Quantitative Analysis of the Urban Factors Limiting Central District Plane Form Expansion: Twenty-one Case Studies of Asian Megacities' Central Districts

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Abstract
Based on threshold analysis theory, spatial limiting factors such as mountains, rivers, and roads not only affect the way in which cities spread out, but also play a vital role in shaping the flattened forms of their central districts. This study, based on field investigations of 21 central districts in 13 Asian megacities, seeks out limiting factors that determine the boundaries of urban central districts by quantifying the spatial boundary and distance of the limiting factors. The results suggest a strong correlation between the spatial limiting factors and the urban central district's form. The limiting elements constrain the size of buildings and population density based on floor area ratio, building density, and development boundaries. Reduction in population and the inconvenience of traffic have decreased urban vitality, leading to delays in the extension of cities' central districts. It is necessary to fully consider the role of the city's internal limiting elements in order to reasonably plan the construction of an urban central district.

Keywords: limiting elements; quantitative analysis; central district

1. Introduction
After examining the obstacles that limit the growth of a series of cities, Malisz (1974) formulated the "threshold analysis theory" according to which, under normal circumstances, only scale needs to be expanded to develop a town, but when it reaches a certain size, the geographical environment, infrastructure, spatial structure, and other aspects of the short board will not meet demand and will hinder its continued growth. If the town needs to enlarge further, a major adjustment (such as a huge investment) is needed to overcome the limitations and extend urban capacity.

Threshold analysis theory is widely used in urban research to analyze and determine how to bypass or avoid touching restrictive elements to control the scale of urban development. Nelson (2001) refers to threshold analysis theory and proposes a comprehensive land use and facility planning method of "growth management" for some parts of the United States, the goal being to expand cities to ensure optimal architecture and maintain the natural environment. This approach can improve quality of life, reduce financial burden, and improve the environment. YH Qin (2008) applied threshold analysis to the eco-environment and tourism in rural renewal planning. Taking the Sujiatun Township in Taoyuan village as an example, this study analyzes the rural threshold limit and suggests an improved, updated planning method based on the analysis. Hwang (2008) elaborates on threshold theory regarding vertical dimensions, taking Hong Kong as a case study of a city's vertical spread and discussing whether such cities are sustainable solutions for human settlement. In related research on threshold analysis theory, we found that threshold analysis is useful for examining the development of urban spatial boundaries, but there is little research on the mesoscale.

Cities have a large amount of mesoscale spaces that fit threshold analysis theory. For example, Victoria Harbor and Victoria Peak have limited the development of the Hong Kong Island Center, even in terms of expanding land reclamation. However, due to high construction costs, the central district still has to enlarge the narrow sections of the coast. Its axis and the natural environment maintain the same direction. Large historical and private sites limit Chaoyang Central District in Beijing. The Forbidden City, Jingshan, the Temple of Heaven, and other cultural monuments lie to the west and south of Chaoyang Central District. Therefore, in choosing the direction of development, the Chaoyang Central District selected vast land resources in the east and north for expansion.
Hence, we propose that threshold analysis theory also applies to mesoscale elements such as the expansion of the city's central district, which will be influenced by the city's geographical environment and human elements. When the urban central district is developed and reaches a certain stage of growth, one or more limiting elements will hinder it from spreading in a certain direction—that is, the threshold for spatial development in the central district.

Existing research methods are mainly based on the analysis of a single case; General researchers qualitatively study the relationship between the spatial boundaries and the limiting elements. In this study, we investigated 21 central districts in 13 Asian megacities. We quantified the central district's spatial boundaries and limiting elements to determine the latter's influence on the urban central district's boundaries; we then analyzed the differences of this influence. Through an examination of 21 international Asian urban centers, we seek to answer the following questions: (1) Do urban constraints have a limiting effect on the spatial form of the urban central district? (2) How strong is the limit? (3) Which type of constraint limits the urban center's spatial shape the most?

2. Research Methods
2.1 Selecting the City for the Case Study:

The development of central districts in Asian metropolises has a long history, with budding businesses gradually spreading to surrounding areas. The elements of the surrounding space inevitably limit this process. This restriction is reflected in the adverse effects of topographic factors on traffic and construction behavior. However, in the various stages of growth, the restriction's impact on central districts varies across directions. The differences are revealed in the central district's extended form. Due to shorter development timelines and a small scale, early central districts were essentially unaffected by constraints. Over time, the force of spatial constraints is gradually seen, such as in the central district that runs along Hangzhou Yan'an Road, which has a fan-shaped spatial form due to the role of the West Lake. In the megacity's main hub, the constraints are more obviously visible due to long development timelines and large scale.

High construction density and intensity are typical traits of central districts in Asian megacities, as well as a large number of residents. The author of The World According to GaWC 2012, published by the Globalization and World Cities Research Network (GaWC), a think tank sorted Asian cities by city level and geographic location. The author selected 21 typical central districts in 13 international cities, covering the foremost ones in East Asia, Southeast Asia, South Asia and Western Asia, as well as China's Jingjinji Metropolitan Region, Yangtze River Delta, Pearl River Delta, the country's northeast, and key cities in the northwest. We carried out field research in each city's central district.

2.2 Defining the Central District

The spatial definition method of central districts (Public Service Facility Index Method, Yang junyan and Shi Beixiang 2014): First, carry out typical urban research to determine the urban central district of the public service facility index combination of the cut-off value. Next, collect original data according to the calculation of the index spatial distribution map. Finally, through repeated adjustments and checking, delineate the city center area's spatial boundaries, including the following steps:

1) The central district has two key attributes: (1) The functional nature of the public service organization as the central district; and (2) The degree of aggregation of the public service facility space. On this basis, the calculation of the public service facility index is used to reflect a block's capacity characteristics as well as the central district. The public service facility index provides a quantitative analysis of the central district based on land use features, including the public service facility height index (PSFHI) and the public service facility density index (PSFDI), for a clear spatial range of the land to be measured.

2) (PSFDI + PSFHI) C is the combined value of the public service facility index of the central district area.

3) Calculate the public service facilities index of each block and draw the distribution chart of the public service facilities index. Calculate the PSFHI and PSFDII in a single neighborhood as the unit and mark it on the floor plan. Next, define the neighborhood's color according to the numerical size, and obtain the distribution map of the PSFHI and the PSFDII.

4) Define the central district's spatial range for the first time, and obtain the distribution map of PSFHI and PSFII of the public service facility height index obtained in Step 3. Next, draw the spatial range of the central district's foundation.

5) Adjustments and checking determine the urban central district's spatial boundary. According to the above divided area, the overall public service facility index of continuous streets is calculated and compared with the combined demarcation value (PSFDI + PSFHI) C and (PSFDI + PSFDII) C and (PSFDI + PSFHI) HC. The overall public service facility index of the continuous block is not less than the combined boundary value (PSFDI + PSFHI) C and (PSFDI + PSFHI) HC, and the urban central district's spatial boundary is adjusted to form the continuous range of the central district space.

2.3 Analytical Method of Spatial Limitation Elements in the Central District

Minghua (1981) divides the constraints in urban planning into three categories. The first is the natural and human environment, including mountains, rivers, steep slopes, swamps, floodplains, natural landscape resources, natural reserves, and other natural restrictions, as well as urban construction, industry and mining, military, agricultural land, and other land use
restrictions. The second category is limitations due to a lack of urban infrastructure, such as the basic needs of the water supply, the power supply, drainage, and the basic completion of transport facilities. The third category is related to the structure of the city, including changes in urban administrative hubs, business centers, and the rebuilding of certain areas. Central districts in Asian megacities are generally located in the center, and their spatial constraints are mainly reflected by natural physical restrictions and human environment constraints. Natural physical restrictions include soil liquefaction zones (not suitable for high-intensity construction), mined-out areas of soil, seismic fault zones, rivers, lakes, seas, and mountains; human environment restrictions include railway lines and highways, airports and their obstacle-free airspace, large cultural and historical sites, municipal, provincial and national administrative boundaries, and large-scale private sites.

Human environment restrictions are more complex and can be classified to discuss. At the municipal level and above, administrative boundaries are indeed subject to land transfer. For other urban centers, such restrictions are subject to competition between the two main centers; other elements, such as airports and their obstacle-free airspace, promote the periphery's development on a small scale, but have a certain limiting effect on the central district's growth on the urban mesoscale.

The morphological effects of these spatial restrictions on central districts are mainly reflected in the plane extension form; that is, the spatial expansion of a central district under the influence of other spatial elements during growth.

In this section, using the Pearson coefficient, we use univariate linear regression to determine the correlation between the central district's spatial restrictions and spatial boundaries. The specific method is as follows.

First, divide the surroundings into 24 dimensions (1, 2, 3..., 24) and record the city center's historical origin from the case study.

Second, drawing rays from the historical origin in the 24 directions, the distance of the intersection of the ray and the central district's boundary of the historical origin is the extension distance ($x_i$) of the central district in that direction. The distance of the recent intersection of the ray and the surrounding restrictions from the historical origin is the restricted distance ($y_i$) in that direction.

Finally, in order to determine the restricting characteristics of the restrictions on the central district plane, we employ linear regression to study the correlation between extension distance ($x_i$) and restricted distance ($y_i$) in the same direction of the central district.

We examine the case of People's Square in Shanghai to discuss the spatial restrictions' influence on the central district. People's Square was formed in the 1850s. The historical origin of the center in the Bund source area, Located at the confluence of Suzhou River and the Huangpu River, is the starting point for the Bund's development.

The size of People's Square is now 14.67 km$^2$ near the Huangpu River; the Suzhou River flows through
it. There is no large mountain around, but the Beijing-Shanghai high-speed railway and other factors were built nearby.

Assuming that the historical origin of People's Square lies in the center, the surrounding area is divided into 24 dimensions (1,2,3..., 24) of 15 degrees each. Fig.1. displays the rays from the historical origin in each direction.

The direction in which each ray points is in the direction of a dimension, clock wise from the north: NE, NE1, NE2, NE3, NE4, NE5, E, SE1, SE2, SE3, SE4, SE5, S, SW1, SE1, SE3, SE4, SE5, S, SW1, SW2, SW3, SW4, SW5, W, NW1, NW2, NW3, NW4, NW5.

We found that the spatial restrictions of N, NE1, and NE3 are universities, and in the NE2 direction, there are multiple factors such as railways, large-scale green spaces, and the Huangpu River.

Due to close proximity to the Huangpu River, the spatial restrictions of NE4, NE5, E, SW2, SE2, SE3, SE4, SE5, S and SW1 consist of the river. The spatial limiting factors in the SW2 direction are the Shanghai South railway station and surrounding areas.

The spatial restrictions of SW3 and SW4 are the outer ring highway. For SW5, the restrictions are the East China University of Political Science and the Suzhou River. For W, the restriction is the Suzhou River, and the spatial restrictions of NW1 and NW2 are the Shanghai railway station and the surrounding area. The spatial restrictions in the NW5 direction comprise railways and light rails. We measured these limits, extended the distance (Table 3.), and used linear regression to determine the relationship between the extension distance (xi) and restricted distance (yi).

### 2.4 Judgment of the Pearson Coefficient

The Pearson product-moment correlation coefficient (also known as PPMCC or PCCs, commonly denoted as r, or Pearson's r) measures the linear correlation between two variables (X and Y) and can range from 1 to 1. According to the Pearson correlation coefficient, when \(| r | \geq 0.8\), the variables are highly correlated. When \(| r | \geq 0.5\) and \(| r | <0.8\), the two variables are moderately correlated. When \(| r | \geq 0.3\) and \(| r | 0.5\), the two variables have low correlation; \(| r | <0.3\) indicates that the degree of correlation is weak and practically irrelevant.

### 3. Results

The linear regression reveals a significant correlation between the extension distance (xi) and restricted distance (yi) of People's Square (R2 = 0.765). The Pearson correlation coefficient is 0.875, indicating that the extension distance is highly correlated with the restricted distance; it also shows that the plane extension of People's Square is largely constrained by the limitations of urban space.

Using the same method, we subjected the central district boundary elements of the 21 central regions to regression analysis along with the central district extension distance; we found a significant correlation. From the values shown in Table 4., the highest value is the central district of Hong Kong Island, with a Pearson coefficient of 0.938. The two most important elements of the limit – Victoria Harbor, the narrowest at 740 meters, and Victoria Peak, with an altitude of 554 meters – are hindering large-scale traffic development and construction.

The Pearson correlation coefficient in the central region of 12 axons is above 0.8, which is 57% of the total central district. The Pearson correlation coefficient of the other nine central regions is between 0.5 and 0.8, which indicates a moderate correlation. There is no low correlation in the center area. Hence, the extension of the central district's plane form has a significant correlation with the city's spatial limiting factors. In addition, according to the characteristics of the public service facilities gathered in the central district, the 21 urban centers can be divided into two types: linear aggregation and nonlinear aggregation.

From the correlation coefficient, in these two forms, the linear aggregation center is more relevant to the spatial restrictive elements. Of the seven central districts studied, the Pearson correlation coefficient for the districts of Hong Kong Island, Bangkok (Thailand), and Lujiazui (Shanghai, China) are all above 0.9. Except for Dubai Bay, the Pearson correlation coefficients of the other linear aggregation centers are all above 0.8, indicating a highly relevant feature.

The Pearson correlation coefficients of the nonlinear aggregation central districts are lower than those of the linear aggregation centers. Among the 14 nonlinear aggregation central districts, 6 show a highly relevant...
Table 3. Extension and Restricted Distance of People's Square

| Numbering | Direction | Extension distance (xi) | Restricted distance (yi) | Numbering | Direction | Extension distance (xi) | Restricted distance (yi) |
|-----------|-----------|-------------------------|--------------------------|-----------|-----------|-------------------------|--------------------------|
| 1         | N         | 1167 m                  | 6870 m                  | 13        | S         | 2284 m                  | 5431 m                  |
| 2         | NE1       | 1642 m                  | 4255 m                  | 14        | SW1       | 2709 m                  | 6016 m                  |
| 3         | NE2       | 1890 m                  | 10015 m                 | 15        | SW2       | 3479 m                  | 11407 m                 |
| 4         | NE3       | 1761 m                  | 7934 m                  | 16        | SW3       | 4846 m                  | 15526 m                 |
| 5         | NE4       | 1829 m                  | 8418 m                  | 17        | SW4       | 5209 m                  | 14377 m                 |
| 6         | NE5       | 122 m                   | 122 m                   | 18        | SW5       | 1688 m                  | 6656 m                  |
| 7         | E         | 101 m                   | 101 m                   | 19        | W         | 1345 m                  | 3682 m                  |
| 8         | SE1       | 109 m                   | 109 m                   | 20        | NW1       | 1492 m                  | 2000 m                  |
| 9         | SE2       | 109 m                   | 109 m                   | 21        | NW2       | 1141 m                  | 1568 m                  |
| 10        | SE3       | 122 m                   | 122 m                   | 22        | NW3       | 981 m                   | 1637 m                  |
| 11        | SE4       | 3000 m                  | 3520 m                  | 23        | NW4       | 994 m                   | 1844 m                  |
| 12        | SE5       | 2395 m                  | 4340 m                  | 24        | NW5       | 1044 m                  | 3684 m                  |

Fig.1. Constraints Analysis of People's Square
The other eight urban centers show moderate correlation. Xidan (Beijing) has the lowest correlation of all the central districts, with a Pearson’s r of only 0.54. In terms of the proportion of highly correlated central districts and the value of Pearson’s r, the plane extension of the linear aggregation center is more affected by the spatial restrictive elements.

The second point involves the types of spatial constraint elements, which for the linear aggregation center districts are often large-scale mountains, bodies of water, or other natural environmental factors, making construction costs expensive, as on Hong Kong Island. The historical origin of commercial activity on Hong Kong Island is Queen's Road, south of the mountain. This is the starting point for commercial and public construction; the central district has developed along both sides of this thoroughfare. Victoria Bay and Victoria Peak are the major space constraint elements. However, the main limiting elements of the non-linear gathering center are composed of natural and human environment elements. From the angle of the spatial limiting factors and Pearson's r, the more

Table 4: The Correlation Value of the Central Districts

| Central district | Morphological characteristics of public service facilities | Major restrictive elements | Pearson correlation coefficient | Linear regression coefficient ($R^2$) |
|------------------|-----------------------------------------------------------|----------------------------|--------------------------------|--------------------------------------|
| Hong Kong Island | Linear aggregation | Victoria Harbor and Victoria Peak | 0.938 | 0.879 |
| Bangkok, Thailand | Linear aggregation | Station, proprietary land, river | 0.922 | 0.849 |
| Lujiazui (locality), Shanghai, China | Linear aggregation | Huangpu River and the Outer Ring Expressway | 0.908 | 0.825 |
| Zhongshan Square, Dalian, China | Linear aggregation | Mountains and sea | 0.884 | 0.781 |
| YauTsimMong District, Hong Kong | Linear aggregation | Victoria Bay and Beacon Hill | 0.856 | 0.732 |
| Dubai Bay, Dubai, United Arab Emirates | Linear aggregation | Airport, bay, other city center | 0.647 | 0.419 |
| Zayed Avenue, Dubai | Linear aggregation | Bay and other city center | 0.839 | 0.704 |
| Kuala Lumpur Tower, Kuala Lumpur, Malaysia | Non-linear aggregation | Mountains | 0.893 | 0.798 |
| People's Square, Shanghai, China | Non-linear aggregation | Huangpu River and the Outer Ring Expressway | 0.875 | 0.765 |
| Shenyang Zhongshan Square, Shenyang, China | Non-linear aggregation | South Lake and Railway | 0.873 | 0.763 |
| Xinjiekou (business district), Nanjing, China | Non-linear aggregation | Xuanwu Lake, Zijin Mountain, Qinhuai River | 0.861 | 0.742 |
| Chaoyang (district), Beijing | Non-linear aggregation | Temple of Heaven, Tiananmen Square, the National Palace Museum (etc.) | 0.81 | 0.665 |
| Mandarin Orchard (hotel), Singapore | Non-linear aggregation | Bay and road | 0.809 | 0.655 |
| Futian (district), Shenzhen | Non-linear aggregation | Lotus Hill and Administrative Boundary | 0.761 | 0.579 |
| Chunxi Road, Chengdu | Non-linear aggregation | River, railway | 0.734 | 0.539 |
| Sloane's (food business), Bangkok | Non-linear aggregation | Station, proprietary land, river | 0.73 | 0.532 |
| Gangbuk (district), Seoul | Non-linear aggregation | Mountain and Han River | 0.718 | 0.516 |
| Connaught Place (financial and business center), New Delhi, India | Non-linear aggregation | Mountain, railway | 0.66 | 0.435 |
| Teheranno (commercial street), Seoul | Non-linear aggregation | Han River, large-scale proprietary land | 0.597 | 0.356 |
| Luohu (district), Shenzhen | Non-linear aggregation | Shenzhen reservoir, mountain, administrative boundary | 0.551 | 0.303 |
| Xidan (commercial trading area), Beijing, China | Non-linear aggregation | University group, large historical and cultural monuments, railways | 0.54 | 0.291 |
natural an environment restriction factor, the higher the correlation, while the more relevant the human environment, the lower the correlation. We can see that the influence of natural restrictive elements is stronger than that of human environment elements when it comes to limiting spatial boundaries.

Finally, the spatial limitations of the central district's spatial limiting factors on the city's central district is mainly reflected in the direction in which its expansion is restricted; this means that the main direction of the central district is the same as the direction of the spatial boundary. For example, on Hong Kong Island along Queen's Road, the two main directions were northwest and east, and the urban spatial boundary is parallel to these two directions.

4. Conclusion

We explored the influence of urban spatial limiting factors on the spatial extension of urban central districts. The results show a strong correlation between the two. Urban spatial constraints play a vital role in shaping the flattened form of the city's central district. First, mountains, rivers, and other natural environmental features formed by the terrain and human environment affect the city in terms of the development direction of the scale, layout, and level. Second, the limiting elements constrain building size and population density based on development intensity, building density, and development boundaries. Third, the reduction in population and the inconvenience of traffic have decreased urban vitality, leading to delays in the extension of the city's central district. Finally, when planning urban central districts, in order to conduct reasonable planning, one needs to fully consider the city's role in internal limiting elements and the central district of the plane.

Although the various constraints on urban central districts' growth have various effects, these elements are only limited to determine the growth of one of the many elements of space. For most central districts facing development issues, their environmental, policy, economic, and even cultural elements affect the direction's spatial expansion, with varying degrees of impact. These invisible factors, together with the urban constraints discussed in this paper, create the rich and diverse spatial forms of modern urban centers.

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Note

A megacity is a metropolitan or urban area with a total population of more than 5 million according to the Notice on Adjusting the Standard of Urban Scale Division (2014) of China government. Shenzhen and Dubai have more than 5 million inhabitants because of their huge floating population.

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