Study on the historical changes in the central axis of Beijing based on modern technology

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ABSTRACT:

With the acceleration of urbanization, the Chinese government has placed increasing importance on the preservation of historical and cultural sites. Recently, the Beijing municipal government has been working on the World Heritage application for the Beijing Central Axis for several years and has set a clear goal to formally apply for World Heritage status before 2025. Currently, the project has entered the final sprint stage (Zhang Yongjun, 2018(12):105-107).The Beijing Central Axis, as an important carrier of natural and cultural heritage, embodies a unique cultural heritage. As "Beijing's unique and magnificent order," the Central Axis is not just a single line but a corridor. However, during the preparation for the World Heritage application, there have been different understandings of the concept of the Central Axis, and the selection of heritage sites has not been comprehensive and systematic. Therefore, in studying the issues related to the Central Axis, utilizing POI data to conduct kernel density analysis and linear regression analysis on the cultural landmarks within Beijing can help infer the location of the Central Axis in different periods. By employing spatial analysis methods using ArcGIS, a systematic study of the characteristics of the Beijing Central Axis can be conducted, summarizing its distribution and spatial form characteristics across different dynasties. This research can provide valuable reference for future in-depth studies, conservation and utilization efforts, and the World Heritage application of the Central Axis.

1. INTRODUCTION

With the acceleration of urbanization, the protection of cultural heritage has been receiving increasing attention from the government. The Beijing municipal government has encountered some issues in the process of applying for World Heritage status for the Beijing Central Axis. These issues include differing understandings of the concept of the Central Axis and a lack of comprehensive and systematic selection of heritage sites. To address these problems, GIS technology and POI (Point of Interest) data can be used to study the historical and spatial characteristics of the Beijing Central Axis, providing valuable references for future in-depth research, protection, utilization, and the application for World Heritage status for the Central Axis.

Beijing, as the ancient capital during the Liao, Jin, Yuan, Ming, and Qing dynasties, boasts a profound historical and cultural heritage. The Beijing Central Axis embodies the ancient concepts of urban construction and political ideology spanning five thousand years of Chinese history. It is a valuable cultural heritage both in terms of tangible and intangible aspects. Renowned architect Liang Sicheng once praised it as follows: "The unique grand order of Beijing arises from the establishment of this Central Axis." The most widely recognized Beijing Central Axis was initially constructed during the reign of Emperor Kublai Khan in the Yuan Dynasty. It stretches from the central point of Yongdingmen in the south to the central point of the Bell and Drum Towers in the north, spanning a total length of 7.8 kilometers. Over the course of more than seven centuries, it has witnessed the vicissitudes of Beijing's transformation and is considered the soul of the city. The Beijing Central Axis, like the axial urban planning of Washington D.C.'s Capitol Hill in the West, also embodies a sense of centrality. It signifies that the capital city is not only the center of a nation but also a spiritual center. Thus, people intentionally create this central axis to emphasize the status of power and the dignity of the ruling class, serving as a symbolic representation of a nation's ambitious expansion and territorial development.

From the current perspective, scholars have observed and measured the central axis of Beijing by examining existing buildings or inferring the locations of past structures. They have discovered that the central axis is not aligned exactly north-south but deviates slightly from the meridian(Miao et al.,2021). The existence of this deviation was initially proposed by Professor Kui Zhongyu, who accidentally noticed it while observing satellite images and aerial maps of Beijing. He subsequently confirmed the existence of the deviation through measurements using tools like rulers on maps and GPS receivers on-site, and speculated on the possible reasons behind it.There are three main categories of explanations for the deviation of the central axis. The first category is based on traditional Chinese Fengshui theory. Kui Zhongyu suggested that the direction of the deviation in the urban central axis of Yuan Dynasty's Dadu, which corresponds to present-day Beijing, coincidentally connects to the vicinity of the Yuan Shangdu City Wall ruins located northwest of Duolun County, Zhalantun City, Inner Mongolia Autonomous Region. Therefore, it is speculated that the builders intentionally linked the Shangdu City and Dadu City through this long-distance alignment to demonstrate the unity of the two capitals, aiming for auspiciousness as believed in ancient times.Professor Ji Xuming and others pointed out that the deviation of the central axis is due to the auspicious position in the Five Elements theory, where the position of prosperity and abundance is considered fortunate for emperors. This auspicious position naturally leads to a deviation within the range of ±2.5°, and the measured deviation of 2°12'9.35" by Kui Zhongyu precisely falls within this range.Wu Tinghai proposed that Liu Bingzhong, the designer of Dadu, was highly skilled in the art of Yin and Yang and had exceptional measurement abilities in ancient times, making it unlikely for such a significant deviation of more than two degrees to occur(Chen,20). According to Wu, the central axis was established through the observation method, determining the central platform and subsequently the axis. However, the axis of the imperial palace differed from the axis of the capital city. Over the years and various dynasties, these two axes have been mistakenly combined or even misaligned. Therefore, the present-day central axis actually represents the internal axis of Yuan Dadu rather than the axis of the capital city.The current central axis is a relic modified during the Ming and Qing dynasties, influenced by feudal rituals.

During the Ming Dynasty, the deviation of the central axis occurred, related to the alignment required for the construction of imperial mausoleums in relation to the imperial city. The selected location for Ming imperial tombs was Changping Tianshou Mountain, which has a dragon-like shape and excellent Fengshui. The main peak of the mountain aligns precisely with the imperial city, resulting in a slight deviation of the axis direction.From a technical perspective, scholars have analyzed historical records and made reasonable speculations about the ancient construction and measurement processes. They believe that Yuan Dadu had four axes: the construction centerline, the fixed centerline, the measured centerline, and the baseline for construction measurement. The layout of Beijing's hutongs (traditional alleys) served as positioning guides during the construction of the capital city. They attempted to analyze the reasons for the deviation from the perspective of the technological level of measurement.However, despite its slight deviation, this central axis, which guides the urban planning and development of Beijing from ancient times to the present, remains significant. It has become the city's axis in the past, present, and future on its developmental path.

POI data, which stands for Points of Interest data, is spatial data about geographic entities within a Geographic Information System(Ma C X,Peng F.L,2023). It can be used to study cultural heritage sites within a city. By conducting kernel density analysis and linear regression analysis on POI data, it is possible to infer the locations of the central axis in different periods. By combining these locations with spatial analysis methods in GIS, it becomes possible to systematically study the characteristics of Beijing's central axis. This approach can help summarize the distribution patterns and spatial forms of different dynasties, providing a better understanding of the historical evolution and spatial layout of the central axis.In general, POI data can provide valuable information for the preservation and utilization of Beijing's central axis. By analyzing and studying these data, we can gain a better understanding of the historical spatial characteristics of the central axis, providing guidance and support for future efforts in its preservation and nomination for the World Heritage List.

2.METHOD

2.1 Linear regression

The direction of the central axis line has been a subject of ongoing controversy, as buildings along the central axis are influenced by various objective and subjective factors. The resulting coordinates of the buildings on the axis do not form an ideal straight line, but rather a series of line segments connected together. Based on this, a linear regression will be performed using the coordinate data provided by the points of interest (POI) to obtain a new straight line. This new central axis (obtained through linear fitting) will be compared with the prime meridian to verify the relationship between the "new central axis" and the prime meridian.Fitting line can be expressed as follows:

$$y_t = ax_t + b \tag{1}$$

Where x_t=longitude coordinates
y_t=latitude coordinates
a =slope of the line
b =y-intercept
Error equation can be expressed as follows:

$$v_{yt} = [x_t \;\; 1]\begin{bmatrix}\delta_A \\ \delta_B\end{bmatrix} + (A_0 x_t + B_0 - y_t) \tag{2}$$

The solution of its least squares as follows:

$$\delta_X^{\wedge} = (A^T A)^{-1} = A^T l \tag{3}$$

The residuals as follows:

$$V = A\delta_X^{\wedge} - l \tag{4}$$

Write a MATLAB program to fit a straight line through the coordinate points of a polyline representing the central axis of a building using the method of least squares. The program should output the graph and equation of the ideal central axis line.

place	X	Y
Zhonglou	447840.0139	4423167.5899
Gulou	447838.6236	4422964.2794
Wanningqiao	447851.1234	4422503.3357
Wanchunqiao	447975.5396	4420855.5988
Shenwumen	447908.3051	4420944.1624
Qianqinggong	447906.6401	4420700.1907
Qianqingmen	447905.9001	4420591.7589
Baohemen	447905.2989	4420503.6581
Zhonghedian	447925.7101	4420435.7457
Taihedian	447925.2479	4420367.9759
Taihemen	447923.7224	4420144.3353
Jinshuiqiao	447965.2406	4419344.3316
Wumen	447938.3153	4419988.3582
Duanmen	447935.7738	4419615.6241
Tiananmen	447950.0451	4419412.2081
Zhengyangmen	447980.3941	4418503.8451
Jianlou	447979.4711	4418368.3057
Yongdingmen	448060.8723	4415751.7278

Table 1. The 18 pairs of coordinate points used for the straight line fitting.

2.2 Kernel Density Analysis

Kernel Density Analysis is a commonly used non-parametric test method in POI (Point of Interest) data analysis. It primarily examines the distribution characteristics of the data and investigates the spatial clustering of POI by estimating the density of points or line features within their neighborhoods(Sun and Hu,2023). The fundamental idea of this method is to calculate the surface value on a smooth surface, using the kernel density function with the sample points' positions as the center and within a specified radius distance (h). The surface value is maximum at the location of the sample point and inversely proportional to the point's distance. The surface value gradually attenuates from the center outward as the distance from the point increases. In this method, the magnitude of the kernel density value represents the degree of clustering of the POI, with larger point areas indicating a higher level of clustering. Kernel Density Analysis can reflect the distribution and clustering degree of buildings near Beijing's central axis, providing insights for studying the urban layout of Beijing. The calculation formula for this method is as follows:

$$\frac{1}{n}\sum_{i=1}^{n}\frac{k}{n}\left(\frac{x-\alpha i}{n}\right) \quad (5)$$

Where $f(x)$=Kernel Density Function
n =The number of POI features within a given distance range.
h =The distance decay threshold, also known as bandwidth.
k =The spatial weighting function.
$x-ai$ =The distance value from the central line point to the sample point.
The formula for calculating the distance of the bandwidth (h) is as follows:

$$\frac{1}{n}\sum_{i=1}^{n}\frac{k}{n}\left(\frac{x-\alpha i}{n}\right)h = 0.9 \times min\left(SP\sqrt{\frac{1}{ln\,(2)}} \times Ym\right) \quad (6)$$

Where SP =The standard distance
YM =intermediate distance value
The size of the bandwidth (h) has a significant impact on the calculation results. As the bandwidth increases, the point density becomes smoother. Conversely, when h decreases, the result becomes rougher and even fragmented. In experiments, it is necessary to choose an appropriate bandwidth based on specific needs for detailed analysis and research.

3. DATA ANALYSIS

3.1 Linear regression analysis.

Use the 18 coordinate points in Table 1 to perform straight line fitting with MATLAB program.
After the program runs, the output graph is shown in Figure 1, and the residual error results after fitting are shown in Table 2, and the equation of the straight line as follow:

$$y = -30.009518x + 17862355.0418 \quad (7)$$

Residual	Residual Value
r1	275.487792
r2	30.455059
r3	-55.375668
r4	2030.557620
r5	101.446285
r6	-192.491262
r7	-323.130106
r8	-429.272628
r9	115.345245
r10	33.705046
r11	-235.715074
r12	210.222395
r13	46.233721
r14	-402.769569
r15	-177.910735
r16	-175.514875
r17	-338.753060
r18	-512.520187

Table 2. Residuals of the first fitting.

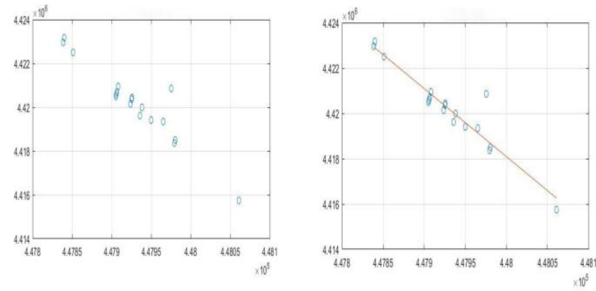

Figure 1. The original discrete data and the first-fit image of a linear fit.

It is obvious from the figure that there is a point with obvious offset. In order to achieve a better fitting result, the point (447975.5396 4420855.5988) was removed. The output result after re-running the program is shown in Figure 2, the fitting residual results are shown in Table 3, and the linear equation as follow:

$$y = -32.0853x + 18792045.2866 \quad (8)$$

Residual	Residual Value
r1	216.600448
r2	-31.318285
r3	-91.201787
r4	184.318585

r5	-113.075188
r6	-245.250132
r7	-352.640632
r8	234.347040
r9	151.747401
r10	-120.839369
r11	411.282048
r12	191.401533
r13	-262.877432
r14	-8.394072
r15	57.000585
r16	-108.153574
r17	-112.947170

Table 3. Second fit residual results

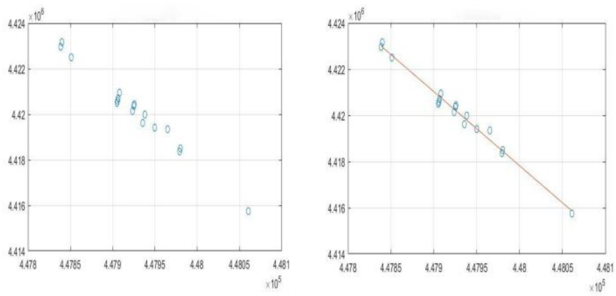

Figure 2. The original discrete data and the second-fit image of a linear fit.

The coordinates of two points A (447840.013912, 4422964.088614) and B (448060.872321, 4415877.780593) were calculated on a fitted line. The azimuth angle was determined to be 357°10′34″. Assuming that the meridian line aligns with the north-south direction, it was found that the line does not coincide with the meridian and forms a counterclockwise angle of 2°49'26".This result once confirms the fact that the central axis of Beijing city is not aligned with the true north-south direction.

However, the exact cause of this angular deviation is still inconclusive in this article. It could be due to errors resulting from ancient technological limitations, intentional adjustments for auspicious Feng Shui considerations, or adherence to ceremonial norms. However, it is almost certain that it is unrelated to the Earth's movement. The physical mechanisms that contribute to the axial oscillation and polar motion, which are a natural coupling of energy between the Sun's radiation pressure, Earth's movement, the obliquity of the ecliptic, and the geographical distribution of land and ocean on Earth's surface, are responsible for these variations. While the annual polar motion can affect longitude and latitude, its changes are minimal. On the other hand, long-term polar motion can have a stronger impact. However, considering Beijing's geographic coordinates, the resulting longitude variation should be clockwise, not the counterclockwise deviation of over two degrees observed presently. Therefore, we can almost confirm that the angle between Beijing's central axis and the meridian is unrelated to the Earth's movement. The cause of this angular deviation is more likely attributed to construction, urban planning, or other human factors.

3.2 Spatial Analysis of the Central Axis

The vicinity of the Beijing central axis is home to numerous religious sites catering to both the ruling elite and the common people. Many of these sites were imperial-sponsored temples and monasteries, indicating the significant emphasis placed on religious activities by the ruling class at that time.The central axis, being the focal point of the city, holds not only architectural significance but also carries immense political importance. The stability of the central axis ensures the stability of the imperial palace, which, in turn, ensures the stability of imperial power within the palace walls. This stability extends to the entire nation, promoting peace and security among the people. The construction of religious buildings along the central axis in Beijing has had a significant influence, considering their religious nature and impact on the urban landscape.The construction of religious sites in Beijing initially began during the Tang Dynasty, with a significant increase during the Yuan Dynasty when it became the capital. The highest number of constructions occurred during the Qing Dynasty, as depicted in Figure 3. According to historical records, nearly every emperor of the Yuan Dynasty built a temple upon ascending the throne. The number of temples continued to rise during the Ming and Qing Dynasties, with a substantial quantity remaining despite some reduction during the late Qing and Republican periods due to damage and destruction.

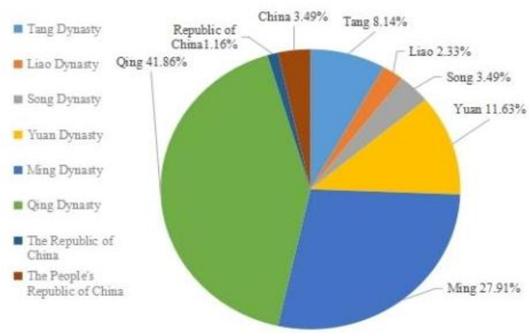

Figure 3. Statistical Chart of the Number of Religious Sites Constructed in Various Dynasties

Simultaneously, Western religions such as Christianity and Catholicism began to enter China, leading to the construction of various churches in Beijing to facilitate missionary activities. Ancient superstitious beliefs led people to interpret this as a divine warning, prompting them to pray more fervently for divine protection. Therefore, the large number of religious buildings constructed during the Qing Dynasty aligns with the psychological and practical needs of ancient people. Manipulating and controlling people's thoughts through religious beliefs were common political strategies employed for the stability of the nation and the state.

Based on the ArcGIS software, a statistical analysis of the straight-line distances from these points to the central axis of Beijing was conducted, resulting in Figure 4. The majority of religious buildings with the shortest straight-line distances to the Beijing central axis fall within the range of 0.5 kilometers to 1 kilometer. These buildings are primarily distributed around the Imperial City, with a concentration in the southwest and northeast directions, which aligns with historical records of that time.

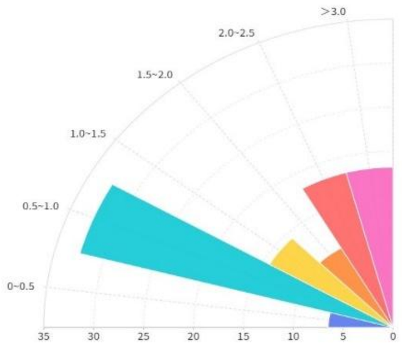

Figure 4. Statistical Chart of Straight-Line Distances from Religious Sites to the Central Axis

Using ArcMap 10.2, a kernel density analysis was performed. After multiple attempts with different cell sizes, it was determined that the optimal cell size for this study is 0.0005x0.0005. To determine the most suitable bandwidth, a comparison was made by setting the search radius to 50 meters, 25 meters, and 10 meters while conducting several value experiments-Figure 5.When comparing the 50-meter bandwidth to the 25-meter bandwidth, the layout of the buildings appears blurred and unclear. Comparing the 50-meter bandwidth to the 10-meter bandwidth, it is noticeable that as the bandwidth decreases, the density values within the search range become higher, resulting in less smooth curves.Considering the small size of the study area, a bandwidth of 10 meters was selected for further experiments. Figure 6 is used to display the distribution of different types of buildings.

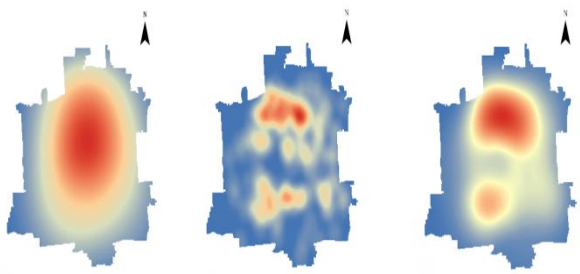

Figure 5. Comparison of 50-meter bandwidth, 10-meter bandwidth, and 25-meter bandwidth

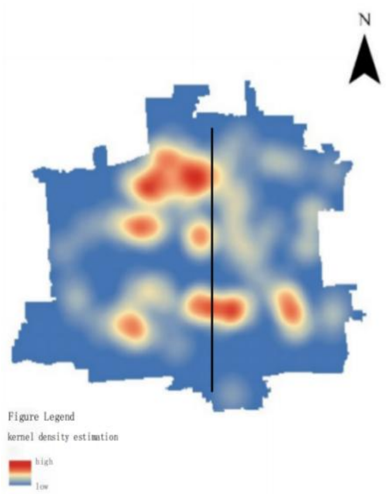

Figure 6. Kernel density analysis of buildings on the central axis of Beijing

In the POI data Excel worksheet file, the relevant POI data required for spatial analysis is filtered out. By utilizing the Excel's table conversion feature, an attribute table is obtained. Then, on the vector map, the desired polygons are filtered out, and their attribute table is linked with the point attribute table to connect the attributes of the two features.Based on the completion time of the buildings along the central axis, they can be classified into four categories: Yuan Dynasty, Ming Dynasty, Qing Dynasty, and Modern. In ArcGIS, different colors are assigned to each category, and they are represented accordingly. The map production is completed in ArcGIS by overlaying the time chart with the topographic map of Beijing. Finally, the spatiotemporal distribution map of the buildings along the Beijing central axis is obtained (Figure 7).

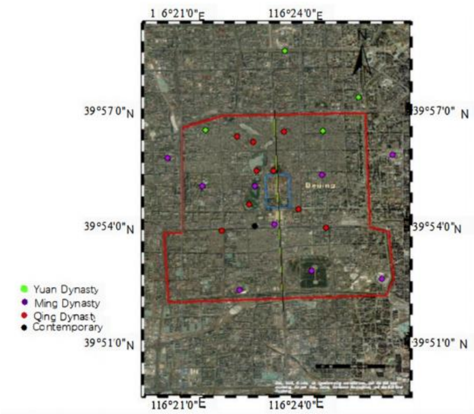

Figure 7.Temporal and spatial distribution map of buildings on the central axis of Beijing

The vicinity of the Beijing central axis is home to numerous religious sites catering to both the ruling elite and the common people. Most of these sites were imperial-funded and designated temples and monasteries, indicating the significant importance placed on religious activities by the ruling class of that time.The central axis, being the focal point of the city, holds not only architectural significance but also carries strong political implications. Its stability ensures the stability of the imperial palace, which, in turn, ensures the stability of imperial power within the palace walls. This stability extends further to promote peace and security throughout the nation, ensuring the well-being of the people.The construction of religious buildings with a religious nature along the Beijing central axis has had a significant impact on the development of religious architecture in Beijing.

4 DISCUSSIONS

The Beijing central axis is a historic axis that embodies the historical and cultural significance of Beijing, serving as the essence of the city. This study conducted a digital analysis of the POI data based on the buildings along the central axis using POI data and the ArcGIS system. MATLAB was utilized to perform linear fitting and generate output images, revealing that the axis does not align perfectly with the true north-south direction and exhibits a counter-clockwise deviation of 2°49′26″. Furthermore, the ArcGIS software was employed to conduct a comprehensive analysis of various aspects, including the construction timeline and spatial distribution of buildings and religious structures along the central axis. The urban spatial layout, centered around the Beijing central axis, was visually depicted through maps. This research significantly contributes to the understanding of Beijing's urban planning and design principles and holds reference value for the protection of the

Beijing central axis. It also provides valuable insights for future in-depth research, preservation efforts, utilization, and the potential application for World Heritage listing of the central axis.

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