthetic preferences and usage habits led to notable differences in size and shape, reflecting broad cultural integration and social interaction. Additionally, the functional use of mugs demonstrated adaptability and innovation, serving not only as everyday drinking vessels but also possibly playing important roles in social ceremonies and cultural activities. The rich decorative culture, including the use

of painting, carving, and glaze, further confirmed the flourishing of crafts and technological innovation during this period.

The larger volumes of certain mugs, such as sample-1, sample-9, sample-17, sample-22, sample-23, and sample-18, might be a response to the niche market for personalized customization. For instance, Ao et al. [25] observed that some Qing dynasty bowls were as large as basins, exceeding conventional sizes, and interpreted these as symbols of status and wealth. Similarly, Costin and Hagstrum [60] noted differences in the forms of everyday items and luxury goods in early Peruvian markets due to consumer orientation. Moreover, the Opium War of 1840 marked not only the collapse of China's traditional natural economy but also triggered significant shifts in Guangzhou's trade model towards a technology-dependent economy. The introduction of new industrial technologies revolutionized mug production [61], leading to standardization that could have induced convergence and similarity in most mug designs. For example, Busto-Zapico [62] identified similar trends in the standardized production of early Spanish pottery. Zhao [63], using the Qing Dynasty's "Ceramic Production and Transportation Diagrams," illustrated details of industrialized production. Ao et al. [25] attributed the high degree of standardization in the diameters and heights of Qing dynasty ceramic bowls to advancements in production technology. Indeed, Li et al. [64] argued that assembly line production had emerged during this period, impacting the artistry of goods.

Considering the socio-historical context of the Qing dynasty, there were likely two production models for mugs under the impact of emerging craft technologies. The first was traditional craftsmanship, focusing on artisanal skills and personalized designs to meet the demands of custom and high-end markets. The second was semi-industrial production. Given the nascent state of industrial production, semi-industrial mug designs might have sought a balance between standardization and artistic aesthetics, reflecting considerations of efficiency and cost control. This could have led to simplification in form and decoration to meet mass production needs. Therefore, high-end market consumers at the time might have preferred uniquely handcrafted items, showcasing more artistic creativity and craftsmanship details, reflecting the artisans' skills and innovation. On the other hand, growing trade and commercial activities likely promoted the development of semi-industrial production, gradually enhancing the status and influence of relevant workshops and manufacturing companies. As Liu and Zhang [65] observed, the common cylindrical mugs of

the Republic of China period were a result of standardized production.

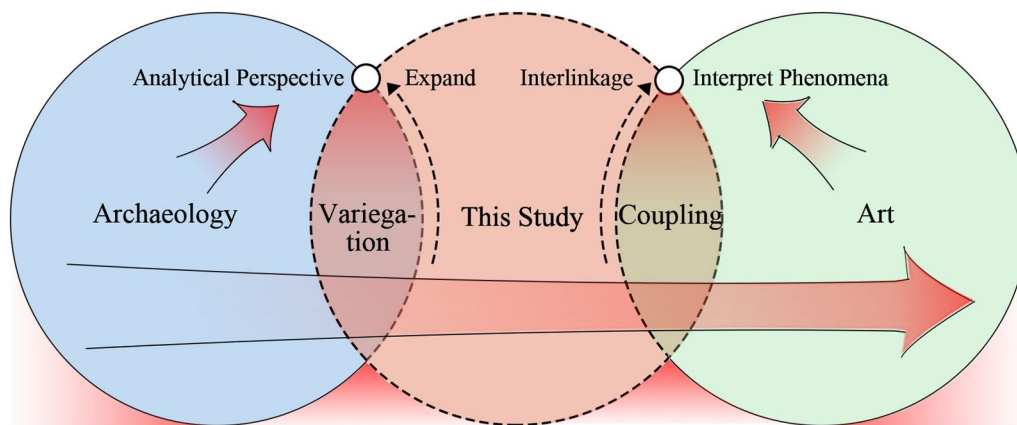
Since ancient times, Chinese cups and bowls have gradually shifted from functionality to symbolism [16]. Pre-historic artifacts primarily met living needs, but by the Shang and Zhou dynasties, artifacts began to integrate cultural, religious, and social identifiers, such as musical instruments [66]. The design of vessels reflected both functionality and the social status of the user [67], like Jue, which transcended practical use to become a symbol of status. During the Spring and Autumn and Warring States periods, vessels tended towards simplification [68], while Tang dynasty vessels reflected Sino-Western integration [37]. The appearance of high-footed cups in the Yuan dynasty showcased multifunctional design innovation [36]. Due to maritime prohibition policies and Western cultural influences, the functionality and forms of Qing dynasty cups and bowls transformed [25], with mugs not only meeting diverse drinking needs like tea, coffee, beer, and milk but also breaking traditional functional boundaries, becoming symbols of the convergence of traditional and modern, Eastern and Western cultures [69]. Qing dynasty mugs were influenced by cultural, economic, and social backgrounds, particularly market demand and Western cultural infiltration [65].

Most ancient Chinese tea and wine cups did not have handles [16] and significantly differed in shape and size from mugs, lacking a direct lineage [21]. Mugs mainly entered the Chinese market through foreign trade. This study categorizes the bodies of Ming and Qing dynasty mugs into six different types and observes significant volume differences in Cantonese mugs (101 ml–1153 ml), with an average capacity of about 531 ml. Liu and Zhang [65] revealed that household mugs from the Republic of China period were primarily cylindrical and generally ranged between 150 ml and 350 ml. However, there

is a lack of literature discussing the lineage between the Qing Dynasty and Republic of China mugs, and why such a large variance in mug volumes existed during the Qing Dynasty. The large handle design reflects the influence of British style on Chinese local design, while the diversity of mug forms might be an adaptation to the bustling foreign trade market in Guangzhou at the time.

Mainstream narratives in the literature on traditional Chinese vessels often overly emphasize their functional aspects, seldom delving into their design styles and the underlying cultural, social, and technological implications. Although Guo [40] provided a detailed compilation and analysis of ancient cups and bowls, including their names, craftsmanship, dimensions, and excavation sites, this study did not extend to the vessels' morphological and aesthetic dimensions. Based on the quantitative typological analysis, this paper not only focuses on the historical development of mugs but also systematically performs 1:1 modeling, dimension measurement, and comparison of sample models. By analyzing subtle changes in dimensions like diameter, base diameter, maximum diameter, and tilt angle, we further explore the impacts of technological innovation, cultural exchange, and social changes, providing a deeper and novel theoretical reference for the study of ancient Chinese vessels.

This study further clarifies the various cup bodies and handle forms of Qing dynasty mugs through quantitative typological analysis, adding a new dimension to the quantitative description of forms. The study closely relates to Kharchenkova's [26] demonstration of the popularization trend of mugs and the research on ancient ceramic forms by Liu and Zhang [65], and Zheng [70]. Notably, it delves deeper into the relationship between form, functionality, and cultural integration, echoing Yang's [71] research on the forms of ancient stem cups, confirming that form is not solely



**Fig. 8** Academic Contribution Map (adapted from Li et al. [74])



determined by functionality but is the result of multiple interwoven factors. Additionally, this study responds to Zhang and Han's [72] perspective on the interplay of social, cultural, and political factors in the forms of export wares. It emphasizes the importance of aesthetics, cultural customs, and body aesthetics in the design of mug handles, complementing Feng's [73] principle of functionality first. Overall, the contribution of this research lies in providing a comprehensive, detailed, and in-depth interpretation of the forms of mugs, valuable both academically and for practical product design.

Figure 8 illustrates the academic contributions of this study in the fields of archaeology and art history. In archaeology, existing literature employs quantitative typological analysis to examine the morphology of unearthed pottery such as pots, bowls, and vases, yet studies focusing on cups are less. This paper enriches the research in this area. Furthermore, there is a scarcity of literature that analyzes the relationship between shape and function from the perspective of angular measurements. This paper provides a practical application example in Fig. 5, thereby diversifying the analytical perspectives. While most of the literature related to ceramics in the field of art is dominated by interpretive historical inquiry and qualitative studies, this paper adds coupling to the implicit excavation of influences in terms of methodology.

The study employs a diversified methodology and tools to minimize the subjective decision-making process in determining how variables are defined and extracted. However, this is not only possible for interpretative descriptions of phenomena. Due to the relative scarcity of literature on this subject and the lack of a widely recognized morphological classification framework, a certain degree of subjectivity in classification is inevitable, despite the reference to authoritative literature. From a traditional taxonomic perspective, typological classification still relies to some extent on subjective impressions and visual interpretation, which is an unavoidable limitation of this type of research. Studies on Cantonese mugs are rare, and this paper is significant in its analysis of their stylistic artistic features.

Limitations: (1) although this study uses three-dimensional modeling and multi-point numerical verification to obtain morphological data of samples, it still falls short compared to 3D scanning and point cloud data technologies; (2) compared to Zhang's [75] study, it does not fully cover contemporary religious and philosophical thoughts, potentially overlooking some cultural impacts; (3) unlike Feng [73], it does not deeply explore the correlation between vessel form and hand size and gripping methods; (4) due to the scarcity of literature focused on

mug forms, there is currently no widely recognized standard for morphological classification. While the paper attempts to construct a method for morphological classification, it recognizes its limitations in this regard. Nevertheless, it provides a case reference for future research; (5) Despite referencing Lu [16] for the classification logic of porcelain forms and providing morphological analysis data in Tables 1, 3, and Fig. 4, this paper still faces limitations in summarizing the morphological trends of mugs due to the absence of specific parameters and criteria for defining morphological transitions. Improvement suggestions: (1) optimize data collection methods, incorporating multi-angle, high-definition images of the vessels to ensure the completeness and reliability of research data; (2) include more interdisciplinary perspectives, such as archaeology, anthropology, and human-computer interaction design, to deepen understanding of the cultural significance and functionality of vessels; (3) increase the sample size and refer to the typological classification methods of other ceramic vessels to establish a scientific standard for cup form classification; (4) The introduction of more precise parameters and criteria for distinguishing the morphological transformations of mugs is necessary. Moreover, a deeper understanding of morphological changes requires the integration of historical contexts and technical details of the manufacturing processes. The refinement and expansion of these methods will aid in accurately interpreting and classifying the morphological characteristics of ancient artifacts, thereby gaining a more comprehensive understanding of their cultural and societal significance.

## Conclusions

The quantitative morphological analysis of mugs from the Ming and Qing dynasties indicates: (1) the volume variation (ranging from 37 to 11,127 ml, average=981 ml) reflects diversified market demands, consumption preferences, and cultural differences; (2) the extreme range of volume is 11,090 ml, while for height, it is 25 cm, revealing that there is not an absolute positive correlation between these two variables; (3) the low center of gravity in handle design (mean width of handles=3.4 cm, average height of mug body=9.9 cm) considers the distribution of liquid weight and ease of operation, enhancing stability during use and reducing hand fatigue; (4) 14 mugs have a wall-side junction angle >70°, while the average handle-side junction angle is approximately 41°, demonstrating a design balance between stability and comfortable grip; (5) the volume of mugs has been increasing since the early eighteenth century, generally categorized into large volume ( $\geq 500$  ml), middle volume (200–499 ml), and small volume (<200 ml). The volume of a Celadon mug from the Qianlong period (11,127 ml)

exceeds the typical range for a tea-drinking utensil, illustrating the role of wealth and status symbolism in form design.

The analysis of form evolution reveals: (1) the forms of mugs in the eighteenth century displayed diversity, similarity, and continuity of features, with a trend from representational (Ming Dynasty) to abstract to minimalist (Qing Dynasty), especially in the three-dimensional modeling for handle grip comfort (from single outward curved form to ear-shaped form to entwined branch form); (2) the belly shape evolved from an arc-barrel body (focusing on heat retention) to a bulbous body, then to a cylindrical body (combining heat retention, practicality, and economy); (3) mug types and handles can be divided into six categories and styles, with the cylindrical body and ear-shaped handle as mainstream, but the artistic emphasis is on the bulbous cup body and tail outward curved handle; (4) most mugs exhibit a slight outward tilting of the body and a trend of expanding curvature, while Cantonese mugs tend towards a more upright shape and smaller volume (mean volume less than half of ordinary mugs).

To thoroughly understand the form of Qing Dynasty export mugs, it is necessary to consider their use and aesthetics, as well as their status within the socio-economic background. Market demand orientation becomes a primary driver in the artistic evolution of mug forms, while adjustments in commercial systems form a secondary force. Despite the sea ban policy limiting the export of wares, rising market demands, financial pressures, and the prevalence of tea culture have prompted adjustments and innovations in mug forms and functions. The evolution of mugs displays an interplay of design comfort, aesthetic direction, and production technology. This paper explores how socio-economics influences the form of material cultural products and relates them to the market economy. Future research will delve deeper into the combined impact of production technology, trade strategies, and cultural exchanges on product forms.

### Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s40494-024-01237-x>.

**Additional file 1.** Sample data.

### Acknowledgements

Many thanks to the editors and reviewers for their professional advice on revisions, which led to a significant improvement in the quality of the article.

### Author contributions

Conceptualization, J.A. and W.L.; methodology, Z.X. and W.L.; software, Z.X. and W.L.; validation, J.A., Z.X. and W.L.; formal analysis, W.L., Z.X. and R.Q.;

investigation, Z.X., W.L. and S.J.; resources, J.A., Z.X. and S.J.; data curation, W.L. and Z.X.; writing—original draft preparation, J.A., Z.X. and W.L.; writing—review and editing, J.A. and W.L.; visualization, Z.X. 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.

### Funding

This study is funded by the 2022 Guangdong Philosophy and Social Science Lingnan Culture Project (Grant No. GD22LN06).

### Availability of data and materials

The data used to support the findings of this study are included within the article. We have uploaded the source data named 'sample data' as an appendix file.

### Declarations

#### Consent to participate

Not applicable.

#### Institutional review board statement

Not applicable.

#### Competing interests

The authors declare no competing interests.

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Received: 21 October 2023 Accepted: 6 April 2024

Published online: 17 April 2024

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