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Comparative Analysis of Differences among Northern, Jiangnan, and Lingnan Classical Private Gardens Using Principal Component Cluster Method

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Abstract: This paper investigates the design essence of Chinese classical private gardens, integrating their design elements and fundamental principles. It systematically analyzes the unique characteristics and differences among classical private gardens in the Northern, Jiangnan, and Lingnan regions. The study examines nine classical private gardens from Northern China, Jiangnan, and Lingnan by utilizing the advanced tool of principal component cluster analysis. Based on literature analysis and field research, 273 variables were selected for principal component analysis, from which four components with higher contribution rates were chosen for further study. Subsequently, we employed clustering analysis techniques to compare the differences among the three types of gardens. The results reveal that the first principal component effectively highlights the differences between Jiangnan and Lingnan private gardens. The second principal component serves as the key to defining the types of Northern private gardens and distinguishing them from the other two types, and the third principal component indicates that Lingnan private gardens can be categorized into two distinct types as well.

Keywords: Classical gardens; Private gardens; Differences; Principal component analysis; Cluster analysis

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1. Research background and objectives

Private gardens occupy a crucial position in the long history of garden art in China. They are not only an essential component of garden art but also a fusion of multiple factors, including history, culture, and art. Over five thousand years of civilization have given rise to a unique artistic style in Chinese classical gardens [1]. Many scholars have researched Chinese classical gardens from various perspectives. However, current studies often focus on qualitative analysis, primarily relying on textual descriptions supplemented by images, while quantitative research on the regional differences of classical gardens remains insufficient [2,3]. Traditional comparative research often relies on heuristic methods, where scholars articulate design theories and principles based on

personal understanding and experience, a process that carries subjective biases [4]. Comparative research on the differences between different types of classical Chinese gardens through statistical methods can address classification issues. Additionally, through exploratory data analysis, researchers can be inspired to explore new directions and perspectives in their studies.

To achieve this objective, this paper builds upon previous research and delves into the coordinating mechanisms among the design elements, geographical locations, design principles, and related landscape design elements of classical private gardens. Through a comprehensive literature review and field research, we systematically collected relevant variables and employed statistical analysis methods, aiming to precisely analyze the differences and characteristics in the design elements and principles of private gardens in Northern China, Jiangnan, and Lingnan.

2. Research objects

China boasts a long history of private gardens, and while Jiangnan gardens are renowned, unique private gardens can also be found in other regions, each representing the local characteristics of private gardens. Therefore, from the perspective of regional representation, this research selects representative gardens as analysis samples to explore the unique styles and differences of private gardens in the three major regions: Northern China, Jiangnan, and Lingnan. The selected gardens include Prince Chun's Garden, Prince Kung's Garden, and Beile (A title used for royal princes or nobility in historical China) Tao's Garden, all of which embody the characteristics of Northern private gardens in Beijing. The Humble Administrator's Garden, Lingering Garden, and Lion Grove Garden showcase the features of Southern private gardens in Suzhou, Jiangsu Province, and the Ke Garden in Dongguan and Qinghui Garden, as well as Liang Garden in Foshan, which represent the characteristics of Lingnan private gardens. The collection of all garden elements is based on literature reviews and on-site photographs, resulting in a total of 273 original variables. The selection of variables focuses on various garden design elements and influencing factors, such as architecture, water features, stones, pavements, plants, geographical locations, design principles, and other related landscape design elements [4].

3. Research methodology

Cluster analysis is a data classification method based on the principle of similarity, which aims to identify similar and dissimilar groups from a set of objects. Within the same cluster, objects exhibit a high degree of similarity to each other, while significant differences exist between different clusters [5]. This approach not only promotes the intuitive understanding of relationships between objects but also dramatically enhances the efficiency of data analysis.

To conduct the cluster analysis, we first utilized Statistical Package for the Social Sciences (SPSS) statistical analysis software to perform Principal Component Analysis (PCA) on all elements. The core function of PCA is to condense data, which reduces the original multiple variables to a few principal components through mathematical transformations. When the eigenvalues of these principal components exceed 1, and their cumulative contribution rate reaches a predetermined percentage threshold, it can be considered that these principal components effectively capture most of the critical information in the original data [6–9].

Based on the loading matrix established by SPSS software, the characteristic vectors of each variable can be calculated using the following formula [10]:

$$K_n = \frac{a_n}{\sqrt{x_n}} \quad (1)$$

Subsequently, we standardized all variables using the means and standard deviations obtained from SPSS software. This process involves subtracting the mean of each variable from its original value and dividing it by its standard deviation, thereby transforming the data into values with a zero mean and unit variance. This aims to eliminate the influence of different units of measurement on data analysis, as illustrated in the following formula [11]:

$$Z_n = \left(\frac{x_n - \overline{x_n}}{SD_n}\right) \quad (2)$$

After obtaining all the data, the scores of each plot on a specific principal component can be calculated, and the comprehensive score can be obtained by weighing through the contribution rates, as shown in the following formula [11]:

$$\text{Garden score} = f(x) = \sum_{n=1}^{n} (Z_n \times K_n) \quad (3)$$

where n=1,...273, x_n represents the eigenvalue of the variable, $\overline{x}_n$ is the mean of variables, SD_n denotes the standard deviation of variables, Z_n is defined as the standardized variable value, a_n represents the load of the variable, and K_n is the eigenvector corresponding to the principal component eigenvalues.

4. Results and analysis

4.1. Principal component analysis

We conducted an in-depth data analysis using the SPSS statistical analysis software on 273 landscaping element variables covering nine private gardens. **Table 1** demonstrates the eigenvalues and contribution rates of each principal component. The variance contribution rates explained by the eigenvalues of the first four principal components reached 26.691%, 20.704%, 14.176%, and 10.863%, respectively [12–14]. The cumulative contribution rate of these four principal components reaches 72.434%, indicating that they collectively account for over 70% of the information from the original data. In contrast, the contribution rates of the 5th to 8th principal components to the variance are below 10%, suggesting a relatively limited impact. Therefore, we focus on the first four principal components to explore the differences among private gardens in the North, Jiangnan, and Lingnan regions.

Table 1. Eigenvalues and contribution rates of each principal component

Principal component	Eigenvalue	Contribution rate (%)	Cumulative contribution rate (%)
1	72.866	26.691	26.691
2	56.523	20.704	47.395
3	38.701	14.176	61.571
4	29.657	10.863	72.434
5	23.344	8.551	80.985
6	19.593	7.177	88.162
7	18.492	6.774	94.936
8	13.826	5.064	100.000

Factor loadings serve as essential metrics for assessing the degree of correlation between principal components and their corresponding original variables. In general, a greater absolute value indicates a stronger explanatory capacity of the principal component regarding the respective indicator variable [15,16]. **Table 2** details the loading matrices, means, and standard deviations for the first four principal components, where factor loadings with absolute values exceeding 0.3 are typically considered statistically significant. **Table 2** reveals that the first four principal components encompass three types of loadings: positive, negative, and zero. In the dimensions of the first four principal components, the dependent variables can be categorized into a positive set that is meaningfully related to the axis, a negative set that is meaningfully related to the axis, and a zero set that is related to both the positive and negative sets on the axis. Additionally, the SPSS software provides the mean and standard deviation information for all variables.

After completing data processing in SPSS, we used the obtained variable values, means, standard deviations, and principal component coefficients to construct a corresponding mathematical model to calculate the scores of the nine gardens. The results of this process are organized in **Table 2**.

Table 2. Scores of the nine Gardens on the first four principal components

Principal component	Humble Administrator's Garden	Lingering Garden	Lion Grove Garden	Prince Chun's Garden	Prince Kung's Garden	Beile Tao's Garden	Ke Garden	Qinghui Garden	Liang Garden
1	9.747	8.773	7.942	2.969	2.832	-1.119	-12.275	-10.177	-8.692
2	6.006	5.959	5.982	-12.760	-5.818	-10.317	3.828	4.480	2.639
3	0.106	-0.906	0.804	11.947	-3.070	-11.850	3.858	-0.081	-0.807
4	-0.827	-1.319	-1.778	-0.558	8.283	-5.923	-8.389	4.239	6.271

4.2. Cluster analysis

Scatter plots are used for the visual identification of clusters. The horizontal axis displays the scores of the nine gardens on one principal component, while the vertical axis corresponds to their scores on another principal component. By comparing them pairwise, we found distinct clustering characteristics when comparing Principal components 1 and 2, 2 and 3, and 1 and 4.

Specifically, **Figure 1** reveals that the nine gardens can be distinctly classified into three categories. On the horizontal axis, there are three categories, including the Jiangnan private gardens cluster in the positive direction, with three gardens scoring closely together, the Lingnan gardens cluster in the negative direction, far from the Jiangnan private gardens, and the Northern gardens cluster near zero value, with positive and negative distributions, and there is no apparent clustering. This indicates that Principal component 1 primarily captures the dimensional information that distinguishes Jiangnan from Lingnan's private gardens. On the vertical axis, the gardens cluster into two categories. One category is in the positive direction, comprising three Jiangnan gardens and three Lingnan gardens and the other category is in the negative direction, including three Northern gardens, further confirming the significant role of Principal component 2 in defining the differences between Northern gardens and the other two categories.

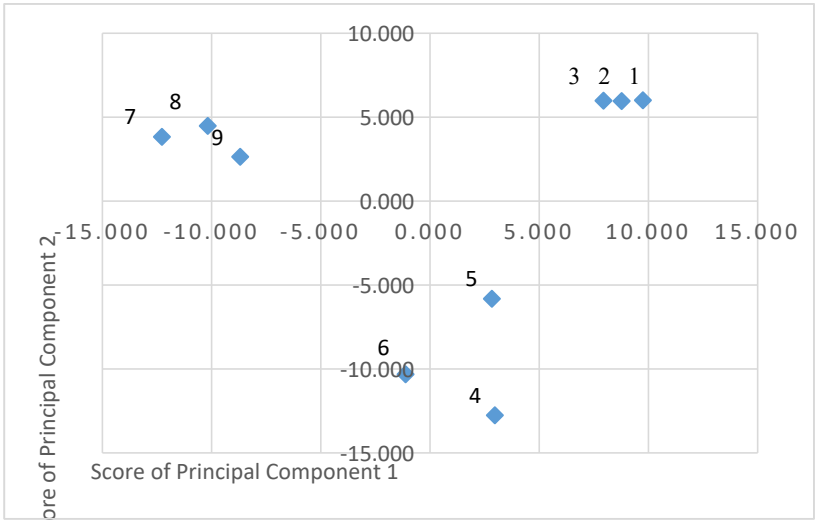

Figure 1. Scatter plot of relationships among the nine gardens based on scores of Principal components 1 and 2

By observing the scatter plot in **Figure 2**, we can draw the following conclusions. On the horizontal axis, the distribution of the three Northern private gardens appears to be quite dispersed, with significant distances between them, and they do not clearly distinguish between Jiangnan and Lingnan gardens. This suggests that Principal component 3 is not a precise dimension for judging the differences among these three types of gardens. However, the situation is different on the vertical axis. The three Jiangnan private gardens are closely clustered together. In contrast, the three Northern private gardens and three Lingnan private gardens are more widely dispersed. The Lingnan private gardens are further divided into two categories, with Qinghui Garden and Liang Garden concentrated in the positive vertical direction, while Ke Garden is distanced in the negative direction, suggesting that the fourth principal component may play a crucial role in distinguishing the different types within the Lingnan private gardens.

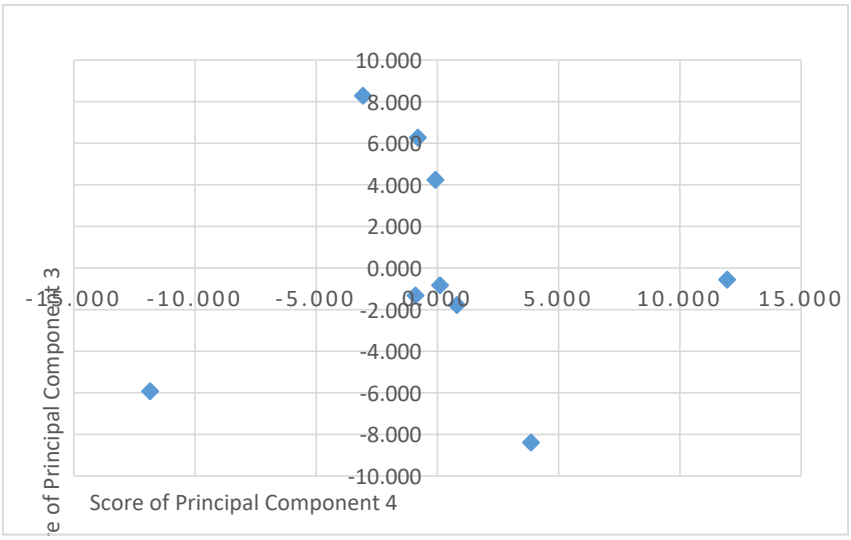

Figure 2. Scatter plot of relationships among the nine gardens based on scores of Principal components 3 and 4

Table 3 to **Table 5** provide a detailed list of positive, negative, and zero variables with absolute factor

loadings exceeding 0.3 among the first four principal components. In particular, those variables with absolute factor loadings greater than 0.7 are highlighted with underlines [17]. According to the scatter plot, the positive variables in **Table 3** are primarily associated with the characteristics of Jiangnan private gardens, while the negative variables are closely related to Lingnan private gardens. Among them, the underlined variables are especially significant as they serve as key indicators for distinguishing between Jiangnan and Lingnan private gardens. In **Table 4**, the positive variables encompass characteristics common to both Jiangnan and Lingnan private gardens, while the negative variables specifically refer to the unique attributes of northern private gardens. According to the positive and negative variables in **Table 5**, the negative variables pertain to those of northern private gardens, and the underlined variables may represent unique variables of northern private gardens.

Table 3. List of positive and negative variables in Principal component 1

Positive variables	Water system, supplemented by rockeries; halls and corridors, supplemented by rockeries; *Ting shan* (the mountain picked in the courtyard in front of the hall); lotus hall; flower hall; four-sided hall; mandarin duck hall (the indoor partition divides the space into two equal sections); dwelling; platform; sacrificial architecture; platforms for water play; island; round pavilion; half pavilion; fan-shaped pavilion; stele pavilion; cave; inner and outer corridors; climbing corridor; winding corridors; gallery house; half corridor; archway; stone slab bridge; zigzag bridge; pavilion bridge; open hall; stone ornaments; *neng qiang fa qiang* (a structural approach that makes the eaves prominently uplifted at the wing butts); *shui qiang fa qiang* (this approach creates a unique visual effect through the upward curve of ridges and the straight edge of eaves); double eave roof; Chinese style tile; plain clay tube tiles; whitewashed wall; garden within a garden; Malus spectabilis pattern gate; French windows; hollowed-out windows; rows of decorative perforated windows; *Bubujin* (rectangular patterns formed by slats); lantern-shaped brocade; ice crack pattern; flower wall; louvered window walls; herringbone pavement; plant pattern pavement; *Malus spectabilis* pattern pavement; animal pattern pavement; ice crack pattern pavement design; hexagonal paving where hexagons serve as the basic units, is embedded with various materials such as pebbles and broken tiles; auspicious pattern pavement; Swastika pattern pavement; coin pattern pavement; tortoise shell brocade pavement; gravel path; stone pillar; stacked stone rockeries; earthen hill; yellow stone; stone wharf; scattered placement; symmetry placement; stone shores; streams; water brooks; wells; contrast between concealment and openness; *qu shui liu shang* (drinking water from a winding canal with one wine cup floating on it so as to wash away ominousness); *Yulania denudata*; *Pterocarya stenoptera*; *Magnolia grandiflora*; *Phragmites australis*; *Wisteria sinensis*; *Ulmus pumila*; *Acer palmatum*; *Cinnamomum camphora*; *Ginkgo biloba*; *Cupressus funebris*; *Musa basjoo*; *Acerpalmatum thunbf*; wintersweet; *Firmiana simplex*; willow; *Styphnolobium japonicum*; *Paeonia suffruticosa*; *Albizia julibrissin*; *Prunus mume*; *Punica granatum*; *Syringa oblata*; *Hydrangea macrophylla*; *Zelkova serrata*; *Triadica sebifera*; *Trachycarpus fortunei*; *Zanthoxylum bungeanum*; *Ligustrum lucidum*; *Hibiscus syriacus*; *Cercis chinensis*; *Michelia figo*; *Ilex cornuta*; *Buxus sinica*; *Acer genus plants*; *Nerium oleander*; Toona sinensis; *Rosa multiflora*; *Cerasus*; phoenix tree; *Morus alba*; *Prunus armeniaca; Diospyros kaki*; Malus spectabilis
Negative variables	Buildings and walls enclosing courtyards; theatrical stage; Islamic garden landscaping techniques; boat hall; bridge pavilion; *lian fang bo sha* (peripheral outlines of garden buildings in clusters and groups); practical front eaves corridor; watchtower; arch bridge; high-walls and narrow ventilated alleys; hanging gable roof; green door and window frames; brick carving; gilded paint; ceramic sculpture; gray sculpture; stained glass; clay sculptures; green-painted column; diamond-shaped doors; fruit and floral pattern; colored glass; arched window; oyster shell window; multicolored carved glass; blue brick wall; yellow painted wall; grayish-blue wall; colored railing; brick railing; granite paving; coral stone; stone wall; Ying stone (limestone from Yingde County in Guangdong Province); yellow stone; tree stone; shell decoration; geometric-shaped pool bank; fountains; spring, river, pond, waterfall, and sea combined scenic areas; animal patterns; marine culture patterns*; Sterculia nobilis Smith*'s seed; *Chrysanthemums; Camellia japonica*; *Rhapis excelsa*; *Tacca palmata*; *Hymenocallis littoralis*; sunflower family; *Cymbidium*; *Murraya exotica*; *Michelia alba*; *Litchi chinensis*; *Dimocarpus longan*; *Artocarpus heterophyllus*; *Magnolia grandiflora*; *Bauhinia variegata*; *Tabernaemontana divaricata*; *Ixora chinensis*; *Gardenia jasminoides*; *Rhaphiolepis indica*; *Jasminum sambac*; *Caesalpinia pulcherrima*; *Cycas revoluta*; *Hemerocallis fulva*; *Ficus microcarpa*; *Areca catechu*; *Averrhoa carambola*; *Plumeria rubra*; *Callistemon viminalis*; *Yulania denudata*; *Mangifera indica*; *Magnolia liliflora*; *Psidium guajava*; *Citrus maxima*.

Table 4. List of negative variables in Principal component 2

Negative variables	North-south axis; residential garden zoning; theatrical stage; architectural courtyard layout; Western gardening techniques; Western fountain sculptures; round pavilion; climbing corridor; practical eaves corridor; culture of the character "Fu"; hanging gable roofs; green glazed tiles; yellow glazed tiles; green window and door frames; brick carving; gilded paint; green-painted columns; *Bubujin* (rectangular patterns formed by slats); false windows; tiger-striped wall; bluish-gray wall; ice-cracked wall; screen wall; colored railing; auspicious pattern paving; pebble path; granite pavement; earthen hill; sundial; arranged planting; willow; *Styphnolobium japonicum*; *Chrysanthemum*; *Vitis vinifera*; *Syringaoblata lindl*; *Juglans regia*; *Malus spectabilis*; *Euonymus bungeanus; Cotinus coggyg*ria

Principal component 4 reflects the dimensional differences in the internal types of Lingnan private gardens, providing a solid basis for exploring the distinctive elements among different Lingnan private gardens. In **Table 5**, the positive variables point to a set of characteristic variables for one type of Lingnan private garden, while the negative variables correspond to the unique attributes of a different kind of Lingnan private garden.

Table 5. List of positive and negative variables in Principal component 4 and their intersection with variables of Lingnan Private Gardens

Positive variables	Dwelling; stone boat; pavilion; sacrificial architecture; platforms for water play; island; hexagonal pavilion; bridge pavilion; cave; emperor's inscription tablet/monument/plaque; covered bridge; concepts of poetry and painting; deeper meanings; stone slab bridge; bridge corridor; open hall; pyramidal roof; green glazed tiles; green door and window frames; stained glass; garden within a garden; rows of decorative perforated window; turtle shell pattern; gable wall; cloud wall; louvered wall; colored railing; stone railing; stone wall; tree stone; stone wharf; scattered placement; specially placed; symmetry placement; stone shore; fountain; suppress scenery; added scenery; vista line; obstructive scenery; borrowed scenery; framed views; transitions between large and small spaces; contrast between solid and void spaces; animal patterns; *Eriobotrya japonica*; *Wisteria sinensis*; *Pinus*; *Musa basjoo*; *Chimonanthus praecox*; *Nymphaea tetragona*; *Sterculia nobilis Smith*'s seed; *Prunus persica*; *Plumeria rubra*; *Mangifera indica*; *Magnolia liliflora*; *Psidium guajava; Cit*rus maxima
Negative variables	Entrance hall; pavilion corridor; flat roof; whitewashed wall; arched window; plant pattern paving; *Malus spectabilis* pattern flooring; stacked stone rockery; *Chrysanthemum*; *Prunus persica*; *Parthenocissus tricuspidata*; *Tacca palmata*; *Litchi chinensis*; *Bauhinia variegata*; *Tabernaemontana divaricata*; *Gardenia jasminoides*; *Rhaphiolepis indica*; *Jasminum sambac*; *Caesalpinia pulcherrima*; *Hemerocallis fulva; Areca* catechu

5. Discussion

5.1. Comparison of differences among three types of private gardens

The most distinct differences among the three major private garden systems are concentrated in their unique layout concepts and architectural structure types. Specifically, Jiangnan gardens are characterized by the separation of residences and gardens. Notable examples, such as the Humble Administrator's Garden, Lingering Garden, and Lion Grove Garden, are cleverly arranged with halls and ponds at their core, surrounded by pavilions and towers, interconnected through winding paths and corridors. In contrast, Lingnan Garden often adopts a courtyard-style layout. For instance, Ke Garden employs the "peripheral outlines of garden buildings in clusters and groups" technique, enclosing the residence and garden into a closed courtyard. Qinghui Garden uses a clever division between buildings and walls to place scenery within individual courtyards, varying in size. Northern gardens, however, are marked by a distinct north-south axis and traditional *Si he yuan* (courtyard house) structure. During the Qing Dynasty, they were further influenced by Western garden concepts. For example, the garden of Beile Tao's residence emphasizes the relationship between the east and west axis, the introduction of arcs, and the composition tends toward geometric forms, contrasting sharply with the meandering and twisting layouts of Jiangnan gardens.

In the designed layouts of classical gardens, architecture is undoubtedly an indispensable and crucial design element. As shown in **Table 1**, the diversity of architectural structures has become a significant mark for visually distinguishing between Jiangnan and Lingnan gardens. Jiangnan private gardens are renowned for their wide variety of architectural types, characterized by lightweight forms and elegant colors. The eaves are cleverly designed using techniques such as *neng qiang fa qiang* (a structural approach that makes the eaves prominently uplifted at the wing butts), *shui qiang fa qiang* (an approach that creates a unique visual effect through the upward curve of ridges and the straight edge of eaves), particularly notable in their double-eave designs for pavilions and towers. In contrast, while both Northern and Lingnan private gardens also employ cornices, their degree of elevation is far less pronounced than that of Jiangnan gardens, and they mostly feature single-eave structures. Lingnan gardens have given rise to unique architectural types such as watchtowers,

high-walls, narrow ventilated alleys, boat halls, and *lian fang bo sha* (peripheral outlines of garden buildings in clusters and groups), all adapted to their unique climate conditions characterized by high temperatures, heavy rainfall, humidity, and frequent typhoons. Although Northern gardens do not exhibit significant differences in architectural functions when compared to Jiangnan gardens, they present a distinctly different style in the private gardens of nobility and royalty. They utilize green or yellow glazed tiles and red or green frames and columns, resulting in bright and vivid colors that are rare in the private gardens of Jiangnan and Lingnan.

The differences in detailed design are also significant. Private gardens in Jiangnan excel at using bricks and stones to pave the ground, with pebbles meticulously arranged into herringbone patterns, ice crack patterns, and other auspicious designs. In contrast, the paving in the private gardens of Lingnan tends to be more regular, taking into account the rainy climate. Sometimes, a full paving design is used to promote drainage, with materials predominantly being brick or granite. The essence of decorative art in Lingnan Gardens lies in the "Three Carvings" and "Three Sculptures." Three Carvings refer to wood carving, brick carving, and stone carving, and the Three Sculptures encompass pottery sculpture, clay sculpture, and ash sculpture. For example, the "Hundred Birds Returning to Their Nest" depicted in the Ke Garden is carved by Hai Diteng, with the beauty of "Three Sculptures" observable in the ridge, the top part of a lintel, walls, flower beds, and other places. These decorative elements are relatively rare in gardens of Jiangnan and Northern China. In Northern private gardens, roads, platforms, and vacant areas are primarily made of bricks, with some paths paved with strip stones or gravel, even incorporating animal patterns, such as the camel pathway in Prince Gong's Mansion, thus sharing a similarity with Jiangnan gardens. However, the pathways relatively lack the meandering characteristics seen in Jiangnan gardens.

As an indispensable element, as shown in **Table 1** and **Table 2**, plants are not only essential components of garden design in the private gardens of Jiangnan but often become the focus of appreciation. For example, in the Humble Administrator's Garden, the Pavilion of Eighteen Datura Stramium features whitewashed walls as the backdrop, accompanied by lakes and rocks, reflections displayed in the clear water, with the solitary *Magnolia gradiflora* and *Ginkgo biloba*, the paired *Pinus*, and the clustered bamboos all emphasize the important role of plants in the private gardens of Jiangnan. Additionally, *Pterocarya stenoptera*, *Wisteria sinensis*, *Ulmus pumila*, *Acer palmatum*, *Musa basjoo*, and *Paeonia suffruticosa* are also common sights in Jiangnan gardens. The Lingnan region is renowned for its rich variety of plant species and distinctive regional characteristics, widely employing tree species that evoke the southern style, such as *Areca catechu* and *Arecales*. Due to the hot and rainy climate, shade and heat-resistant plants are highly favored, including *Ficus* plants and fruit trees like *Dimocarpus longan* and *Averrhoa carambola*, as well as vibrant and fragrant plants such as *Murraya exotica*, *Magnolia grandiflora*, and *Ixora chinensis*. These plants are not found in Jiangnan or northern gardens. Although northern gardens are limited by cold climates, they also exhibit unique characteristics in plant landscaping. Influenced by imperial thoughts and Western gardening culture, some areas adopt a formal, linear layout to enhance compositional effects, with trees such as *Sophora japonica*, *kapok*, *Juglans regia*, and *Ziziphus jujuba* occupying significant positions. In private gardens, shrubs like *Malus spectabilis* and *Syringa oblata* are predominant, alongside a keen interest in cultivating flowers like *Chrysanthemum* and vine plants such as *Vitis vinifera*.

The differences in geography and culture profoundly influence the style of garden art. The gardens of Jiangnan are often praised as "scholar's gardens." Although their owners reside in bustling cities, they harbor an endless yearning for the natural mountains and forests, integrating the poetic and artistic essence into their garden designs, thus imbuing the gardens with profound cultural connotations and aesthetic pursuits. In contrast, the gardens of Lingnan are deeply influenced by maritime culture. As seen in **Table 1**, this characteristic is particularly evident in Lingnan gardens, notably through the widespread use of boat halls, such as the boats in the

Ke Garden, the *Xiao jie lou* (The residence of an unmarried young lady from a wealthy family in Feudal era) in the Qinghui Garden, and the boat halls in Liang Garden, along with oyster shell windows made from shells, all of which express a deep affection for the maritime life of Lingnan. Furthermore, Lingnan private gardens draw on the essence of Islamic garden design, often incorporating geometric lines on the shores of ponds. In comparison, while maintaining the basic style of natural gardens, Northern gardens emphasize the axis due to the infiltration of imperial thought and Western garden concepts. For example, Beile Tao's Garden intentionally incorporates elements of European gardens, such as fountains and Western sculptures, showcasing a unique charm created by the fusion of Chinese and Western styles. Data from the charts also reveal that the use of the zigzag bridges and French windows as iconic elements in Jiangnan private gardens far exceeds that of the other two types of gardens.

5.2. Comparison of types within the three categories of private gardens

The scatter plot reveals that the ratings of the three private gardens in the Jiangnan region are highly close to each other. In contrast, the ratings of the three Northern gardens and the three Lingnan gardens are more dispersed, indicating a high level of similarity in the landscaping elements of Jiangnan gardens, with no obvious classification.

We find that the nature of these two groups is not distinct, and both incorporate diverse gardening elements. Based on the analysis of variables with factor loadings exceeding 0.7 in absolute value, the distinguishing features of the positive group include water-friendly platforms, rocky shores, and rocky islets, while the negative group has only one variable, flat roofs, which seems to point to the differences in the treatment of water bodies. Although both groups of gardens are dominated by geometric shorelines, Qinghui Garden and Liang Garden are more naturalistic in their localized details, exuding the flavor of private gardens in the south of the Yangtze River. However, given the limitations of the current observations and variables, the current study is not sufficient to fully define the exact differences between these two types of gardens, and future research needs to expand the scope of the data to dig deeper and clarify the differences between them.

In the analysis results of the fourth Principal component, the grouping of Lingnan Gardens is noteworthy. The Ke Garden stands out as an independent group, while the Qinghui Garden and Liang Garden are classified into another group. A deeper exploration of the positive and negative components reveals that the characteristics of these two groups are not entirely distinct, as they both encompass a diverse range of landscaping elements. Based on the analysis of variables with absolute factor loadings exceeding 0.7, the significant features of the positive group include platforms for water play, stone shores, and stone wharves, while the negative group only has the flat top as a variable. These differences seem to indicate variations in the treatment of water bodies. Although both groups of gardens primarily feature geometric shorelines, Qinghui Garden and Liang Garden appear more natural in their local details, showcasing the charm of Jiangnan's private gardens. However, given the current limitations of observation and variables, the existing research is insufficient to comprehensively define the exact differences between these two types of gardens. Future studies should expand the data scope to further explore and clarify their distinctions.

6. Conclusion

This study used principal component clustering analysis to obtain the analysis results of 9 classical private gardens in Northern, Jiangnan, and Lingnan gardens, revealing the differences and similarities between these three types of gardens. It is hoped that the gardening rules between these three types of gardens can be discovered, which will help explore the characteristics and differences of other types of gardens and provide new research ideas for targeted studies on the differences between different types of gardens in the future. In future research, we will

further enrich the research elements and provide guarantees for the accuracy of the research results.

Disclosure statement

The authors declare no conflict of interest.

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