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Mapping geopolitical dynamics of vessel typology in Qing-era Guangdong via export paintings-based computational text analysis

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Existing studies have primarily focused on how the functional evolution of vessels responded to external demands, and many have overlooked the influence of regional institutional contexts and global trade networks. Drawing on computational text analysis via KH Coder, this study analyzes 24 vessel typology cases to examine the geopolitical forces that shaped the structural and functional transformation of Guangdong vessels from the 15th to the 20th century. The evolution of ship types in Qing-era Guangdong reflected not only strategic responses to maritime prohibition policies, external threats, and port conditions, but also embodied a gradual shift in design logic—from broad-beamed flat bottoms, to elongated and agile forms, and ultimately to wind-resistant stability. Economic and military imperatives served as primary drivers, while geographic location and shipbuilding techniques functioned as key supporting variables. Together, these factors shaped the distinctive typologies and adaptive mechanisms of Guangdong merchant vessels within the global maritime system.

During the Ming and Qing dynasties, Guangdong, as a geopolitically significant region in southern China, witnessed a complex and multi-layered interplay between trade development, regional power structures, and policy regulation mechanisms[1]. As the primary vehicle linking inland regions to external trade networks, the evolution of merchant vessel typology reflects not only internal technological trajectories but also spatial adaptation strategies under the reconfiguration of macro-level political and economic orders. However, existing scholarship has primarily focused on the physical dimensions of ship design—such as structural features and navigational performance—while rarely addressing, from a geopolitical perspective, how vessel forms transformed in response to the entangled influences of state control, regional tensions, and trade regulations[2]. In particular, under the restrictive maritime policies of the "sea ban" era, merchant ships along China's southern coast underwent structural adjustments to navigate the dual pressures of state-imposed constraints and the dynamics of active maritime trade. The institutional drivers and spatial logic underlying such adaptations remain insufficiently explored[3].

Guangdong's merchant ship system demonstrated a high degree of adaptive evolution under the dual influence of central shipping regulations and local trade networks during the Ming and Qing dynasties. This evolution was not only reflected in localized technical adjustments to ship structures but also served as a direct response to geopolitical arrangements such as external blockades, border defense strategies, and navigation restrictions. While geopolitical factors have been mentioned in existing literature, they are often simplified as external disturbance variables, lacking empirical analysis of their interconnections with trade expansion, technological innovation, and social organization. This is precisely the value of this study.

UNESCO's 2001 Convention on the Protection of Underwater Cultural Heritage[4] explicitly calls for a multidimensional understanding of maritime heritage that integrates institutional history, technological evolution, and cultural spatiality. South Korea emphasizes in the Law for Protection of Cultural Property[5,6] that marine heritage is part of the nation's cultural property. Guangzhou also proposed in its revised Law for

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Protection of Cultural Property[7] in 2019 that the "evolution of merchant ship design" should be used as a key entry point to create a narrative system for the protection and dissemination of marine cultural heritage, thereby achieving the living inheritance of traditional shipping culture and the reuse of public spaces. This series of policy signals indicates that merchant ship design is not only a remnant of material and technological traditions but also a key node where national and local power structures, institutional logic, and cultural identity intersect.

Ships have been instrumental to the development of human civilization, and their structural characteristics and transformations serve as key indicators of technological capability, economic activity, and sociocultural context across different historical periods. Compared with research on glassware[8], porcelain[9], shipwrecks, currency, customs buildings[10], or maritime paintings[11], studies examining the structural dimensions of vessels and their relation to maritime networks remain relatively marginalized.

Respess[12] investigates how states deployed disciplinary technologies through regional port systems in the medieval maritime order, shaping ship design and navigational efficiency. Van Noort[13] finds that merchant vessels along the Maritime Silk Road functioned not only as carriers of material exchange, but also as instruments of cultural and political transmission, reflecting the institutional arrangements and geopolitical strategies underpinning China's interaction with the external world. Ciordia[14], in her study of ancient Greek maritime trade, argues that merchant ships served as pivotal conduits for cross-cultural exchange, transporting goods and information while simultaneously shaping religious and cultural identities. The variation in vessel forms across maritime regions further highlights the spatial embeddedness and cultural plurality inherent in merchant ship systems. For example, through an analysis of the relationship between early Egyptian tombs and boat-shaped pits, Vanhulle[15] demonstrates how Egyptian ship design embodied local understandings of seaborne transport technologies and cultural values, thereby exerting a lasting influence on the configuration of regional social structures.

Some scholars widely focus on the impact of ship design on performance, stability, and safety, although their research priorities and methodologies differ. Weng et al.[16] emphasize the effect of ship morphology on collision frequency and damage severity, noting the differences in collision frequency prediction for various shapes, such as elliptical and fan-shaped hulls. This finding highlights the complexity of the relationship between ship morphology and collision impacts. In a recent study, 홍순구[17] analyzed the design of turtle ships and proposed that, in specific historical and practical contexts, adjustments to the shape of ships were made based on operational needs and tactical requirements, providing an important perspective on the flexibility and practicality of ship design. Meanwhile, 김건수[18] explores the relationship between ancient ship structures and their shapes through the analysis of boat-shaped pottery from the Three Kingdoms period, emphasizing the role of traditional techniques in the evolution of ship morphology and revealing the deep connection between ship design and cultural context. Krivoshapko[19] and Petacco et al.[20] provided a more detailed modeling and optimization framework for ship design through the analysis of fluid dynamics surfaces and geometric variables, proposing how to improve ship stability and efficiency through geometric variable refinement and superstructure optimization during the design process. Zang et al.[21] highlight the significance of the second-order free surface component at the bow in wave-structure interaction, stressing that neglecting this factor could lead to a significant underestimation of wave impact on the ship's structure, thereby emphasizing the importance of considering environmental factors in ship design. Regarding wind environment influence, Guzelbulut et al.[22] propose advancing wind-assisted ship designs with a crescent-shaped wing configuration, showing that maximizing thrust during entry increases the average thrust generated by the sail by 12.3%, while minimizing propeller power entry improves the sail's effectiveness by 22%, reducing power consumption. Further research by Yang and Kim[23] reveals the distribution characteristics of increased pressure on the ship's surface due to bow shape and wave amplitude.

Existing research has primarily focused on the adaptation and optimization of vessel design under varying historical and geopolitical conditions, particularly in response to complex maritime environments and tactical demands. While the evolution of ship structures has been extensively studied, current literature tends to concentrate on specific periods or regions, often overlooking the broader impact of historical and geopolitical forces on the transformation of vessel typology and function. Notably, there remains a lack of focused analysis on the geopolitical dimensions of ship design in Guangdong during the Ming and Qing periods. To address this gap, the present study investigates the morphological and structural evolution of Guangdong vessels, aiming to uncover the geopolitical drivers behind the transformation of merchant ship typologies within the global maritime expansion network.

The first objective is to review archeological findings from Chinese shipwreck sites and to trace the patterns of vessel development from the Tang to the Qing dynasties. The second objective is to identify the sociopolitical factors influencing ship development through an integrated analysis of historical ship illustrations and Guangdong maritime history, using KH Coder for textual data mining. The third objective is to conduct a structural and functional comparison of 24 types of Guangdong's seagoing trade vessels from the 15th to the 20th century using visual analysis and content-based image interpretation, in order to reveal the geopolitical forces underlying their evolution. This study argues that, in addition to external forces, China's internal trade policies and institutional frameworks also played a critical role in shaping vessel design and transformation.

The research is structured into five stages. Stage 1 involves defining the research question. A literature review was conducted to examine previous studies on the evolution of ship forms, to identify research gaps, and to establish research objectives and hypotheses, thereby clarifying the academic value of this study. Stage 2 focuses on the extraction, classification, and coding of textual materials, followed by term frequency (TF) statistics to identify factors influencing ship morphology. Stage 3 constructs a co-occurrence network based on coded groups to reveal potential interrelationships between clusters and their constituent elements. Stage 4 undertakes a case analysis of merchant ship forms during the Ming and Qing dynasties, comparing the morphological changes in Guangdong merchant vessels across different periods and examining the geopolitical forces underlying these transformations. Stage 5 discusses the findings and raises new academic questions. Specifically, this stage responds to the research questions, hypotheses, and inferences outlined in the introduction; compares results with previous scholarship to highlight differences; identifies unresolved issues; considers the potential and technical challenges of applying text mining in heritage studies; and acknowledges the study's limitations while suggesting avenues for improvement.

Methods

Geopolitical theory

Geopolitical theory serves not only as an analytical framework for understanding state behavior but also as a conceptual tool for uncovering the dynamic interplay among spatial structures, power mechanisms, and resource allocation. Mahan's Sea Power Theory[24] emphasizes the pivotal role of maritime dominance in national ascendancy, establishing a direct link between sea control and imperial expansion. The theory encompasses three core concepts. Space Determines Power posits that a state's strategic position within the global system is fundamentally shaped by its geographic location, accessibility, and control over key maritime corridors. The resource–strategic position–corridor triad highlights that geopolitical dominance derives from a nation's integrated control over natural resources (e.g., ports and island chains), geographic chokepoints (e.g., straits), and global trade networks. The embeddedness of geographic structure and political institutions refers to the mutual constitution of spatial configurations and institutional design, whereby state governance shapes—and is shaped by—territorial organization, directly influencing geopolitical strategies and technological choices.

Table 1 | Events related to the archeology of Chinese shipwreck sites

No.	Dynasties	Archeological events	Scale/m
1	Sui (581–617)	In 1975, archeologists discovered a Sui Dynasty twin-hull wooden ship on the eastern bank of the Ze River in Pingdu, Shandong. The ship was constructed by connecting two U-shaped dugouts.	L = 23 W = 2–2.82
2	Southern Song (1127–1279)	In 1987, the "Nanhai No. 1," an ancient ship recovered from the waters near Yangjiang, Guangdong, was identified as a pointed-bow vessel.	L = 30.4 W = 9.8
3		In 1996, local fishermen accidentally discovered the "Huaguang Reef No. 1," the first ancient Chinese ship with six layers of hull components to be unearthed.	L = 22.14 W = 8.1
4	Song (960–1279)	As early as the Song Dynasty, China utilized bilge keel designs, a notable example being the Song Dynasty sea vessel excavated in April 1979 at Dongmenkou, Ningbo.	L = 15.5 W = 5
5	Yuan (1279–1368)	The Penglai ancient ship, the longest ancient vessel excavated in China, dates to the Yuan Dynasty and is significantly larger than typical maritime cargo ships of its time.	L = 33.2 W = 6
6		In May 2014, during a dredging project in Wanfu Village along the Banjiang River in Taicang, Jiangsu, a wooden shipwreck was discovered. This ship is the largest wooden vessel unearthed in Jiangsu in recent years.	L = 17.83 W = 5.76
8	Ming (1368–1644)	In April 1956, archeologists discovered an ancient wooden ship in the Jiazhuang Village section of the Songjin River tributary in Liangshan County, Jining, accompanied by 174 artifacts.	L = 26.47 W = 5.34
9	Qing (1644–1911)	In 1994, during soil excavation at a brick and tile factory in Pingyantou, Houqibu Village, Tuqi Town, Xiangshan County, Ningbo, Zhejiang, an ancient maritime vessel was uncovered.	L = 20.34 W = 7.85
10		In June 2009, underwater archeologists determined the depth of the "Xiaobaijiao No. 1" shipwreck site to be between 18 and 22 meters through surveying techniques.	L = 38.8 W = 9.9
11		The Changjiangkou No. 2 ancient ship, a merchant trade vessel from the Qing Tongzhi period, is located in the submerged mudflats northeast of Hengsha Island in Chongming District, Shanghai, at a depth of 8 to 10 meters. The ship's remains reveal a structure with 31 compartments.	L = 39 W = 13

L Length, *W* Width.

Table 2 | Evolutionary patterns of various types of ships in China from the Tang Dynasty to the Qing Dynasty (618–1912)

No.	Types	Functions	Mature period	Boom period	Trends in morphological evolution
1	Sha Ship (沙船)	Inland and Coastal Transport Vessel	Tang Dynasty (618–907)	Qing Dynasty (1644–1911)	From the Tang Dynasty's simple flat-bottom design to the more refined hull structure of the Ming and Qing Dynasties, the design of the Sha Ship (沙船) was gradually optimized to adapt to increasingly complex navigational conditions.
2	Guang Ship (广船)	Ocean-going Trade Ship	Song Dynasty (960–1279)		The Guang Ship (广船) reached maturity during the Song Dynasty and attained its peak in terms of form and function by the Qing Dynasty. The ship's hull became sturdier, and its decorative elements more elaborate, reflecting the cultural characteristics of the Lingnan region and the prosperity of maritime trade.
3	Fu Ship (福船)	Ocean-going Vessel		Ming Dynasty (1368–1644)	After the Fu Ship (福船) reached maturity during the Song Dynasty, its design peaked in the Ming Dynasty. The hull became more elongated, and its sharp-bottom design enhanced speed and resistance to wind and waves. The multi-mast, multi-sail configuration improved navigation efficiency.
4	Bird Ship	Fast Warship			The Bird Ship (鸟船) matured during the Song Dynasty and became the primary warship type in the Ming Dynasty. Its design focused more on speed and agility, with a lightweight hull suitable for swift assaults and reconnaissance missions.
5	Centipede Ship(蜈蚣船)	Multi-oared Warship	Ming Dynasty (1368–1644)		The Centipede Ship (蜈蚣船) became mature and widely used during the Ming Dynasty. Its design featured numerous oar holes along both sides, and the multi-oar configuration provided the vessel with exceptional propulsion and maneuverability, making it ideal for coastal combat.

Contemporary geopolitical theory has further evolved to include analytical approaches that expose the complex coupling mechanisms among spatiality, institutional systems, and technology[25]. Geopolitical spatial modeling applies GIS and spatial analytics[26] to identify how spatial configurations constrain or enable geopolitical actors. Naval form as power response explores the evolution of ship typologies as material embodiments of state responses to geopolitical pressures and maritime power projection, aligning with the relational sociology framework proposed by Li et al.[27]. Institutional–geopolitical embedding examines how political institutions become integrated within shipbuilding technologies, navigation planning, and trade regulations. Accordingly, vessels are not merely transportation devices but materialized expressions of institutional logic, geopolitical imperatives, and technological capacity. Their typological transformations reflect a state's spatial ambitions and external strategies at specific historical junctures. This perspective may be further informed by Li et al.[28] through the layered event-coding methodology, which reveals causal linkages across historical processes and multi-actor dynamics.

Archeological studies on Chinese Shipwreck Sites

Hou[29], Lin[30], and Zeng[31] have provided archeological reports on Chinese shipwreck sites, revealing the historical characteristics and functional differentiation of ancient Chinese ships (Table 1). Table 2 illustrates the evolutionary patterns of various ship types[32].

Analytical techniques, research ideas and data sources

Computational text analysis refers to the process of extracting meaningful information from large-scale structured or unstructured textual data, revealing latent patterns and trends through algorithmic techniques[33]. This study employs three primary text analysis methods. Word frequency analysis identifies key themes and concepts by calculating term occurrence, providing a foundation for subsequent content interpretation. It is particularly useful in examining ship construction, navigational features, and historical evolution[34]. Semantic coding structures the latent semantic relationships embedded in the text[35], offering a more precise understanding of the connections among vessel design, function, and historical context,

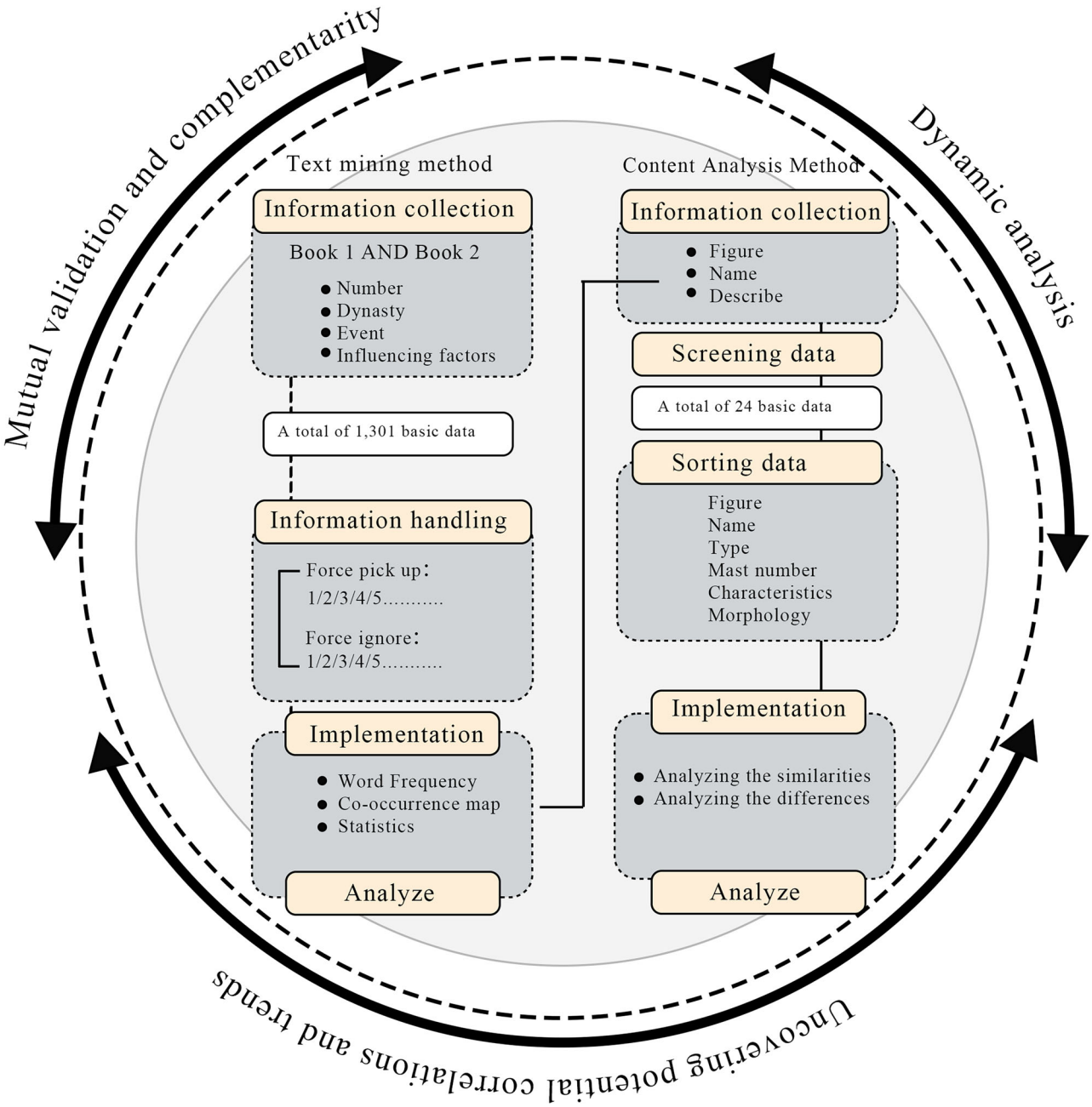


Fig. 1 | The research process of this study.

thereby supporting insights into the cultural, technological, and social dimensions embedded within the narratives. Topic co-occurrence network analysis constructs a network of interrelated thematic terms, enabling the identification of inter-topic influences. This approach is especially effective in exploring the global dissemination and cultural exchange of merchant vessels, as well as the intertwined relationship between ship design and maritime systems across historical contexts[36].

KH Coder is a robust computational platform for text analysis, offering a diverse range of analytical features and visual interfaces. Compared with ROST CM 6.0, developed by Wuhan University[37], KH Coder demonstrates greater flexibility and accuracy in processing complex data sets, particularly in multidimensional analysis and visualization. The primary textual sources used in this study include History of Guangdong Shipping–Ancient Part by Ye[38], and the two-volume work Ancient Chinese Shipbuilding and Sailing edited by Jin and Zhao[39]. To maintain thematic focus, only content directly related to merchant ships was extracted for analysis. Materials such as images, figures, appendices, and annotations—unsuitable for textual processing—were excluded from the data corpus.

Two methodological approaches were employed in this study (Fig. 1). Text mining extracted quantitative data on dynasties, events, and influencing factors from textual sources, which were then processed through statistical and co-occurrence analysis to uncover latent relationships. Content analysis, primarily applied to visual materials, involved data screening and classification of features to compare similarities and differences. Iterative application of these two methods enabled mutual validation and dynamic analysis, thereby advancing the exploration of underlying patterns and drivers of ship form evolution.

Results

Statistics of TF

Data preprocessing was conducted by importing Excel files into KH Coder in the Stanford POS Tagger format, followed by checks for vocabulary

Table 3 | Semantic classification of words in the top 100 words

Type	Noun(total TF = 4953)	Verb(3329)
Group	**Character:** Businessman-66, Boatman-44, Sailor-14, Authorities-31, Viceroy-13, Inhabitant-13, Merchant-26, Peddle-14 **Function:** Trade-230, Import-20, Export-20,Quantity of goods-63, Salt-56, Cargoes-85, Goods-18, Silk-14, Copper-13, Product-14, Merchant ship-76, Transhipment-15, Dealings-11 **Haulage:** Ship-370, Flotillas-20, Boat-95, Cargo ship-20, Sailboat-31, Sandboat-14, Jetty-20, River-31, River way-19, Route-27, Transport-37, Transport by water-29, Haulage-31, Ferry-20, Watercraft-23, Navigate-22, Sea-going vessels-12, Sea freight-15, Fish-12, Vessel-25, Hull-20, Sail-31, Paddle-15, Turreted junk-25, Ocean liner-24, Quick sand-13, Wind speed-13, Passage-12, Outlet-12, Cropland-12 **Appliances:** Ship type-20, Sail-31, Paddle-15, Hull-20, Structure-14, Turreted junk-25, Scale-26 **Shore**: Coast-96, Oversea-78, Seashore-20, Island-15, Isles-13, City wall-14 Passage-12, County annals-11 **Item**: Cargoes-85, Goods-18, Salt-56, Silk-14, Copper-13, Foodstuff-15, Product-14, Treasure ship-14 **Management:** Shibosi-19, Qing dynasty-72, Qing Kangxi-20, Qing Qianlong-39, Rule-20, Formulation-20, Naval blockade-25, Customs-28, Toll-20, Yamen-13, Official residence-11	**Action Verbs:** proceed-41, navigate-35, manufacture-24, establish-24, moor-21, depart-19, increase-16, transport-16, utilize-15, construct-15, load-15, calculate-15, carry-15, reflect-14, bring-14, found-14, excavate-14, return-14, levy-14, traffic-14, drive-14, set-up-14, trade-14, enter-14, gather-13, open-up-13, extract-13, control-13, manage-13, stream-13, place-13, be responsible for-13, transfer-13, pass-13, estimate-12, rise-12, possess-12, occur-12, build-12, donate-12, be known as-12 **Non-action Verbs :** stipulate-25, command-21, require-17, implement-15
Total TF	Haulage (967)å Function (635)å Management (287) å Shore (259)å Item (229)å Character (221)å Appliances (151)	Action Verbs (600)å Non-action Verbs (78)

consolidation. Preliminary statistics revealed a total of 61,626 words, of which 35,706 were valid for analysis. These were classified into 12,738 lexical categories, subsequently consolidated into 11,686. To ensure analytical precision, this study introduced two data processing mechanisms: Force Ignore and Force Pick Up. Force Ignore refers to the systematic removal of functional words (e.g., auxiliary verbs, pronouns, conjunctions) to eliminate semantic noise. Force Pick Up involves manual verification and mandatory retention of semantically meaningful terms, ensuring that keywords reflecting ship morphology, maritime institutions, and geopolitical contexts are preserved. Through this procedure, 8247 semantically redundant words and 258 synonymous categories were excluded. This refinement improved the accuracy of statistical analysis and co-occurrence networks, ensuring that the findings more clearly reveal the driving forces behind ship evolution. A detailed sentence segmentation method was adopted, resulting in 1,300 sentences, paragraphs, and units for analysis. Based on semantic differences, the top 100 words were selected to construct a grouped statistical table (Table 3).

Thematic co-occurrence networks and place-word map mapping

A keyword co-occurrence network was subsequently generated using KH Coder. This network consisted of "nodes" representing terms and "edges" signifying their co-occurrence relationships. To enhance interpretability, the network was constructed as a minimum spanning tree, which represents the underlying semantic associations with the fewest possible connecting edges, facilitating the identification of thematic clusters within the text. The minimum TF threshold was set at 15. To further categorize the network, the resulting figure was imported into Photoshop CS6 for visual enhancement and color-coded segmentation based on semantic distinctions. Keywords were manually grouped into five thematic domains: character, geography, location, activity, and period (Fig. 2). Spatial mapping techniques were employed to illustrate the geographical distribution of keywords, supporting the exploration of spatiotemporal semantic patterns. Additionally, the top 10 country-related keywords and top 30 place-specific terms were statistically compiled (Table 4), and their spatial configurations were visualized through a geographical distribution map (Fig. 3).

Historical policies and economic developments have exerted profound influence on the typological evolution of merchant vessels. Quanzhou and Xiamen, as critical nodes along the Maritime Silk Road, emerged as major international trade centers as early as the Song and Yuan dynasties[40]. Quanzhou, known as the "largest port in the East," functioned not only as a hub for Sino-foreign trade but also as a vital platform for cultural exchange. According to Quanzhou Prefectural Gazetteer (泉州府志)[41], during the Song–Yuan period, Quanzhou's port infrastructure and shipbuilding technologies were highly advanced, capable of accommodating large-scale merchant vessels from around the world. The city's economic prosperity and supportive policies facilitated the development of ocean-going ships suitable for long-distance voyages. In contrast, during the Ming and Qing dynasties, Tianjin emerged as a key node for north–south domestic transportation. Influenced by maritime prohibition policies, vessels in Tianjin were predominantly engaged in inland river trade. As a result, the region favored small-scale vessels optimized for shallow waters and narrow canal navigation[42]. A global distribution map of ship typologies reveals that Asian countries such as China, India, and Japan played central roles in shaping merchant vessel development, highlighting the strong trade linkages between Guangzhou and these regional powers. This pattern underscores that the evolution of Guangzhou's ship typologies carries both domestic significance and international academic value. It further illustrates the morphological diversity of merchant vessels and their function as material bridges across global cultural and economic systems.

Co-occurrence correlation analysis based on shipping topics and keywords

Based on the "Correspondence Analysis of Words–Select Words" function in KH Coder, this study set the minimum term frequency (Min. TF) in the "Filter words by Term Frequency" module to 25, and configured the "Filter words by Document Frequency" to include terms appearing in a minimum of 1 and a maximum of 150 documents. A bubble plot was selected as the output format. Figure 4 presents the results of a correspondence analysis (CA) analysis comprising nine distinct thematic clusters. Numbers 1 to 9 in the figure represent different research topics. The dashed lines indicate the proximity of individual words to the centroid, providing a measure of semantic centrality. The size of each bubble reflects the relative TF. The explained variance denotes the extent to which the dimensions of the low-dimensional space preserve the structure and informational content of the original high-dimensional dataset.

Figure 4 presents a CA plot that reveals the semantic clustering of keywords related to the evolution of merchant vessel typologies in Guangdong during the Ming and Qing dynasties. The visualization illustrates the deep interlinkages among geopolitical conditions, technological trajectories, and regional systems. The X-axis (Ingredient 1) accounts for 45.68% of the variance and can be interpreted as a semantic continuum ranging from local specificity to global orientation. The Y-axis (Ingredient 2) explains 13.34% of the variance, reflecting a dimension that contrasts historical tradition with institutional and policy-oriented semantics. In the

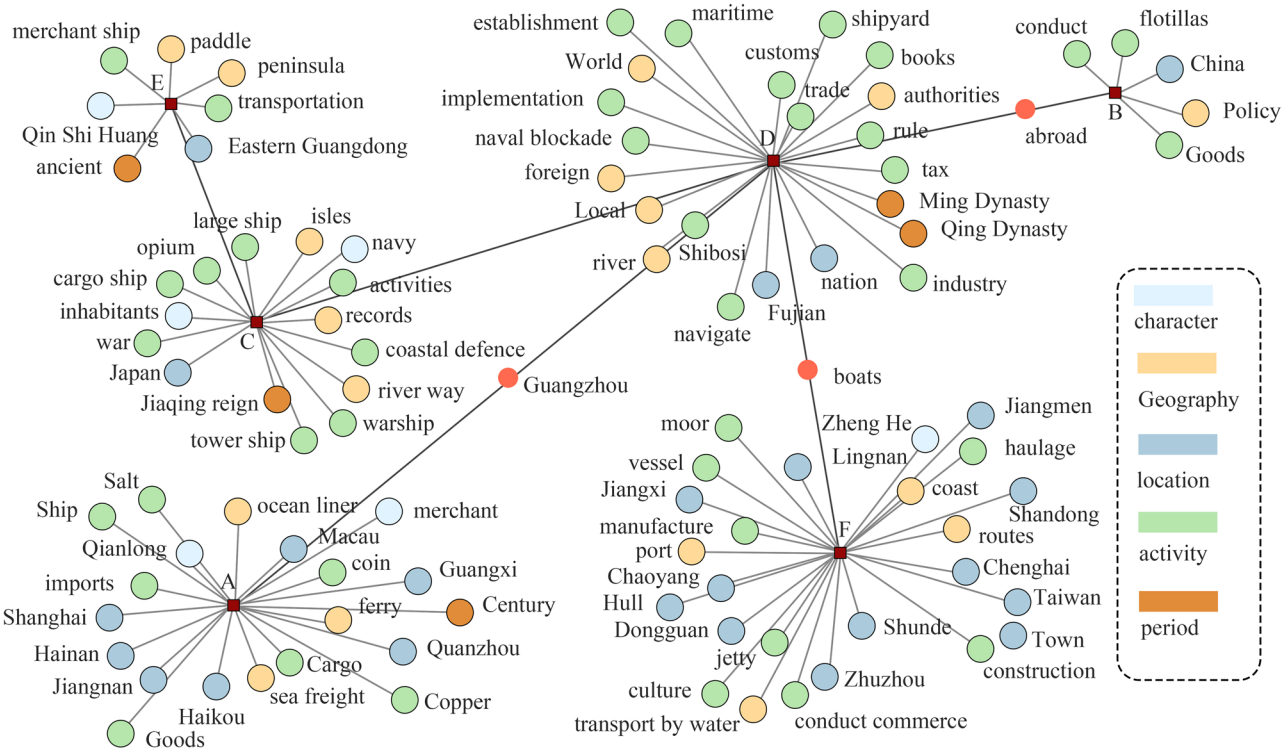


Fig. 2 | Thematic co-occurrence networks based on keywords.

Table 4 | TF statistics and map mapping of navigational location terms

TF is a list of top 30 location words						TF is a list of top 10 countries words	
Locations	TF	Locations	TF	Locations	TF	Countries	TF
Guangzhou (广州)	197	Donguan (东莞)	18	Suzhou (苏州)	9	China	136
Foshan (佛山)	79	Haikou (海口)	49	Shaozhou (韶州)	9	India	39
Chaozhou (潮州)	64	Leizhou (雷州)	14	Jieyang (揭阳)	16	Japan	38
Fuzhou (福州)	56	Gaozhou (高州)	14	Nanjing (南京)	7	Persia	14
Macao(澳门)	43	Huizhou (惠州)	19	Nanxiong (南雄)	7	UK	14
Shantou (汕头)	35	Haiyang (海阳)	11	Chenzhou (郴州)	21	Sri Lanka	13
Quanzhou (泉州)	25	Zhaoqing (肇庆)	18	Nantong (南通)	15	Siam	12
Chaoyang (潮阳)	22	Ningbo (宁波)	10	Qujiang (曲江)	4	Singapore	11
Jiangmen (江门)	19	Xiamen (厦门)	9	Wuzhou (梧州)	4	USA	10
Qiongzhou (琼州)	19	Tianjin (天津)	9	Qingyuan (清远)	4	Korea	9

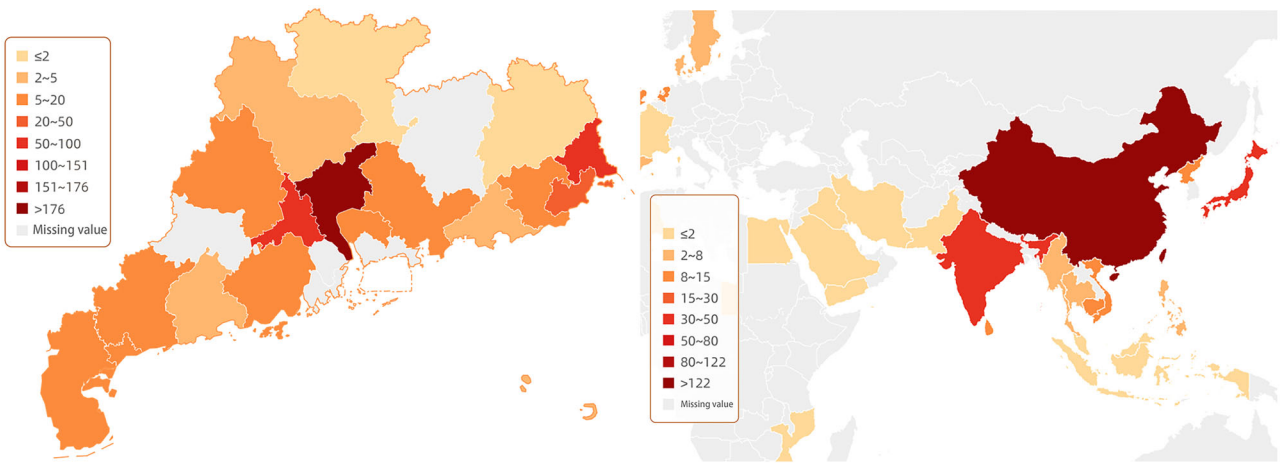


Fig. 3 | Geographic mapping of locations (left) and countries (right) terms.

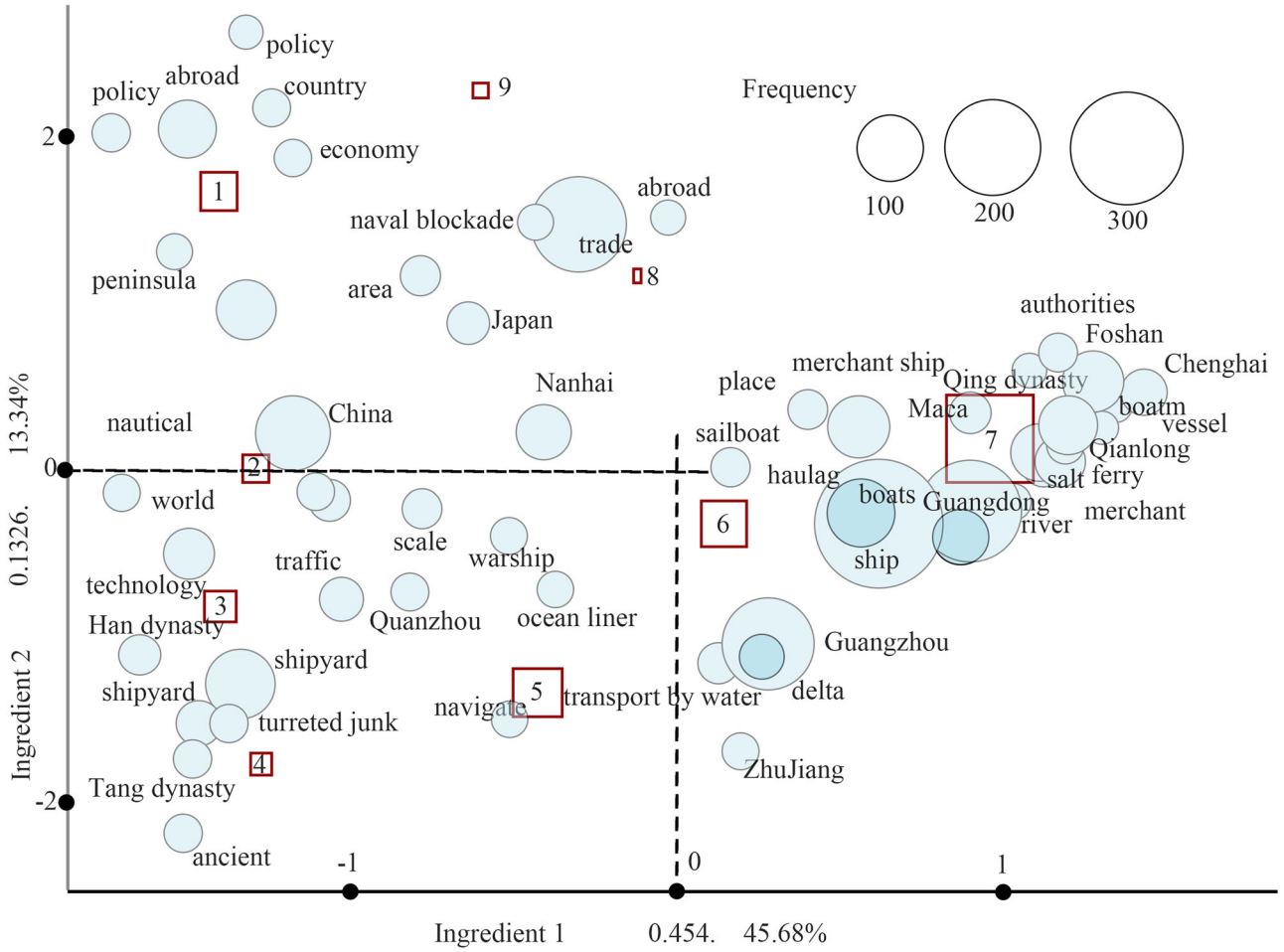


Fig. 4 | MDS analysis based on nine themes in Guangdong's shipping history. (1) Ancient Trade Promoted by the Government and the People; (2) Famous Ancient Chinese Navigator; (3) Ancient Chinese Navigation and Overseas Traffic; (4) An Introduction to the Major Ships of Ancient China; (5) Shipping Activities in Guangdong from the Sixteenth to the Sung and Yuan Dynasties; (6) Water transport system modeled on the Chor Chuen model in Ming Dynasty Guangdong Province; (7) Before the Opium War in the Qing Dynasty, the water transport at the mouth of Guangdong was in full bloom; (8) Relationship of water transport to political rule and socio-economics; (9) Impact of the closed-sea policy on water transport and its co-consequences.

lower-right quadrant, keywords such as Guangdong, Guangzhou, and merchant ship cluster together, highlighting Guangdong's spatial centrality and technological significance as a maritime hub. The upper-right quadrant, containing terms like policy, abroad, trade, and economy, emphasizes the institutional influence of global markets and national policy on shipform evolution. The lower-left quadrant features Han dynasty, Tang dynasty, technology, and shipyard, indicating the historical continuity of institutional and technological influences on vessel design. In the upper-left quadrant, terms such as China, Japan, and naval blockade suggest the constraints imposed by interstate geopolitical dynamics on maritime routes and functional configurations.

Analyzing the structure and function of ships in Guangdong during the Ming and Qing Dynasties

Table 5 summarizes 24 types of seagoing vessels used in Guangdong during the Ming and Qing periods[43], encompassing official ships, transport vessels, and coastal defense warships. The table provides detailed information on each vessel's name, function, number of masts, structural features, and morphological configuration. The data illustrate the diversity of Qing-era Guangdong ships in terms of functional specialization, technological construction, and regional adaptability.

Figure 5 compares the morphological evolution of vessels between the Ming and Qing dynasties. Seagoing vessels such as the Tributary Vessel to Siam, White Cao Junk, and Black Cao Junk were primarily employed in foreign trade and official missions, embodying both long-distance navigational capabilities and institutional symbolism. In contrast, inland waterway vessels emphasized adaptability to shallow waters and maneuverability. Examples include the Wooden Horse Boat, Smuggling Patrol Skiff, and Xiangshan Rice Transport Vessel, which reflect the functional demands of the inland economic system. Additionally, festival boats such as the Mid-July Amphibious Ritual Boat and Opera Boat illustrate the ceremonial and esthetic dimensions of local maritime culture.

Merchant ships of the Ming dynasty were primarily designed for long-distance voyages and maritime trade, characterized by robust forms adapted for transoceanic commerce and tributary activities[44]. By contrast, in the Qing dynasty, ship design gradually shifted toward riverine navigation, with the emergence of the river steamer influenced by Western technology[45]. This transformation reflects not only a functional shift from oceanic voyages to inland transport but also institutional changes shaped by the Qing dynasty's policies of maritime restriction and subsequent treaty-port openings. In short, the most significant change in Guangdong merchant ships between the Ming and Qing periods lies in the transition from an ocean-oriented, heavy-load trade model to a river-based, diversified regional shipping system, ultimately progressing toward steam-powered vessels under foreign technological influence.

Discussions

Lexical items such as "shipbuilding," "overseas," and "cargo volume" highlight the strong association between vessel functionality and cargo transport technologies, indicating that as oceanic trade expanded, ship

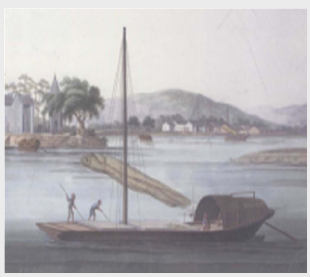
Table 5 | Chart of the types of ships that opened up the sea for trade in Guangdong during the Qing Dynasty

Sample	1 ■	2 ■	3 ■
Figures			
Name	Tributary Vessel to Siam (暹罗贡船)	White Cao Junk (白艚船)	White Salt Transport Ship (白盐船)
Type	Official Vessel (官方用船)	Transport Ship (运输船舶)	
No. of Mast	Triple-masted		Double-masted
Feature	A large Cao junk with painted black eyes and a mast displaying two flags: the horizontal banner reads “Siam Kingdom,” and the vertical one reads “Secondary Tribute.”	A sizable Cao vessel with red stingray-shaped head motifs and large painted eyes at the bow; a tiger-head symbol is painted at the prow. A carp-shaped flag is attached to the mainmast, while a “divine flag” is hoisted at the stern.	A white Zao salt transport ship, with black eyes painted on the bow gunwales.
Form	The vessel features pointed bow and stern with a flat bottom	The vessel has a pointed bow, a square stern, and a relatively tapered bottom	
Sample	4 ■	5 ■	6 ■
Figures			
Name	Military Payroll Gunboat (解饷炮船)	Dongchang Salt Transport Vessel (东场盐船)	Black Cao Junk (乌艚船)
Type	Naval Defense Warship (海防战船)	Official Transport Vessel (官方运输船舶)	Transport Ship (运输船舶)
No. of Mast	Double-masted		Triple-masted
Feature	A warship with a double-dragon pearl-chasing motif under the flag tower’s crossbeam; the fish-shaped bow features an elongated black eye. The hull narrows downward, and the vessel is equipped with a folangji cannon.	A vessel with black eyes painted on both bow gunwales. Behind the eyes are a single-fluke anchor and a prominently structured rudder, resembling those of the white salt ship.	A Cantonese-style Wu Cao junk used for maritime trade, constructed primarily from ironwood. The trough-shaped hull has stingray-like bow and stern ends, both marked with two white painted eyes.
Form	The vessel has a pointed bow, a square stern, and a relatively tapered bottom		
Sample	7 ◆	8 ◆	9 ◆
Figures			
Name	Mayangzi Boat (麻阳子船)	Mid-July Amphibious Ritual Boat (七月半水陆船)	Anti-Piracy Rice Skiff (捕盗米艇)
Type	Medium-Sized Passenger Boat (中型客船)	Festival Boat (节日船)	Naval Defense Warship (海防战船)
No. of Mast	None	Single-masted	Double-masted

Table 5 (continued) | Chart of the types of ships that opened up the sea for trade in Guangdong during the Qing Dynasty

Sample	1 ■	2 ■	3 ■
Feature	The vessel features an elevated bow and a stable, streamlined hull in natural timber color, conveying structural balance and visual continuity.	The boat is adorned with a greenish hip-and-gable (xieshan) roof over a four-pillar ceremonial gateway; at the stern, a red flag and two blue pennants are mounted, while multicolored water lanterns—red, yellow, blue, green, and purple—are hung throughout.	The bow resembles a rayfish with visible black eyes, and the stern is marked by an exceptionally large and prominent rudder. The deep blue hull is accented with vivid red trim, producing a highly striking visual effect.
Form	The vessel has a pointed bow, a square stern, and a flat bottom	The vessel features a raised bow, a slightly upturned stern, and a flat bottom	The vessel has a pointed bow, a square stern, and a relatively tapered bottom
Sample	10 ◆	11 ◆	12 ◆
Figures			
Name	Opera Boat (戏船)	Fifth-Month Dragon Boat (五月龙船)	Henglou Barge (横楼)
Type	Recreational Passenger Vessel (娱乐客船)	Festival Boat (节日船)	Recreational Passenger Vessel (娱乐客船)
No. of Mast	None		
Feature	Dominated by a red color scheme, the vessel displays red only on the stern planks and flags. Notably, the bulwarks of the cabin are decorated with a blue background featuring a Taiji (Yin-Yang) pattern composed of red, black, and white elements.	Constructed primarily from durable, water-shedding, and rot-resistant teak and kempas hardwoods, the vessel is spindle-shaped and features ornamental carvings of a dragon head and tail.	A decorative yellow canopy gate is placed at the center, and all cabin windows are fitted with green ice-crack patterned latticework and glass inlays.
Form	The vessel has a pointed bow, a broad stern, and a flat bottom		
Sample	13 ◆	14 ◆	15 ◆
Figures			
Name	Wooden Horse Boat (木马船)	Wheel-Hub Boat (轂船)	Smuggling Patrol Skiff (缉私艇)
Type	Official Vessel (官方用船)	Transport Ship (运输船舶)	Naval Defense Warship (海防战船)
No. of Mast	A-frame twin post		None
Feature	The vessel features a scroll-shaped, wood-colored stern, a spacious and well-structured cabin, and elegant decorative elements. It is characterized by high speed.	A shallow-draft, flat-bottomed boat with a natural wood finish, equipped with twin-mast columns.	The vessel is slender and streamlined in form, with cabin walls painted in deep blue at the base.
Form	The vessel has a high and rounded bow, a broad stern, and a flat bottom	The vessel features a pointed and elevated bow, a square stern, and a flat bottom	The vessel is characterized by a pointed bow, a relatively wide stern, and a slightly curved bottom
Sample	16 ◆	17 ◆	18 ◆
Figures			

Table 5 (continued) | Chart of the types of ships that opened up the sea for trade in Guangdong during the Qing Dynasty

Sample	1 ■	2 ■	3 ■
Name	Shixing Oil Boat (始兴油船)	Black Pavilion Barge (黑楼)	Xiangshan Rice Transport Vessel (香山米船)
Type	Transport Ship (运输船舶)	Official Vessel (官方用船)	Transport Ship (运输船舶)
No. of Mast	None	None	Single-masted
Feature	The deck is covered with thick, tightly fitted hatch covers, on top of which a furled sail is placed.	The hull is primarily brown, with a black-painted cabin structure; a large scull is mounted at the stern. The vessel lacks a fixed mast, and the sail is made of woven straw matting.	The boat has a pointed bow and square stern, with a low prow and no superfluous ornamentation at the front.
Form	The vessel has a pointed bow, a broad stern, and a flat bottom		
Sample	19 ◆	20 ◆	21 ▼
Figures			
Name	Duck Skiff (鸭艇)	Floral Pleasure Boat (花舫)	Official Vessel (官船)
Type	Transport Ship (运输船舶)	Recreational Passenger Vessel (娱乐客船)	Official Vessel (官方用船)
No. of Mast	None		Double-masted
Feature	A duck skiff equipped with two bamboo-woven duck pens on both sides; this type of vessel served both aquaculture and transportation functions.	A sand skiff originally designed for inland river navigation, later modified into a Pearl River tourist boat. The hull features a flat bow and upturned stern, propelled by a single scull. The cabin is relatively enclosed, with door panels predominantly painted in dark green.	The bow includes a porch and main hall covered by a connected canopy. Twin double-hook anchors are mounted symmetrically on both sides. The canopy and side railings are painted red, while the cabin windows display various blue decorative patterns.
Form	The vessel has a pointed bow, a broad stern, and a flat bottom	The vessel has a high bow, a broad stern, and a flat bottom	The vessel features a relatively elevated bow, a broad stern, and a slightly curved bottom
Sample	22 ▼	23 ◆	24 ▼
Figures			
Name	Rowing Skiff (桨艇)	Jumping Bai Boat (跳白船)	Three-Board Boat (三板艇)
Type	Naval Defense Warship (海防战船)	Transport Ship (运输船舶)	
No. of Mast	Single-masted		None
Feature	A long-barreled musket with a red handle and black barrel is mounted at the bow, with additional weapons stored at the stern. The cabin is covered with thick layers of densely packed thatch.	A slender-hulled vessel with deep blue-colored cabin walls; weaponry is visibly placed at the stern.	A small wooden boat without a deck, equipped with a sail, one mast, and three planks. The bow and stern are sharply raised, with the stern extending above the cabin.
Form	The vessel has a pointed bow, a square stern, and a relatively tapered bottom	The vessel has a pointed bow, a broad stern, and a flat bottom	

Noted: ■ Seagoing Vessel (海船); ◆ Inland Waterway(内河); ▼ Warship (战船)

design increasingly prioritized multifunctionality and high payload capacity to accommodate growing trade demands[44]. Concurrently, terms such as "Qing dynasty," "merchant," and "Qianlong" reflect the commercial prosperity during the Kangxi to Qianlong reigns[46], illustrating the interplay between state regulation and private commerce. Keywords like "salt," "books," and "silk" indicate the diversity of outbound trade goods, while "customs" and "scale" imply the institutionalization of trade through the establishment of customs offices and standardized taxation systems. The presence of terms such as "fleet" and "navy" reflects military responses to threats such as piracy, underscoring the critical role of security in

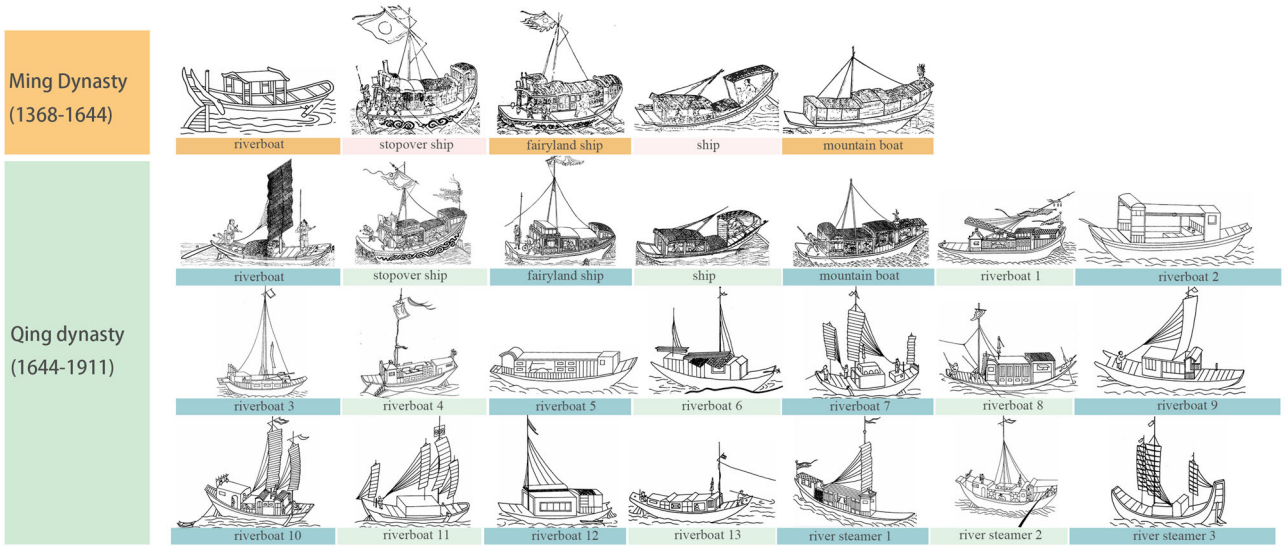


Fig. 5 | Comparison of the usual ship types in Guangdong during the Ming and Qing Dynasties.

maintaining maritime order. Geographic factors, including "inland waterways," "canals," and "voyage distance" influenced vessel choice, highlighting the significant impact of environmental conditions on ship design and navigation routes[47]. Trade hubs such as Guangzhou, Foshan, and Chaozhou formed a dense maritime network across the Guangdong region, playing central roles in shipping and commerce[48]. Lexical items such as "shipbuilding," "cargo," and "technology" emphasize the decisive influence of technological advancement on Guangdong's maritime and shipbuilding industries, while references to "maritime ban" and "inland waterways" reveal the direct impact of state policy on shipping activities[49]. Word frequency statistics show that the "vessel" group (TF = 482) ranks second only to "economy" (TF = 486), reinforcing the critical role of ship functionality in maritime trade, particularly in relation to transport and cargo loading. Geographic terms (TF = 59) exert the greatest influence on maritime trade, as the design and routing of merchant vessels are highly contingent on spatial conditions. In contrast, the impact of political (TF = 129) and military (TF = 60) factors appears relatively limited.

Economic and military lexicons form the core clusters, while geographic terms constitute secondary clusters. This indicates that economic and military concerns dominate maritime trade, although geography remains a significant but less dominant factor. The clusters of economy and military are linked through the term "Trade," accompanied by related words such as "Resources," "Haulage," and ship types like "Treasure Ship" and "Turreted Junk," revealing that the evolution of ship forms was driven by trade needs. Events in the Guangzhou region are closely associated with both geographic and military clusters, underscoring its geopolitical centrality in the global trade network. The connection between military and political clusters via the term "Ship" further suggests that merchant vessels were not only economic tools but also served political and military functions, contributing to maritime governance and state power projection. Frequent references to cities such as Guangzhou, Fuzhou, and Quanzhou, as well as high Pearson RSD values in places like Foshan and Chaozhou, suggest that geographic positioning (e.g., port access, hydrological conditions) and shipbuilding techniques jointly shaped the geopolitical significance of these coastal nodes.

During the Qing dynasty, salt, as a vital commodity, not only increased the transport capacity of merchant ships but also stimulated improvements in storage and moisture-proof design, demonstrating the profound influence of cargo characteristics on ship functionality[50]. The shipbuilding techniques of the Sui and Tang dynasties laid the foundation for later merchant vessel design, particularly in hull structure and navigation technology, and exerted a lasting influence on subsequent developments. Although the design of merchant ships during the Ming and Qing periods emphasized transport capacity, the craftsmanship of the Tang and Song dynasties remained evident in historical records and archeological sites[51], reflecting the continuity of technological traditions across centuries. In the Ming dynasty, maritime trade in Guangdong flourished, especially with India and Sri Lanka, making the region a crucial node along the Maritime Silk Road and highlighting its significance within global commercial networks. In the late Qing dynasty, policy shifts—particularly following the Opium War—had a profound impact on regional trade. Guangdong's shipping routes gradually expanded to European markets, underscoring the decisive role of political factors in shaping maritime trade routes and international cooperation.

Throughout the Ming and Qing periods, the design and construction of Guangdong merchant vessels underwent substantial transformation, reflecting the convergence of navigational technology and economic imperatives. Ming Dynasty merchant ships emphasized decorative and symbolic elements, featuring spacious, flat-bottomed hulls primarily constructed from teak and cypress wood. The ship's bow was streamlined and sharply curved upward, embodying the art of maritime navigation[52]. During the Qing Dynasty, emphasis shifted toward practicality and durability, with the adoption of lightweight alloy materials. The ship's hulls were painted in simple, understated colors, and the design incorporated a double-planked hull structure. The bow shape evolved from streamlined to pointed, enhancing the ship's ability to withstand wind and waves[50]. The emergence of the Qing Dynasty's Sha boat expanded the range of ship types available, primarily used for shallow-water navigation. Together with Guang boats and Fu boats, they formed the three major ship types of Guangdong shipping. Environmental factors along the coastal ports of Guangdong also shaped ship design in response to geographic conditions, ensuring safe and efficient navigation[53]. Overall, the evolution of merchant ship design in Guangdong reflects advances in shipping technology and changes in economic activity and trade demands, particularly in terms of adapting to ocean voyages and complex maritime environments. Merchant ship design increasingly emphasizes speed, wind and wave resistance, and versatility.

During the early Qing Dynasty, the design of merchant ships gradually developed standardized specifications that met the trade demands and navigational conditions of the time. According to Fong[45], by a certain period of the Qing Dynasty, merchant ships at sea had established corresponding standards in terms of structure, materials, seaworthiness, and speed. These standards not only covered the technical details of hull design but also imposed specific requirements on the functional aspects of vessels, thereby gradually establishing a merchant ship design philosophy that aligned with

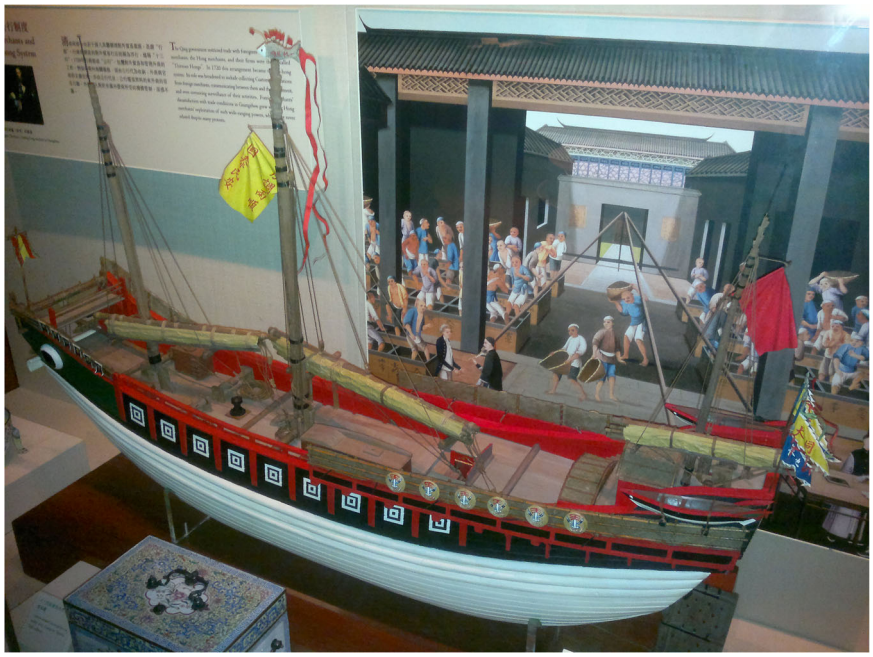


Fig. 6 | Keying Ship Model (Collected in the Hong Kong Museum of History).

Fig. 7 | Replica of No.1 Tong'an Shuttle-Junk Diagram from the Archives of the Qing Grand Council Memorials.

economic needs and the maritime environment. The work of He and Faure[54] found that although ship design during the Tang and Song dynasties did not fully reflect the standard models of later merchant ships, it had already made certain innovations in hull structure and functionality, laying the foundation for subsequent merchant ship design. However, there were still differences between Tang and Song Dynasty shipbuilding techniques and Ming and Qing Dynasty merchant ship design in terms of hull construction, material selection, and navigation technology, particularly in terms of adaptability to complex marine environments. By studying the relationship between Western Steamship Companies and Chinese Seaborne Trade during the Qing Dynasty[55], it is evident that from the late 19th to the early 20th century, Qing Dynasty merchant ship design gradually aligned with international shipping standards, particularly in adapting to European market demands, resulting in significant improvements in ship functionality and speed. Additionally, Elleman[56] notes in "A History of the Modern Chinese Navy, 1840–2020" that merchant ship design from the late 19th to early 20th centuries promoted similarities between Chinese and Western shipping industries in terms of hull design and navigational performance. Compared to earlier designs, changes in Qing Dynasty merchant ship design during the later period can be partially attributed to the profound impact of the international political environment following the Opium Wars on shipping routes and trade cooperation.

A three-masted sailing vessel that departed from Hong Kong in 1884 and sailed to London—primarily transporting tea—represented one of the longest-distance maritime journeys undertaken by a Chinese junk. The Keying Ship traveled via the Cape of Good Hope and the eastern coast of the United States, ultimately arriving in London in March 1848, setting a record for the farthest voyage made by a Chinese sailing vessel[57]. Constructed from teakwood, the ship measured approximately 45 meters in length, 10.7 meters in beam, and had a displacement of about 800 tons (Fig. 6). The vessel was secretly purchased in 1846 by a British merchant, violating contemporary Chinese laws prohibiting the sale of native vessels to foreigners, and drew significant attention in Western maritime circles. In response to wartime maritime demands, the Qing government began modifying naval warships based on the Tong'an Sloop design around 1795. The Tong'an Sloop[58] was a multifunctional vessel suitable for both trade and combat. A standard unit of the vessel was approximately 7.2 zhang in length and 1.9 zhang in beam, while larger variants reached 8.2 zhang in length and 2.6 zhang in beam (Fig. 7). The "red-headed ship" is a traditional ship type unique to the Chaozhou-Shanwei region, primarily used for long-distance trade. During the Qing Dynasty, it played a significant role in transporting large numbers of Chaozhou-Shanwei people to Southeast Asia in search of livelihood[59]. These three-masted sailing ships typically measure approximately 25 meters in length, 9 meters in width, and 7 meters in height, constructed using durable materials such as teak wood, ensuring excellent durability and stability. The bow is painted red and adorned with an eye, symbolizing the ability to discern the direction of distant voyages in the vast ocean, while also signifying good fortune[60]. The Red-headed Ship was primarily designed for long-distance voyages and the transportation of bulk cargo, featuring a high-arched bow and a wide stern, making it suitable for

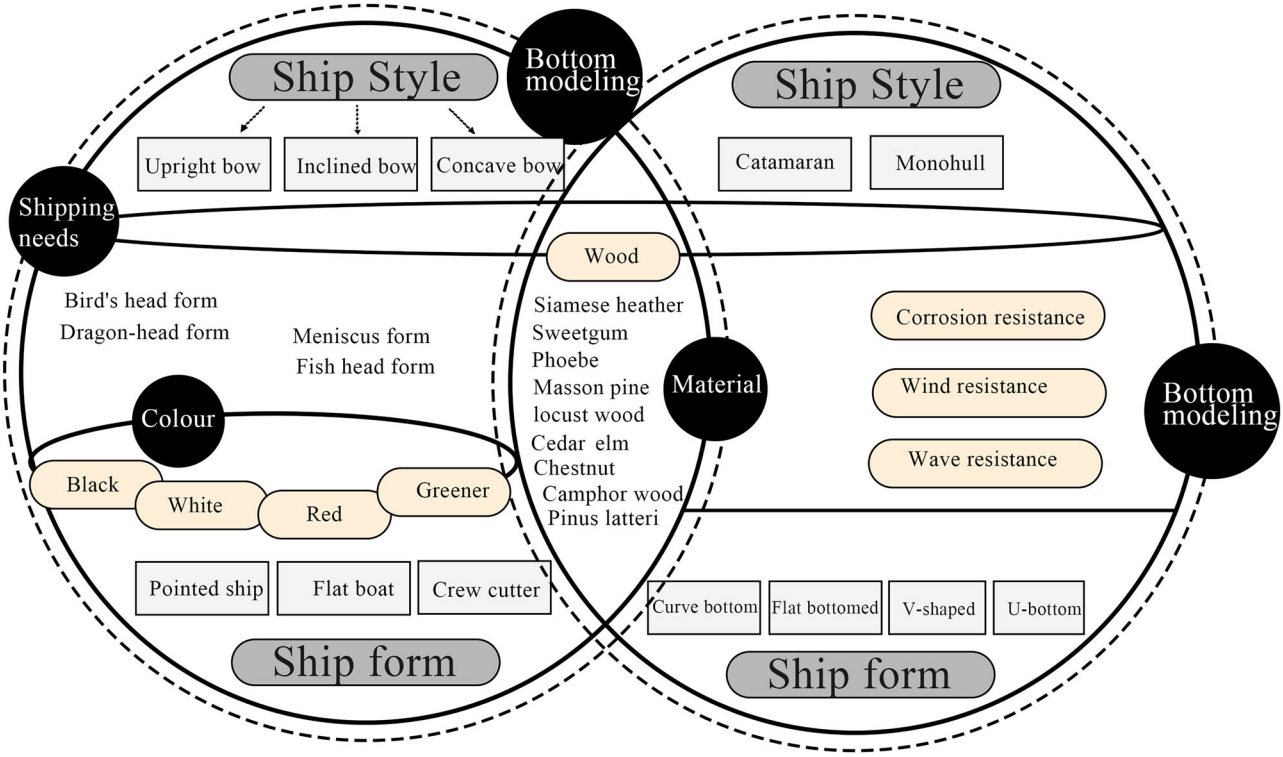


Fig. 8 | Morphological features of Guangdong ships in the 15th–20th centuries.

carrying large quantities of goods and meeting the demands of oceanic navigation. The ship also included storage spaces and living quarters for the crew.

This study examines the evolution of Guangdong merchant ship design during the Ming and Qing dynasties, focusing on features such as bow shape, hull structure, material usage, and color schemes (Fig. 8). First, bow shapes not only included common designs like bird-head, fish-head, and dragon-head styles but also incorporated contemporary social and cultural elements, reflecting the close connection between ships and local beliefs and customs. For example, some ships featured "dragon patterns" as decorations to pray for safe voyages. Changes in bow design also reflected adaptations to navigational performance: sharp bows were suited for navigating rough seas, while wide, rounded designs enhanced stability, making them suitable for extended voyages. In terms of hull structure, as shipping requirements have diversified, merchant ships have evolved from monohulls to catamarans. Structural improvements have not only enhanced stability but also optimized cargo capacity, speed, and durability. The design of catamarans is particularly suited to the needs of Guangdong merchant ships on long-distance trade routes, significantly improving their navigational performance. In terms of materials, in addition to traditional pine and cypress wood, by the late Qing Dynasty, with technological advancements, merchant ships began using more durable synthetic materials and new types of wood, which enhanced the ships' corrosion resistance and durability. The gradual adoption of metal materials further strengthened the stability and safety of the hull structure, enabling the ships to better withstand harsh marine environments. In terms of color application, the use of red and green not only enhances the ship's visibility but also carries profound cultural symbolic meanings. Red is often associated with good fortune and peace, while green is closely linked to environmental protection and sustainable development. In recent years, color usage in ship design has increasingly emphasized environmental adaptability and visual guidance, improving the ship's visibility in ports and at sea.

Knowledge mining originated in the fields of computer science and information technology. As a method of information extraction and processing, its application in the social sciences and humanities has revealed its powerful data analysis capabilities. Techniques based on semantic and textual analysis have formed various branches, and the computational text analysis methods used by Kim et al.[61], Bai et al.[62], and Xu et al.[63] share similarities, all emphasizing the use of automation and algorithmic means to structurally analyze large volumes of textual data. These methods not only effectively improve the efficiency of text data processing but also offer new perspectives for extracting latent information from complex texts. Li et al.[33], Zhang et al.[34], and Häberle et al.[64] have extended the application of these methods to fields such as mural art, architectural decoration, and urban geography, demonstrating the broad applicability of computational text analysis in interdisciplinary research. Therefore, the analysis steps in this study possess replicability and can provide theoretical insights and technical support for subsequent research in related fields. In the "Methodology" and "Results" sections, this study outlines the specific steps and processes of the method. For example, the method can be applied to sentiment analysis of news reports or to the analysis of behavioral patterns and interaction relationships in social networks[65]. Furthermore, it can provide a more refined analytical framework for policy research and the fluctuation trends of public opinion, revealing latent social demands and public sentiment[66]. This method can also offer precise user profiles and trend forecasts for market research and consumer behavior studies[67], enhancing the scientific and accurate nature of decision-making.

Geopolitical theory has evolved from the classical paradigm of environmental determinism to the critical geopolitical approach, which emphasizes spatial power control and institutional embeddedness, and more recently to the post-geopolitical turn that focuses on trans-regional networks and mobility mechanisms. Within this theoretical framework, the organizational logic of power space, mechanisms of institutional resource allocation, and the geographic adaptability of technological artifacts are regarded as key variables in shaping global governance structures and the evolution of transportation regimes. Ju[68], Matsumoto, and Birch[69], have examined the applicability of the co-construction model of geopolitical power and institutional–technological systems in port governance, maritime power configurations, and logistics systems. Building on this foundation, the present study extends the theoretical scope and empirical application of geopolitical

theory to the analysis of vessel typological transformation. In recent years, geopolitical theory has also been widely adopted in interdisciplinary fields such as mobility studies and historical political economy of geography. This research integrates it into a compound analytical framework that links the technological history of vessel typologies, institutional evolution, and geographic path dependence, thereby establishing a perspective that is both spatially structural and institutionally explanatory.

The application of computational text analysis not only reflects the phenomenon of the intersection of technology and society, but also serves as a microcosm of interdisciplinary research, particularly in data-intensive and information-complex fields. This study provides valuable insights into the digital transformation of sociology, communication studies, and the humanities, revealing the practical utility of techniques such as word frequency statistics and semantic coding. By presenting the research questions and findings of this study, international scholars can verify the generalizability of the analysis results through case comparisons and explore the applicability in cross-cultural research, enhancing the understanding and interpretation of complex social phenomena. To fully interpret the interactive effects of computational text analysis technology and social-cultural context, this study introduces various analytical techniques, such as CA, ship morphology studies, and co-occurrence networks, providing a new research paradigm for social science research.

The evolution of merchant vessel typologies in Guangdong during the Ming and Qing periods was shaped by the interaction between technological advancement and growing economic demands. Merchant ship design increasingly prioritized enhanced wave resistance and cargo capacity to accommodate the expansion of long-distance maritime trade. In a dynamic geopolitical and geographical context, balancing economic functionality with navigational safety required the integration of technological innovation and spatial adaptability. The findings partially support the initial hypothesis: technological innovation significantly improved the efficiency and safety of vessels. For instance, the use of lightweight alloys and double-layered hulls contributed to greater structural stability and load-bearing capacity. However, the study also reveals that isolated technological improvements were insufficient to meet the complex demands of a globally expanding maritime network. Optimal ship design must continuously incorporate both geographic adaptability and the constraints of the political environment.

Although this manuscript centers on the Ming and Qing periods, it lacks fine-grained chronological differentiation within the two dynasties. The temporal segmentation of ship typology evolution, institutional adjustment, and policy response remains underdeveloped, leading to a tendency toward temporal compression in the historical narrative. The Qing dynasty data are notably more comprehensive, which further skews the analytical focus. Spatially, although the study nominally emphasizes Guangdong, it in fact extends to port networks across Southeast Asia—including Siam, Vietnam, and Japan—resulting in blurred spatial boundaries that dilute Guangdong's theoretical centrality within a geopolitical framework. As noted by van Noort[13], the spatial validity of historical maritime systems should be grounded in the overlap between geopolitical power structures and trade network nodes; otherwise, the analysis risks falling into both spatial generalization and theoretical incoherence. For further research, here are a few suggestions for improvement. Firstly, the introduction of a more refined periodization model, such as temporal coding based on major political events or policy inflection points, to enhance the granularity of temporal analysis. Secondly, the application of GIS and multi-scale spatial modeling techniques to reconstruct the spatial logic of Guangdong and its surrounding maritime zones, thereby clarifying research boundaries and regional configurations. Thirdly, the construction of an analytical framework grounded in a tripartite structure of geopolitics, institutional systems, and vessel typologies, in order to reinforce Guangdong's structural significance within geopolitical power dynamics. Finally, as demonstrated by Li et al.[70], the adoption of scientometric approaches can be used to examine spatial patterns and collaborative networks on specific topics across regions.

This study centers on the typological evolution of merchant vessels in Guangdong during the Ming and Qing periods, systematically revealing the deep influence of geopolitical factors on their technological trajectories, functional design, and regional adaptability. Drawing on historical literature and computational text analysis, the study demonstrates that changes in ship typology were not merely tactical responses to maritime prohibitions, external threats, and port conditions, but also reflected a gradual morphological evolution from wide-bodied flat-bottom vessels to elongated agile forms and eventually to wind-resistant stable structures. Economic and military demands are the main drivers, while geographical location and shipbuilding technology are important secondary factors, together shaping the unique form and adaptive mechanisms of Guangdong merchant ships in the global shipping system. This study contributes to an expanded understanding of China's maritime heritage and offers theoretical grounding for constructing a multidimensional historical narrative of regional shipping culture.

Data availability

All data generated or analyzed during this study are included in this published article. The Supplementary Data 1 (Chinese Historical Terms) and Supplementary Data 2 (Text Material) have been uploaded as supplementary materials. The vessel images in Table 5 are sourced from publicly available data on Figshare: https://doi.org/10.6084/m9.figshare.25511137.

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

Competing interests

The authors declare no competing interests.

Additional information

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