Shaping the Colonial Port cities: Trade Network and Spatial Structure in the Early modern period

Chaoqun Wang, Jie He
Harbin Institute of Technology, Shenzhen, Architecture Department, 518055 Shenzhen, China - hejie2021@hit.edu.cn

Abstract: This paper presents a comprehensive research framework examining the interplay between colonial trade networks and the spatial form of port cities during the early modern era. Firstly, the study constructs a geographic database of nearly 300 colonial port cities, using intercity trade data from East India Company archives as network edges to analyze their structural and morphological evolution. Secondly, it processes historical maps of colonial ports through a fine-tuned multimodal large language model to extract and classify spatial morphological features, establishing a systematic typology of urban form patterns. Thirdly, the research develops regression models to reveal correlations between network status and morphological patterns. Preliminary findings highlight Batavia's dominant yet volatile role within the network and reveal a trend toward decentralization over the 18th century. The research contributes to both urban historical studies and digital humanities by offering a scalable, comparative approach to interpreting colonial port cities as spatial manifestations of global economic and political forces, while establishing empirical relationships between network status and urban form characteristics. It further provides a refined framework for contextualizing their cultural heritage significance within trans-colonial networks.

Keywords: Colonial port city, Urban form, Urban network, Early Modern Era, Colonial culture heritage, Maritime trade

1. Introduction

Maritime trade activities of European powers during the Early Modern Period (1500s-1800s) shaped a global geographical network of colonialism and trade that spanned the world. Colonial port cities served as pivotal nodes in this network, and their urban spaces were concrete manifestations of the power penetration, ideological export and interest plunder of European colonial metropolises. The development of colonial port cities was always embedded in the tension and contest between colonial and indigenous cultures, yet this dual influence was not an equal two-way shaping process (Boxer C, 1969). Instead, it centered on the will of European colonial metropolises, with indigenous cultures merely acting as passive adaptive elements. The spatial forms of these cities thus became the most intuitive and enduring material projection of such unequal power relations (King A, 2012). These spatial forms exhibited the following characteristics: they often featured a “Dual City / Colonial Urban Dualism”, presenting a fragmented pattern with European and indigenous districts coexisting in the same city; European planning concepts were systematically implanted, and their typical spatial representations—including regular grid road systems, central squares embodying colonial authority, functional zoning serving colonial rule, and port infrastructure adapted for transoceanic trade—were essentially disciplinary spatial practices through which European colonial metropolises transformed their political demands, economic interests and cultural concepts into spatial order.

As products of the disciplinary spatial practices of colonial metropolises, the spaces of colonial port cities were deeply bound to the operation of colonial networks. The demands of resource circulation, power transmission and interest extraction within colonial networks shaped the spatial planning logic of colonial cities. For instance, cities with high weight and influence in colonial networks underwent more thorough spatial restructuring, which was specifically reflected in more complete infrastructure, more rigorous defense systems, specialized European residential areas and prominent European spatial forms. The formation, development and evolution of colonial port city spaces were constrained and shaped by colonial networks, and in turn, these spaces sustained the operation of colonial networks through their own spatial functions.

In summary, the inextricable relationship between colonial port city spaces and colonial networks constitutes the core content of the global maritime historical narrative, yet current research on this topic remains inadequate. On the one hand, from a global history perspective, scholars have focused on the flow of commodities and capital in the global market network under European colonial trade during the Early Modern Period. On the other hand, from regional and local perspectives, scholars have reconstructed the history of colonial port cities from multiple dimensions, including urban economic functions, spatial forms, commercial systems, social structures, and the power contest between indigenous and foreign forces. There is a lack of effective dialogue between these two research orientations.

Therefore, this study attempts to address the question: How did the colonial trade networks established by European powers during the Early Modern Period determine their spatial practices in colonial cities? According to existing data, European spatial practices included, but were not limited to, the establishment of trading posts or factories, the construction of new cities after occupation, or merely stationing in a small area for trade purposes. These practices of varying intensities resulted in urban spatial structures and characteristics with European planning features of different degrees. Thus, this study intends to explore the above question from the following aspects:

1. What kind of port city network was shaped by colonial maritime activities during the Early Modern Period?
2. What spatial structures and characteristics do colonial port cities present, and what intensity of spatial practice do they reflect?
3. What is the correlation between the position of colonial port cities in the broader colonial city network and the intensity of their spatial practices?

This study aims to build a dialogue bridge between macro-level global colonial network research and micro-level local maritime city research, fill the existing knowledge gap regarding how colonial transoceanic practices specifically shaped urban spatial forms, and on this basis, propose a new research approach suitable for comparative case studies of multiple port cities. The spaces of colonial port cities are not only important material carriers of the global maritime historical narrative but also irreplaceable precious cultural heritage, and their systematic analysis holds significant theoretical and practical value.

2. State of the Art

2.1 Colonial Port City History, Colonial Urban Spatial Form, and Colonial Architectural Style

Ross R and Telkamp G (1985) published the proceedings "Colonial Cities", which examined colonial city cases from the perspectives of urban economic functions, spatial forms, and political and social life; In this volume, King and Bruijne in this volume respectively proposed typological frameworks for colonial cities. Hall (2008) edited proceedings focused more on secondary cities rather than major port cities, and included case studies of multiple secondary cities in the Indian Ocean region during the pre-colonial period. The proceedings "Brides of the Sea"(Frank B, 1989) advocated for greater attention to the complex relationship between ports and cities in the study of colonial port cities, discussing how cities participated in trade networks, the evolution of port-city interfaces, the conflict and integration of urban community cultures, and the shaping of cities by technological changes and institutional policies. In its 1997 sequel, "Gateways of Asia" (Frank B, 1997), he further conducted a comparative study of case studies of Asian gateway cities from the 13th to the 20th centuries. The above edited volumes cover the economic, social and cultural dimensions of colonial port cities, providing rich insights for the urban history of the Early Modern Period, but they do not extensively discuss urban spatial characteristics.

There is a substantial body of literature in the fields of urban planning and architecture that reviews the construction history of European powers in colonial port cities and traces the causes of the historical forms of port cities, including the Dutch planning of Southeast Asian cities such as Formosa(Oosterhoff J, 1985) and Batavia (Blusse L, 1985), the Spanish planning of Manila (UNESCO world heritage centre, 2024), and the British planning of major Indian cities such as Madras, Bombay and Calcutta.

Some studies also examine how the urban spatial structure of a single city changed due to evolving planning concepts under the alternating intervention of multiple colonial powers over a long period (Biedermann Z, 2009). Such studies can clearly reconstruct the spatial evolution and driving factors of colonial port cities. In addition, some literature attempts to identify spatial laws of colonial port cities through multi-case comparative studies. Tian et al (2023a) first reconstructed the geographical pattern of colonial trade circles during the Early Modern Period, and then Tian et al (2023b) selected five cities to draw floor plans of their old urban areas for horizontal comparison. Wei et al (2024) used the Conzenian urban morphological theory to compare and analyze 21 colonial cities in Asia and Africa, and conducted a typological classification: segregated, intermediary and integrated types. Baruah N et al (2020) selected 318 colonies in South Africa under the jurisdiction of British and French metropolises as samples, conducted a quantitative analysis of their urban spatial expansion, and systematically explained how the differentiated colonial concepts of Britain and France shaped and drove the divergent characteristics of their colonial expansion models. Major Indian cities, due to the sustained and in-depth influence of the British metropolis, are often used as samples for horizontal comparison (Kosambi M and Brush J, 2020; Wang Y and Ma Y, 2017).

2.2 Spatial Abstract Modelling of the Colonial Port Cities

Port cities, especially topics such as the evolution of the spatial relationship between ports and cities, have been the focus of geographical research since the 1960s, giving rise to classic models such as the Anyport model (Bird J, 1963), Anyport-type model (Wang H and Luan W, 2011), and Typologie des villes-ports (Ducruet C, 2004). Such models mostly describe the interaction laws between the functional evolution of ports and urban spatial expansion with abstract structures, depicting the dynamic process of the port-city space from tight coupling to gradual separation, and then to functional restructuring and coordinated development. Drawing on these classic models, scholars have also summarized abstract models from case studies for colonial port cities. Hoyle B (1968) applied the Anyport model to an empirical study of port cluster cities in East Africa and proposed a revised model suitable for East African cities; Lee S et al (2007) constructed a conceptual model of the port-city relationship of Asian hub port cities; McGee T(1967) summarized the fan-shaped land use pattern of port core area-mixed use radiation area in Southeast Asian port cities; Kosambi M and Brush J (1988) summarized the structural model of Indian colonial cities; Ford L (1993) proposed the land use structural model of Indonesian colonial cities; Knight C and Newman J (1976) restored the three stages of indigenous origin, colonial transformation and post-colonial transition of African colonial cities, explored colonial structural elements, summarized a general spatial model of Africa, and further explained its retention and changes in the post-colonial period.

The above studies, based on in-depth research on urban cases, extract general summary models that can reflect the land use functional zoning of regional colonial port cities. Such studies are highly dependent on detailed surveys of local city samples and are difficult to extend to samples on a larger spatial scale. On the other hand, in recent years, research on urban spatial modeling based on topological structure has emerged: for example, modeling the functional attributes and spatial adjacency relationships of buildings and roads as graphs (Iddianozie C and Mcardle G, 2021); taking space syntax algorithms(Hillier B and Hanson J, 2009). as the representative, modeling the intersection relationships of urban road networks; and modeling the spatial orientation relationships of building groups to identify fixed layout patterns (Tang Z et al, 2023). This method can quickly and quantitatively describe the spatial structural characteristics of multi-sample cities based on basic urban data, providing an effective path for standardized comparative research of multiple samples.

2.3 Colonial image analysis

Colonial maps are not only materials reflecting the evolution of urban forms, aesthetic orientations and changes in visual representations, but can even be regarded as a set of symbolic systems carrying colonial power, reflecting colonial intentions (Rapp R, 1979; Song N, 2022; Mukherjee N, 2026). Kuzur G (2018) explored the differences in cartographic techniques of the same Indian city depicted by different European colonizers, pointing out that such differences precisely reflect the core demands of colonizers in managing the city, i.e., whether their purpose was merely to conduct trade without involving territorial conquest and rule. Her interpretation of cartographic techniques considers the following elements:

Foreground elements; background elements; fortified settlements; natural geomorphic elements; territorial presentation; traffic accessibility; trade-related depictions; rural landscapes; distinctive scenes; color application; compass roses, scales, legends, emblems, flags, seals and symbols.

Silver L (1999) analyzed three core images related to the Dutch East India Company (VOC), namely the topographic views of Ayutthaya and Osaka Castle and the war view of the Battle of Makassar. The research (Luo G, 2022) on the aerial views of Taiwan during the Japanese occupation revealed how the colonial authorities demonstrated their comprehensive control over Taiwan's geographical information and resource status through detailed labeling of the geographical and resource distribution of the entire island of Taiwan, especially highlighting the establishment of colonial institutions. The current academic community has not fully exploited the potential of colonial images in reflecting the historical space and landscape of cities, and has focused too much on critical cartography (Robin A, 2009).

3. Methodology

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3.1 Dataset

The dataset of this study consists of three parts:

3.1.1 Selection of Colonial Port Cities and Key Colonial Port Cities

This study first crawled the lists of Portuguese, British and Dutch colonial cities, trading posts and factories listed on Wikipedia and open-source websites to build a colonial port city database. Key colonial port cities were further selected from literatures and works as the research objects of this study, with a total of 43 key colonial port cities selected, as shown in Figure 1.

For each colonial city, historical information of the city during the Early Modern Period was entered into the database as corpus input to the large model, so as to better understand the historical background information of the images and obtain more accurate outputs.

Figure 1 Map of Colonial Port Cities and Key Colonial Port Cities

3.1.2 VOC Trade Dataset

This study selected the Dutch East India Company (VOC) trade archive dataset, including two parts: Bookkeeper-General Batavia (hereafter BGB) and The Dutch East India Company's shipping between the Netherlands and Asia (hereafter DASD). The BGB dataset contains the VOC's shipping records documented by the Batavia headquarters from 1700 to 1800; the latter records the voyage records between the Netherlands and Asia from 1595 to 1795. Both provide information on the departure location, arrival location and voyage time of each voyage. The data details are shown in Table 1.

Table 1 VOC shipping data

Data name	Source	Description	Time range	Data volume
Bookkeeper-General Batavia (hereafter **BGB**)	https://bgb.resources.huygens.knaw.nl/voyages_results	A historical database recorded by the Chief Bookkeeper at the VOC headquarters in Batavia, which documents the internal commodity circulation of VOC	1700 - 1800	18,322 rows
The Dutch East India Company's shipping between the Netherlands and Asia (hereafter DASD)	https://resources.huygens.knaw.nl/das/voyages?start=50	An authoritative database systematically compiling voyage records on the Europe–Asia route by the Dutch East India Company (VOC) and its precursor organizations	1595 - 1795	18,791 rows

3.1.3 Image Dataset of Key Colonial Port Cities

Based on the selected 43 colonial port cities, colonial historical maps or images were collected to construct an image database. First, the images must be able to reflect the overall spatial structure or spatial interface of the city; second, the production time range must be from the 16th century to the 19th century. Most colonial images are collected from the Atlas of Mutual Heritage website, and available colonial images are also collected on network platforms to ensure that all eligible images of each city are fully collected. A total of 211 images were collected.

3.2 Research Approach

This study is based on the following research approach, see figure 2:

1. Analysis of the Shipping Network of Colonial Port Cities
Based on the VOC shipping dataset, a directed OD matrix network of colonial port cities was constructed with the total navigation frequency as the edge weight, and the centrality indicators of each city, including degree centrality, in-degree/out-degree centrality, weighted degree centrality and closeness centrality, were calculated.

2. Image Analysis of Important Colonial Port Cities
Based on this information, indicators reflecting the intensity of the transformation of the space of key colonial cities by colonial practices were calculated, as detailed below. The collected historical images were input into the large model, and the macroscopic spatial topological structure and detailed symbolic elements of the cities were

extracted through customized Prompts; after verification, correction, integration and summary by human researchers, basic data were formed, and based on this, indicators reflecting the intensity of the transformation of urban space by colonial practices were calculated (see below for details).

3. Analysis of the Mechanism of the Relationship between the Network Position and Spatial Characteristics of Important Colonial Port Cities
For the aforementioned shipping network indicators and image spatial indicators, embedding algorithms were used to generate vector representations of each city in the network dimension and spatial dimension respectively, and then the Mantel test model was applied to explore the correlation between the urban network position and its spatial morphological characteristics.

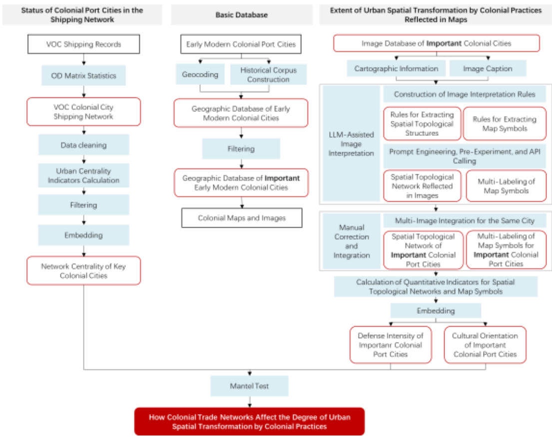


Figure 2. Technical Roadmap

3.2.1 Extraction of Topological Spatial Structure from Colonial Images

Due to the varying levels of detail of colonial images, it is difficult to identify the urban land functional spatial pattern reflected in the maps with a unified standard, as in existing studies on abstract spatial models of port cities. Even if identified, the correctness of the results is difficult to verify. Therefore, this study refers to the research on port-city interface types, extracts elements with clear boundary lines such as port-water-city-military fortress, and translates the urban spatial structure reflected in the images into a highly abstract topological network. The extraction principle is shown in Figure 3.
After observing the collected images and conducting multiple rounds of pre-experiments, this study defined the following node types: *European Fortress, Bulwark City Wall, Local City Wall, Urban Built-Up Area, Ocean, Port, Canal, Suburb*; and the following connection types: *Fully enclosed, Partially enclosed, Embedded, Directly connected, Road connected*. The above rules were input into the large model in the form of instructions, requiring the large model to output statements in json format. Since a single city may correspond to multiple images, after extracting the topological structure of each image, researchers need to determine whether the structures of multiple images of the same city are consistent, merge the similar ones, and retain the significantly different ones.

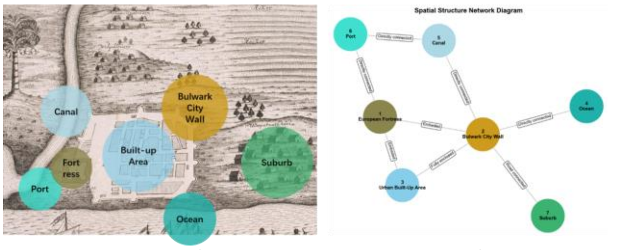


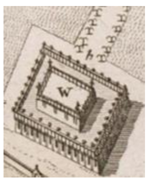
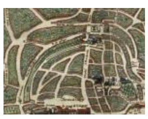
Figure 3. Extraction of Spatial Topological Structure of Colonial Maps, Taking Tranquebar as an Example

3.2.2 Extraction of Detailed Symbolic Elements from Colonial Images

After the overall browsing of the collected images and multiple rounds of pre-experiments, this study formulated the following image symbolic elements (see Table 2) to be extracted:

Table 2 Definition of Symbolic Elements in Colonial Images

Element Type	Element Name	Element Description	Image Illustration
Military Defense Elements	Bulwark City Wall	Defensive city walls with bulwark structures	
	Military Fortress	The core defensive fortification of colonial strongholds, with the functions of garrisoning troops, storing grain and commanding, a single independent building or connected multiple buildings	
	Star Fort	Defensive fortifications adopting a multi-angle bulwark layout	
	Battery	Fixed defensive facilities for placing artillery	
Architectural Elements	Indigenous-style Building	Local residential architectural forms, non-European style	
	European-style Building	European-style buildings, such as iconic Dutch red roofs	
	Indigenous-style Religious Building	Non-Christian buildings, mostly Islamic or Buddhist buildings	

	European-style Landmark Building	More prominent landmark buildings compared with European-style buildings, such as customs houses	
	European-style Religious Building	Christian buildings with a prominent cross as the characteristic	
Functional Space	Public Green Space	Usually appearing in regular geometric blocks, with regular vegetation or geometric layout	
	Public Square	Open space enclosed by buildings with regular shapes	
	Marketplace	A marketplace where merchants from diverse communities gather for trade, mostly labeled through legends	
	Warehouse	Regular rectangular in plan, with length much greater than width and low floors, mostly located near docks and river banks	
	Customs House	Prominent buildings located at ports and city gates, labeled through legends	
	Administrative Building	Administrative institutions of the East India Company, such as colonial government management agencies and governor's offices, mostly labeled through legends	
	Agricultural Plantation	Mostly marked with symbols such as palm trees and seedlings	
Road Elements	Grid Road	Checkerboard pattern with fixed street directions, uniform plot division and strong spatial order	
	Radial Road	Roads extending outward in a radial pattern with core nodes (such as squares and strongholds) as the center	
	Organic Road	No fixed planning paradigm, naturally formed according to natural terrain and indigenous living texture, with tortuous directions and irregular road network forms, fitting the regional environment and original spatial pattern	

3.2.3 Quantitative Calculation of the Colonial Impact Intensity on Urban Spatial Structure

The Colonial Impact Intensity on Urban Spatial Structure is comprehensively calculated from the macroscopic spatial topological structure network and detailed symbolic elements of the images. The quantification of the spatial topological structure focuses on measuring the defense intensity of the city after the transformation by colonial practices, while the detailed symbolic elements reflect the cultural orientation of the urban space.

Setting and Calculation of Quantitative Indicators for the Spatial Topological Structure Network:

1. Defense Grade Index (DGI)
Indicator Meaning: Reflects the intensity of defensive facilities owned by the city.
Calculation Method: Calculated by assigning values to defensive type nodes in the topological structure: no defense (0), Local City Wall (1), Canal (1), Bulwark City Wall (2), European Fortress (3).

2. Fortification Enclosure Index (FEI)
Indicator Meaning: Reflects the openness of colonial port cities, i.e., the enclosure situation and constraint degree of defensive facilities on the city.
Calculation Method: Calculated by assigning values to the edge attributes connected to defensive type nodes: Fully enclosed (3), Semi-enclosed or Partially enclosed (2), Embedded (1), Directly connected (0.8), Road connected (0.5).

3. Defense Node Degree Centrality (DNDC)
Indicator Meaning: Measures the core degree and influence of defensive type nodes in the urban topological graph.
Calculation Method: Count and sum the degree centrality of all defensive type nodes in the urban topological graph.

4. Defense Subgraph Density (DSD)
Indicator Meaning: Reflects the connection compactness between defensive type nodes.
Calculation Method: Construct a defensive subgraph G_defense with Fort, Bastion and Wall as the core; Defense Subgraph Density = actual number of edges in the subgraph ÷ maximum possible number of edges in the subgraph.

5. Harbor Defense Betweenness (HDB)
Indicator Meaning: Measures the control ability of defensive type nodes over the connected paths between the port and the city.
Calculation Method: First, search all the shortest network paths between the Ocean and the Urban Built-up Area,

then count the proportion of these shortest paths passing through defensive type nodes.

6. Defense Control Reachability (DCR)
Indicator Meaning: Measures the rapid control ability of defensive type nodes over other nodes.
Calculation Method: Taking defensive nodes as the starting point, count the proportion of the number of "Urban Built-up Area" and "Port" nodes reachable within 1 step, i.e., the proportion of important protected objects among the direct neighbors of defensive nodes.

Setting and Calculation of Quantitative Indicators for Image Symbols:
This study assigns values for "cultural orientation" according to the symbol types defined in Table 2. A value close to 1 indicates that the element is more inclined to the colonial cultural context; a value close to -1 indicates that the element is inclined to the indigenous cultural context; a value close to 0 indicates that the element is a neutral element. The valuation standards are shown in Table 3.
After assignment, the following three indicators are calculated:

1. Colonial Cultural Bias Score (C-CBS), calculated by standardizing the total score of colonial culture-oriented elements.
2. Indigenous Cultural Bias Score (I-CBS), calculated by standardizing the total score of indigenous culture-oriented elements.
3. Comprehensive Cultural Bias Score (CCS), calculated by adding the standardized values of the above two indicators.

Table 3 Standards for Symbol Valuation in Colonial Images

Element Type	Element Name	Weight
Colonial Culture-Oriented	Bastion walls; European Fortresses; Star forts; Batteries	0.9
	Administrative buildings; Grid roads; European-style landmark buildings; European Christian-style buildings	0.6
	Radial roads; Public squares; Public green spaces; European-style buildings; Agricultural plantations	0.3
Neutral Element	Customs houses; Warehouses	0
Indigenous Culture-Oriented	Indigenous-style buildings	-0.3
	Organic roads; Markets	-0.6
	Indigenous religious styles; Indigenous-style landmark buildings	-0.9

4. Results

4.1 Construction of the Colonial City Network and Analysis of the Network Position of Key Colonial Port Cities

In the colonial shipping network (see Figure 4) of the Early Modern Period, Batavia was the absolute core node, which formed close connections with secondary core cities such as Malacca, Banten, Colombo and Cape of Good Hope through high-density and high-intensity shipping links, jointly constituting the core circle of the network and undertaking the functions of trade transit, military control and administrative center. Cities represented by Makassar, Surat and Nagasaki formed the semi-peripheral layer, which linked with the core area through medium-intensity connections and served the commodity distribution of local markets. Other nodes formed the peripheral layer, which was in a dependent position in the colonial network system.

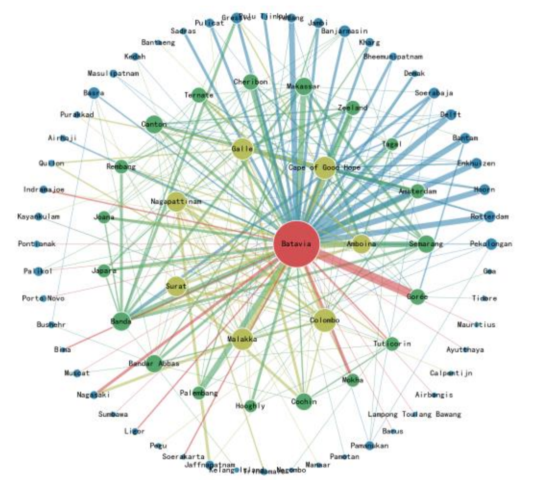
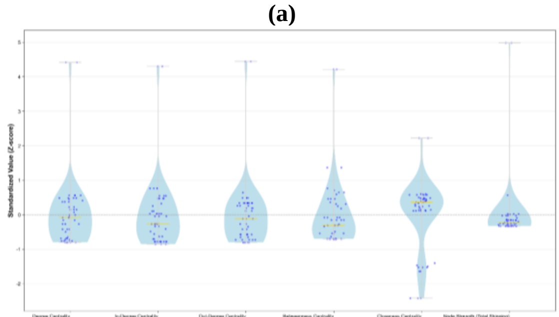


Figure 4 Core-Periphery Structure of the VOC Maritime Urban Network (1596–1801)

The network centrality indicators of the selected importanr colonial port cities were extracted and observed in the Figure 5. The distribution gaps of degree centrality and in-degree/out-degree centrality are relatively small, and the values of most cities are not high; Bantam and Batavia are the most prominent, being the most authoritative nodes in the network. The betweenness centrality and closeness centrality show large differences among samples; in addition to Bantam and Batavia being the most prominent in these two indicators, gateway cities such as Canton, Cochin, Makassar, Bandar Abbas and Surat also emerge, which become regional transit hub cities.

(a)



(b)

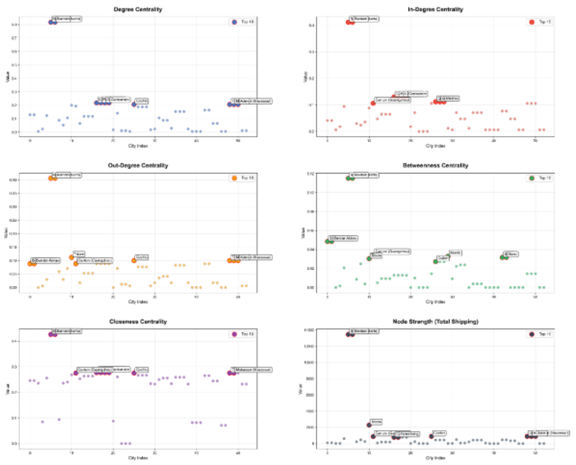


Figure 5. Network Centrality Indicators of Major Colonial Port Cities
(a) Indicator Distribution
(b) Scatter Plots with Top 10 Cities Labeled

4.2 Image analysis of the Important Colonial Port Cities

4.2.1 The basic description of the colonial images

This study collected a total of 211 valid colonial city images. The number of images collected for each city is shown in Figure 6. Cities with a large number of images all have a high administrative level in the European colonial network. Among the cities with abundant images, Colombo is the colonial capital of the VOC in Ceylon; Cochin is the VOC's capital on the Malabar Coast; Surat is the headquarters of the EIC in India before 1687; Makassar is a contested place between the VOC and Portugal for the monopoly of the spice trade; Batavia is the VOC's headquarters in Asia; Manila is the main Spanish stronghold in Southeast Asia; Malacca is an important military defense location for the Dutch to prevent other imperial rivals from passing through the strait.

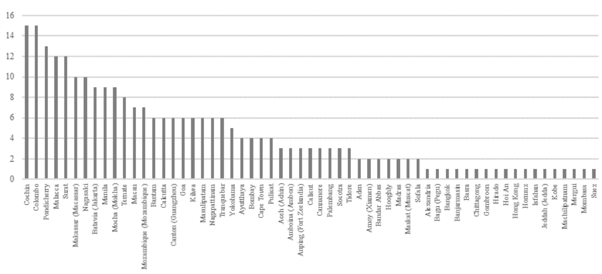


Figure 6. Number of Images per Colonial City

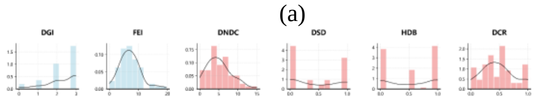
4.2.2 Quantitative analysis of the colonial images

Indicator Measurement of Urban Defense Intensity from the Topological Structure:

See Figure 7(a), from the overall distribution of the indicators, DGI, HDB and DCR show an obvious right-skewed distribution with high-value long tails, and many cities have advantages in defense intensity, port control and defense control reachability; FEI and DNDC are close to normal distribution, indicating that the defense enclosure situation and defense node core degree of most cities are at a medium level; DSD shows extremely large differences among samples, indicating a large gap in the tightness of defense systems among cities.

See Figure 7(b), from the perspective of the scores of various indicators of specific cities, cities represented by Bantam and Manila show high-value agglomeration in multiple indicators such as DGI, DNDC and HDB, forming a strong defense all-round hub cluster; cities represented by Aden and Macassar show outstanding performance in specific indicators (such as HDB and DCR), forming a regional control defense cluster; the remaining cities mostly show low-value agglomeration, forming a weak defense peripheral cluster. The overall network presents a clear core-periphery defense hierarchical structure.

(a)



(b)

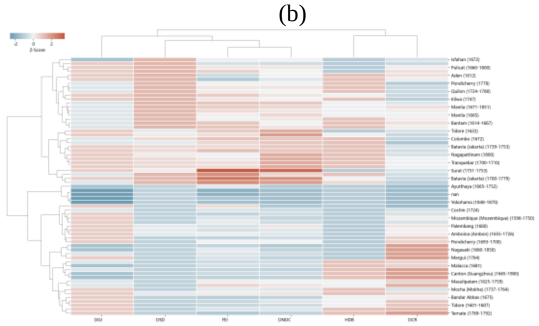


Figure 7. Quantitative Indicator Results of the Spatial Topological Network
(a) Histograms
(b) Indicator Visualization for Each City

K-means clustering was applied to the above indicators of the cities, and three typical spatial structure classifications of colonial port cities were obtained as shown in Figure 8. Cluster 1 shows outstanding performance in Defense Grade Index (DGI) and Defense Control Reachability (DCR), and also ranks high in Fortification Enclosure Index (FEI) and Harbor Defense Betweenness (HDB), representing strategic core ports with complete defense systems and strong control capabilities over core areas, which are key nodes heavily fortified by colonial powers. Cluster 2 is superior to the other two types in multiple indicators, and is significantly leading in Defense Subgraph Density (DSD), Defense Node Degree Centrality (DNDC) and Fortification Enclosure Index (FEI), indicating that its defensive facility network is highly interconnected, the core degree of defense nodes is high, and the urban defense enclosure situation is complete, forming a networked and coordinated defense layout, focusing on realizing regional connectivity and control through a dense defense network. All indicators of Cluster 3 are at the lowest level, with limited control capabilities over ports and cities, reflecting that colonial planning practices have left few traces in the urban space of this cluster.

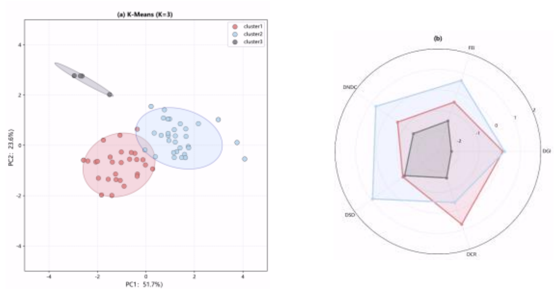


Figure 8. Clustering Based on Quantitative Topological Structure Indicators of Colonial Fortifications (a) Clustering Scatter Plot (b) Radar Chart of Cluster Types

Indicator Measurement of Urban Cultural Orientation from the Image Symbol Indicators:

The colonial cultural orientation, indigenous cultural orientation and comprehensive orientation of the sample cities were visualized as shown in Figure 9, from which it can be identified that Tidore, Muscat, Malakka, Isfahan, Calicut, Canton, Ayutthaya and Aceh clearly retained their indigenous cultural features; while cities such as Macau, Pondicherry, Manila, Kilwa, Cochin, Ambonia, Goa and Tranquebar underwent obvious colonial transformation, and most of them were new cities completely planned by colonizers. Bandar Abbas, Masulipatam, Mombasa and Surat presented a neutral urban cultural landscape.

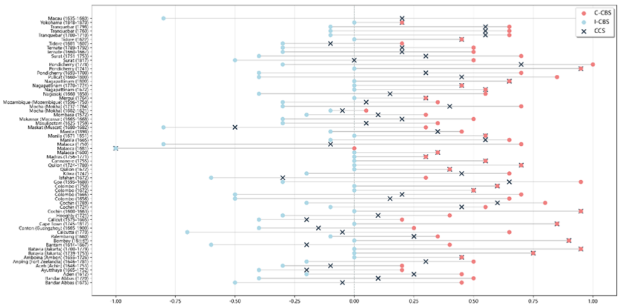


Figure 9 Quantitative Indicator Results of Image Spatial Symbols

Correlation Analysis between the Network Position of Port Cities and Colonial Spatial Implantation

As shown in Figure 10 and Table 4, the results of the Mantel Test reveal the following findings of this study:

There is a significant positive correlation between the defense intensity of colonial cities and network centrality. There is a weak but robust positive correlation between urban defense topological structure and network centrality: ports with more complete defensive facilities and more compact topological structures tend to have a higher centrality position in the shipping network, reflecting the strategic logic of colonial powers of "consolidating hub status through defense".

There is a highly significant positive correlation between the cultural orientation of colonial cities and network centrality. Port cities with a more prominent core position in the shipping network have an urban landscape more inclined to colonial culture, reflecting that core hubs are not only nodes of colonial trade but also frontiers of colonial cultural dissemination.

There is a highly significant positive correlation between the defense intensity and cultural orientation of colonial cities. It is evident that there is a high synergy between defense topological structure and cultural orientation: ports with higher defense investment also have a higher degree of colonial cultural penetration. The two jointly constitute the dual expression of colonial power in the spatial and cultural dimensions, reflecting the integrated colonial governance model of "military defense-cultural control".

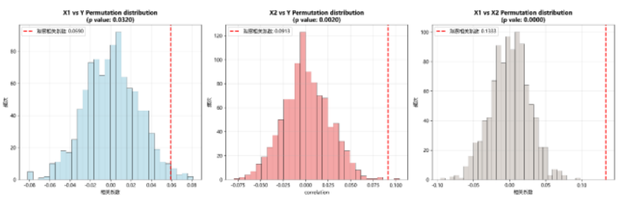


Figure 10 Mantel Test Results

Test Combination	**Correlation Coefficient**	**p value**	**Sig**
X1 (Defense Intensity) vs Y (Network Centrality)	0.0590	0.0320	*
X2 (Cultural Orientation) vs Y (Network Centrality)	0.0913	0.0020	**
X1 (Defense Indicators) vs X2 (Cultural Orientation)	0.1333	0.0000	***

5. Conclusion and Discussion

This study explores the shaping mechanism of European colonial trade networks on the spatial practices of colonial port cities during the Early Modern Period, and clarifies that the port city network shaped by colonial maritime activities presents a core-periphery hierarchical structure. Batavia and Bantam are the absolute cores of the network, undertaking the functions of trade transit and administrative center; Colombo, Malacca and other cities are secondary cores; Makassar, Nagasaki and other cities form the semi-peripheral layer; and the remaining nodes are the dependent peripheral layer. Centrality indicators further confirm the hub value of core cities and the regional transit role of gateway cities.

The spatial structures and characteristics of colonial port cities show significant differentiation with the intensity of colonial practices, and can be divided into three categories through quantitative analysis: strategic core ports have complete defense systems and strong control capabilities; networked defense ports form a dense defensive facility layout; peripheral ports have almost no traces of colonial planning practices—and no formed defense systems. In terms of cultural orientation, new colonial cities present strong colonial cultural characteristics, some regional hub cities have a neutral cultural landscape, while most peripheral cities retain a strong indigenous cultural style. The quantitative indicators of defense intensity and cultural orientation can effectively characterize the differences in the intensity of colonial spatial practices.

The study confirms that there is a significant positive correlation between the position of colonial port cities in the colonial network and the intensity of their spatial practices. Cities with higher network centrality have more complete defensive facilities and deeper colonial cultural penetration, and defense intensity and cultural orientation are highly synergistic. This reflects the integrated spatial disciplinary logic of "military defense-cultural control" of European colonizers, and also verifies the decisive role of the resource and power transmission demands of colonial networks on urban spatial planning.

In summary, this study builds a research dialogue bridge between global colonial networks and local urban spaces, and the proposed quantitative analysis approach provides a new method for comparative research of multiple port cities. However, the research sample is mainly based on the VOC trade network, leading to deviations or missing network centrality indicators of some important Indian port cities. In addition, the efficiency of manual image selection and verification of large model outputs is limited, resulting in the failure to cover all colonial port city samples. In the follow-up, trade data of colonial powers such as Britain and France can be included to further expand the sample database and improve the spatial research framework of global colonial port cities.

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