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Method for selecting viewpoints of architectural heritage landscapes

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Abstract

The selection of viewpoints is a crucial aspect in conducting visual impact assessments of architectural heritage. To address this issue, a quantitative viewpoint selection method based on GIS spatial analysis is proposed. The first step involves defining the factors that influence the selection of viewpoints for architectural heritage. Next, the city's historical architectural areas are divided into units based on courtyards. Subsequently, a candidate set of viewpoints is constructed by extracting the skeleton lines and characteristic points of sub-regions. Finally, following the principles of viewpoint selection, the method achieves the selection of viewpoints for the visual impact assessment of architectural heritage. The Forbidden City is chosen as the practical area for implementation, and the results demonstrate that the viewshed coverage range in the architectural heritage area is as high as 96%. It represents that this approach for visual impact assessments of architectural heritage is more grounded.

Keywords Architectural heritage conservation, Visual impact, Viewpoints, Skeleton lines, Visual integrity

Introduction

Architectural heritage is a tangible representation of historical culture, serving as a significant carrier of cultural identity. The preservation of this heritage necessitates the maintenance of its authenticity and completeness while harmonizing it with the overarching framework of local social and economic advancement [1, 2]. As urbanization continues to accelerate, the tension between modernity and historical landmarks has become increasingly evident, highlighting the importance of assessing the visual impact on landscapes [3, 4]. Specifically, the visual impact assessment of architectural heritage landscapes has emerged as a focal point in this field [5, 6]. Nevertheless, the evaluation of visual impact and its assessment constitutes a systematic research area involving landscape architecture, ecology, geography, psychology, and sociology. Despite extensive research in theory and practice over the years, the results of visual impact assessments remain incomplete [7–10].

Landscape visual impact assessment primarily comprises two stages: viewpoint selection and visual impact assessment. The process of selecting viewpoints is a fundamental aspect of visual impact assessments [11, 12]. These points, which may also be referred to as observation points, survey points, or sample points, are crucial for evaluating granular regions and performing quantitative evaluation operations. The selection of viewpoints significantly affects on the accuracy and objectivity of the assessment results [13]. In the practice of landscape visual assessment, various methods for viewpoint selection have emerged based on differences in the type, scale, and purpose of the evaluation objects. Many methods adopt random or equidistant

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viewpoint selection, such as Daniel [14], who randomly selected evaluation points on paths in a forest, and Qi Tong [15], who evenly selected sample points along the circular path in Zizhuyuan Park, Xu Huan [16], landscape nodes are selected every 3km on the Huai'an section of the Grand Canal. Other methods involve selecting viewpoints through on-site surveys of regional typical features and visibility openness, such as Gkeka-Serpetsidaki [17] prioritized viewpoints based on the results of population census statistical analysis. Overall, these methods demand a significant amount of manual involvement, which can affect the acceptance of visual impact assessment results.

Nowadays, GIS, remote sensing, and three-dimensional technologies are applied to quantitative assessments of landscape visual impact, broadening the research scope and reducing errors in assessment results [18–21]. GIS's functions in geographical data management and spatial analysis can handle various processes such as extracting different spatial regions, calculating features, and identifying critical locations [22–24]. Conducting a direct overall visual impact assessment of architectural heritage, which often involves large areas with interconnected courtyards and intricate spatial complexities,poses great challenges. Even artificial selection of viewpoints may struggle to yield accurate and comprehensive assessment results. Therefore, this study,employs GIS to consider the constituent elements and regional characteristics of architectural heritage, aiming to solve the issue of viewpoint selection in the visual impact assessment of a large number of urban architectural heritage sites. Additionally, given the diverse types of architectural heritage, this study confines its scope to urban architectural heritage of the courtyard layout type to ensure clarity in research objectives.

Visual impact factors and definitions of architectural heritage composition

The factors influencing viewpoint selection mainly arise from the spatial characteristics of architectural heritage areas and the internal structural elements involved in landscape visual perception. The buildings within the architectural heritage area constitute the main visual elements, while the walls hinder the extension of vision. When choosing viewpoints, it is essential to take into account such factors as the height and volume of these elements. Therefore, it is necessary to define these visual impact factors in the form of spatial geometry in order to facilitate description in subsequent spatial calculations.

Here, the vertical height of the walls, the horizontal distance from the viewpoint to the walls are specifically defined as visual impact elements. Meanwhile, the position of the viewpoint in the projection can be represented by coordinates. The above information is illustrated in Fig. 1. The definition and extraction of these factors serve as the foundation and necessary conditions for the quantitative selection of viewpoints. For example, in situations where the viewer is close to the wall, the presence of other objects in the viewer's visual field may be minimal, making it unreasonable to select viewpoints in those areas for visual impact assessment. It should be noted that, the walls are segmented and counted according to their spatial positions, with n sections of walls within the designated area. For example, for a certain wall, n is the number of this segment wall.

(1) H_n represents the vertical height of the walls, where $n=1,2,3,\ldots$;
(2) D_n represents the horizontal distance from the viewpoint to the walls, where $n=1,2,3,\ldots$;
(3) P_n is the viewpoint; x_n, y_n are the coordinates of the viewpoint under projection, where $x_n, y_n \in N$, $n=1,2,3,\ldots$;

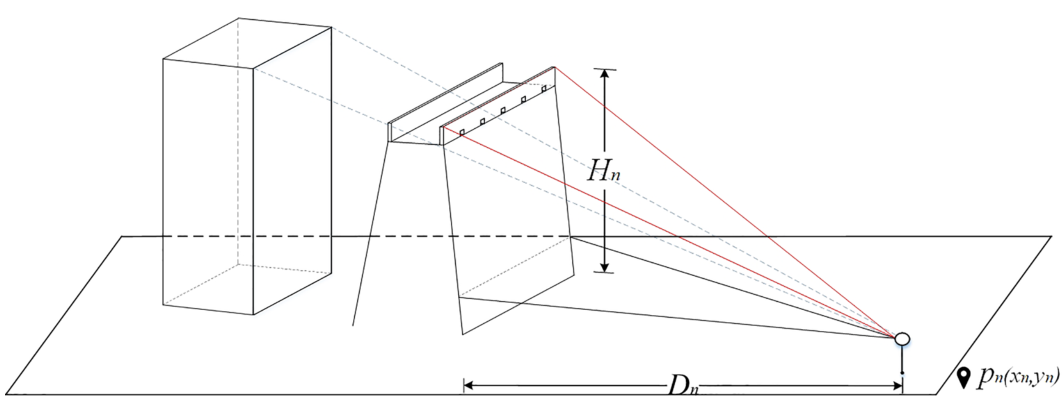


Fig. 1 Visual occlusion is determined by the height of the wall (Hn), distance from the viewer (Dn), position of the viewpoint (Pn)

Key algorithm for viewpoint selection

Skeleton line extraction is a widely used algorithm in GIS for analyzing spatial features of geographical regions [25, 26]. The skeleton line represents the centerline of geometric shapes, especially strip-like geometric shapes, reflecting the central shape characteristics of geometric shapes. In the context of visual assessment of architectural heritage landscapes, viewpoints are frequently situated on the axes of courtyards or roads. Additionally, when courtyards are large or roads are extensive, extra viewpoints may need to be added beyond the axes positioned along the centerline of the region. Therefore, viewpoints chosen based on these principles are generally located on the skeleton lines of the courtyard's geometric space. In addition, the endpoint of the skeleton line is the starting point of the skeleton line segment, representing the starting position of the skeleton line; the intersection point of the skeleton line is where the main skeleton line intersects with the local skeleton line, signifying a change in the skeleton line's direction; the midpoint of the skeleton line is the center position of the local skeleton line, which, when combined with the endpoint or intersection of the skeleton line, represents the basic shape of the skeleton line. Therefore, the endpoints, midpoints, and intersections on the skeleton lines, representing important sample points of architectural heritage courtyards and road geometric centers, are crucial for landscape visual assessment. It is worth noting that the specific arrangement of buildings in architectural heritage can result in asymmetry along the secondary axis, even if they appear symmetrical along the main axis. This irregular spatial structure of courtyards renders the use of characteristic points on skeleton lines suitable for viewpoint selection in architectural heritage visual impact assessments.

Given that spatial areas of architectural heritage are often structured as multi-entry courtyards, and connections exist between the entries through roads, skeleton lines are extracted based on polygons. Consequently, the entire architectural heritage area is segmented into courtyard sub-regions based on entries in order to reduce the complexity of the overall polygon. Similarly, roads are divided into road sub-regions based on the courtyard area. After extracting the skeleton lines, a collection of connected line segments within the courtyard or road boundaries is obtained. Within these collections, there are numerous characteristic points such as endpoints, intersections, and midpoints. These characteristic points can serve as candidate viewpoints for viewpoint selection. Since only a subset of these points can be selected as viewpoint locations due to their large number, further principles and methods are needed to determine the selection and obtain the most representative viewpoints.

It should be noted that, from a cultural and social perspective, space has always been simply the inherent background of our material existence, yet it plays a pivotal role in shaping how society and culture constitute the real world [27]. Similarly, space encompasses various attributes. From the perspective of GIS, we only consider its physical attributes, and other attributes will be discussed in subsequent research. In addition, the prerequisite for extracting skeleton lines is the presence of vector surface features or raster data, which is also the reason for dividing urban architectural heritage into sub regions and displaying them in the form of vector surface features.

In summary, the algorithm for viewpoint selection in the visual impact assessment of architectural heritage landscapes comprises three main parts: dividing the courtyard and road areas of the heritage architecture, extracting the skeleton lines, and selecting appropriate viewpoints.

Method for architectural heritage area division

It is widely recognized that the basic elements in GIS are point, line, and polygon features. Accordingly, for architectural heritage in GIS, the overall area is typically represented by polygon features using walls as boundaries, and individual buildings inside are represented by polygon features. These features are associated with specific attribute information. The areas that truly need skeleton line extraction, i.e., courtyards and roads based on entries, are generally not explicitly represented and require algorithms for extraction. Therefore, this algorithm should by analyzing the connection relationships between line features and polygon features within the overall heritage range and the associated attributes, courtyard and road sub-regions are delineated. However, its related algorithms are too complex and not the focus of this study, so a convenient and effective method for dividing courtyard level roads is proposed. The method for architectural heritage area division consists of three parts:

(1) Draw the minimum bounding polygon of the architectural heritage area.
(2) Delete polygons corresponding to buildings, walls, and observation platforms from the polygons drawn in (1). Obtain the polygon corresponding to the courtyard level road. This process can be visually demonstrated using Fig. 2.
(3) Place the polygons corresponding to the features and the polygons corresponding to the courtyards and roads in the same plan figure, and combine remote sensing images of the architectural heritage area to identify the courtyard polygons and road polygons respectively.

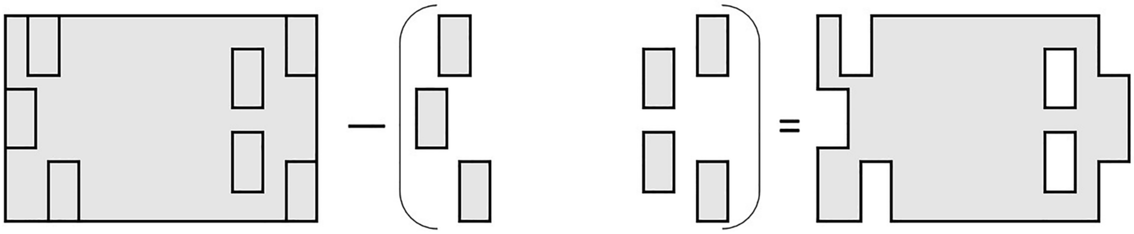


Fig. 2 Method for obtaining polygons corresponding to courtyards and roads

Generation of skeleton lines for architectural heritage sub-regions

The generation of polygon skeleton lines is a well-established algorithm, that primarily employs the construction of a constrained Delaunay triangulation [28]. This triangulation is a collection of non-overlapping triangles, where each triangle's circumcircle does not contain intersections with other line segment intersections within the polygon. The algorithm classifies the triangles based on their position in the triangulation and connects the extracted central points or central lines from various types of triangles to form the skeleton lines.

Viewpoint selection for architectural heritage sub-regions

As mentioned earlier, the skeleton line is a collection of line segments, and the positions of characteristic points such as endpoints, intersections, and center points of these line segments can be used as sample points for viewpoint selection. However, given the abundance of these points not all of them can be labeled as viewpoints. Therefore, further filtering is required. This process initially requires the integration of candidate viewpoints, and then analyzes the characteristics of the architectural heritage area and the distribution characteristics of candidate viewpoints, in order to propose the principles of viewpoint selection and obtain the viewpoint selection process. The algorithm for viewpoint selection in architectural heritage sub-regions comprises five parts: constructing a viewpoint candidate set, recognizing viewpoints within the central axis and buffer zone, identifying candidate viewpoint density, defining viewpoint selection principles, and executing the specific viewpoint selection process. It is necessary to first discuss the requirements for parameters and the relevant settings of parameter values, because the size of the parameters directly influences the results of viewpoint selection. The main parameters are listed in the Table 1.

Table 1 List of viewpoint selects parameters

Flow path	Parameter symbols	Parameter meaning
Build the viewpoint candidate set	l_{TH1}	Length threshold
Central axis buffer range size	l_{TH2}	
Candidate viewpoint density identification	r	
Viewpoint screening process	S_{TH1}	Area threshold
	S_{TH2}	
	w_{TH}	Ratio

l_{TH1} represents the minimum length of the skeleton line, and r is the minimum length used to determine the density of viewpoints, set to half of l_{TH1}. In this case, given the proximity of endpoints, midpoints, and intersections along the skeleton line, it is advisable not to set this parameter too low. Therefore, it is recommended that the minimum distance between viewpoints be set to at least 20–25 m to ensure adequate spacing. Considering that the actual distance between viewpoints may be larger, it is suggested to set l_{TH1} to 40–50 m, and the corresponding value for r to 20–25 m.

l_{TH2} is used to determine the size of the buffer zone for the central axis. Considering that the error between the skeleton line and the central axis is not expected to be too large, l_{TH2} can be set to 1 m.

S_{TH1} is the critical value for setting or not setting viewpoints, and S_{TH2} is the critical value for extracting viewpoints using skeleton line feature points or selecting the midpoint of the sub-area. Due to the complexity of the shapes corresponding to the courtyards, and the fact that their maximum bounding polygons and minimum inscribed polygons are mostly rectangles, for the convenience of calculation and research, the courtyard is approximated as a square [29]. Therefore, when taking the midpoint of a square as a viewpoint, assuming D is the minimum viewing distance is half the length of the square's side. If considering the " D/H index ", according to the relationship between the D/H index and changes in human visual perception [30, 31], it can be concluded that when D/H < 1 (i.e., D < H), the degree of obstruction of the building to the line of sight is higher; When D/H = 1 (i.e., D = H), it is the best location for the human eye to appreciate the building; When D/H = 2 (i.e., D = 2H), the degree of obstruction of the building to the line of sight is not significant; H varies with the actual situation. Here, based on the actual situation, the corresponding value for H to 20 m. Based on the above conclusion, setting the maximum length of the square's side without viewpoints to half of 20 m, it is suggested to set S_{TH1} to 1600 m^2, setting the maximum length of the square's side with one viewpoints to half of 40 m, it is suggested to set S_{TH2} to 6400 m^2.

w_{TH} is used to determine the degree of obstruction to the line of sight. According to the relationship between the D/H index and changes in human visual perception, when D/H = 2, the degree of obstruction of the building to the line of sight is not significant; When D/H > 3, the building hardly obstructs the line of sight. To minimize the obstruction of the line of sight by the wall at the viewpoint, it is suggested to set w_{TH} to 2.

The specific algorithm is outlined as follows:

1.Constructing a Viewpoint Candidate Set

(1) Extract endpoints and intersections of skeleton lines.
(2) Sequentially check whether the length of each line segment in the skeleton line segment set is greater than a threshold l_{TH1} *(i.e., 40–50 m)*. If it is, divide the line segment into sub-segment, ensuring that each sub-segment length is less than the threshold, and extract the connecting points.
(3) The extracted endpoints, intersection points and center points of the skeleton line constitute the viewpoint candidate set.

2. Recognition of central axis and viewpoints within the buffer zone

The vertical and horizontal axes are important geometric distribution direction in the architectural heritage area. Here, both are collectively referred to as the central axis. Considering the potential error between the extracted skeleton lines of the architectural heritage area and the central axis, candidate viewpoints within the central axis region can be identified using a buffer zone analysis algorithm for subsequent viewpoint selection. Typically, the overall polygon of the architectural heritage area tends to be a rectangle. If the polygon is identified as a rectangle, it is easy to extract the vertical and horizontal axes of the rectangle. Conversely, if the polygon is irregular, the minimum bounding rectangle of the architectural heritage area can be calculated, and the vertical and horizontal axes of this rectangle can be extracted as the central axis. Alternatively, given the limited number of many central axes, they can be obtained through manual drawing. Finally, set the buffer zone size threshold l_{TH2} *(i.e., 1 m)*, construct a buffer zone for the central axis, and extract the viewpoints within it.

3. Recognition of Candidate Viewpoint Density

Some courtyard spaces may be narrow, resulting in line segments of the extracted skeleton lines having lengths smaller than the threshold l_{TH1} *(i.e., 40–50 m)*. Especially the distance between intersections and endpoints is small, leading to a concentrated distribution of candidate viewpoints. To address this issue, a spatial clustering method is employed to identify candidate viewpoints with high density. The process of recognizing candidate viewpoint density is illustrated in Fig. 3.

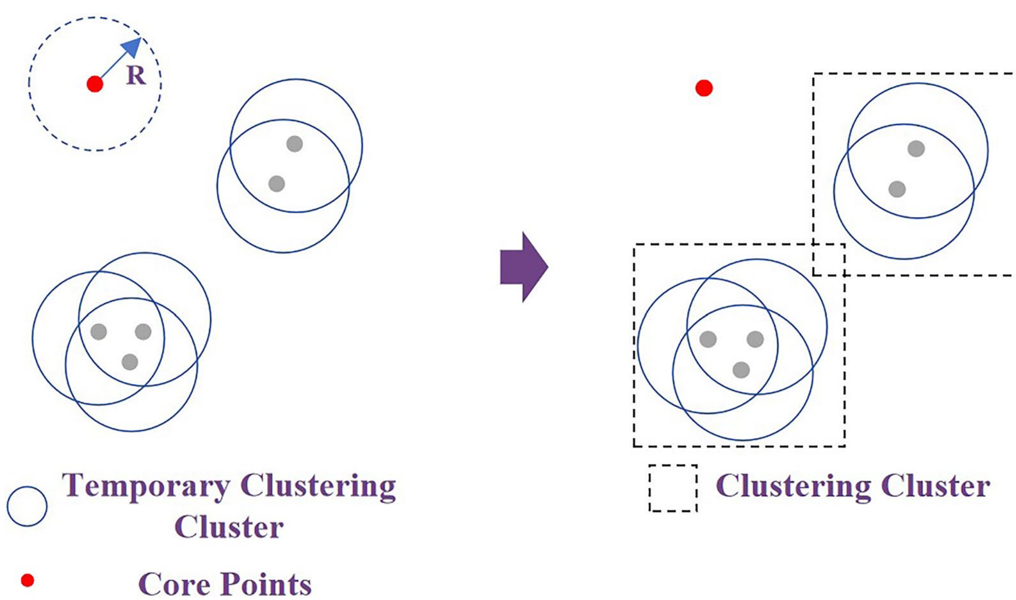


Fig. 3 Identification of candidate viewpoint density

(1) Set the parameter with a threshold of half the length of the line segment, denoted as l_{TH1}, as the radius r *(i.e., 20–25 m)*. Construct a circle with a radius of r with each candidate viewpoint as the center. If the number of candidate viewpoints within the circle is greater than or equal to 2, the candidate viewpoints inside the circle are referred to as temporary clustering clusters. If the number of candidate viewpoints inside the circle is 1, the point is referred to as a core point.
(2) Scan the temporary clustering clusters and check whether the points contained in the current temporary clustering cluster are the same as the points contained in other temporary clustering clusters. If so, merge the current temporary clustering cluster with the judged temporary clustering cluster to obtain a new temporary clustering cluster. If not, upgrade the temporary clustering cluster to a clustering cluster.
(3) Repeat (2) until each point in the current temporary clustering cluster is in a new temporary clustering cluster or clustering cluster. At this point, the temporary clustering cluster is upgraded to a clustering cluster.

4. Principles of viewpoint selection

In essence, the principles of viewpoint selection need to consider the spatial features, geographical conditions, tourist preferences, and even the importance of different buildings in architectural heritage, as well as spatial and attribute information. However, to highlight the principles of selecting spatial features, the influence of relevant attribute information on viewpoint selection has been disregarded, and it will be discussed in subsequent research. The preliminary summary of the spatial feature influencing viewpoint selection principles is as follows:

(1) Priority principle of the central axis area. The viewpoint should be a geometric spatial feature point in the architectural heritage area, so points on the central axis should be considered as viewpoints first.
(2) Principle of prioritizing large courtyard space over small. Obviously, the area of the courtyard space directly affects the number of viewpoint settings. The larger the area, the more viewpoints are needed, and it is unnecessary to set viewpoints for small areas.
(3) Principle the position at the best viewing as the viewpoint. Clearly, the main objective of viewpoint selection is to observe architectural heritage, and thus, the location of the most optimal viewing point should be given precedence.
(4) Principle of abandoning points close to walls. According to the principle of selecting viewpoints with a clear line of sight, consider deleting viewpoints with severe visual obstruction. Due to the fact that the walls does not belong to the viewing object and obstructs the line of sight, viewpoints closer to the fence are equated with viewpoints with lower visibility.
(5) Principle of discarding viewpoints with too close spacing. For other viewpoints too close to one viewpoint, the similarity of the viewing space is high, and it is considered to discard other viewpoints.

5. Specific Process of Viewpoint Selection

(1) Extract points within the central axis buffer zone of the architectural heritage area.
(2) If the area of the courtyard sub-area is smaller than S_{TH1}, do not set a viewpoint. If the area of the courtyard sub-area is greater than S_{TH1} and less than S_{TH2}, directly select the midpoint of this sub-area as the viewpoint. If the area of the courtyard sub-area is greater than S_{TH2}, use skeleton feature points to extract viewpoints.
(3) Calculate the ratio w'_n using formula(1).

$$w'_n = \frac{D'_n}{H'_n}, n = 1,\ 2,\ 3 \tag{1}$$

If $w'_n = 1$, directly select the point as the viewpoint. Here, D'_n is the distance from the point to the building, and H'_n is the height of the building.

(4) Calculate the ratio w_n using formula (2).

$$w_n = \frac{D_n}{H_n}, n = 1, 2, 3 \tag{2}$$

Determine if w_n is less than the threshold w_{TH}. If present, then delete the candidate viewpoint. Here, D_n is the distance from the point to the building, and H_n is the height of the building.

(5) For the remaining candidate viewpoints in (3), based on the x and y coordinates of the points, use calculation formula (3) to obtain the point p at the center position of each clustering cluster. Consider p as a viewpoint, and repeat for $n = 2, 3, 4...$;

$$\begin{cases} x_p = \frac{x_1+x_2+\cdots+x_n}{n} \\ y_p = \frac{y_1+y_2+\cdots+y_n}{n} \end{cases} \quad (3)$$

(6) Based on the results of the candidate viewpoint density recognition, consider the remaining core points as viewpoints. In the end, the selected viewpoints include the points p, the remaining core points, and the remaining points within the central axis buffer zone.

Case study

Using ArcGIS software and the C++ programming language, the development of relevant algorithms was completed through secondary development. Subsequently, the Forbidden City was chosen as a practical case for viewpoint selection. The study involved dividing the Forbidden City's architectural complex into regions, extracting skeleton lines and their feature points, viewpoint selection, and analyzing the results.

Introduction to the study area

The Forbidden City, is located at the center of Beijing's central axis. As the royal palace of the Ming and Qing dynasties in China, it is one of the world's largest and best-preserved site of ancient wooden structure buildings. The Forbidden City, with its three main halls at the center, covers an area of about 720,000 square meters, with a building area of approximately 150,000 square meters. It comprises over seventy palaces and more than nine thousand rooms. The Forbidden City is 961 m long from north to south, 753 m wide from east to west, surrounded by a 10-m-high city wall, and has a 52-m-wide moat. There have been relevant studies on the calculation of visual occlusion area in the Forbidden City before [32]. The importance of selecting viewpoints for the Forbidden City is self-evident. Therefore, this method was attempted to select viewpoints for the visual impact assessment.

Viewpoints selection

The Vector data for the Forbidden City and the surrounding buildings were obtained from the internet, as shown in Fig. 4. Based on the algorithm mentioned earlier, the courtyards and roads of the Forbidden City were extracted (see Fig. 5). The result included the courtyard labeled as "131" (see Fig. 6), which matched the records in the literature [33] and aligned with the actual situation, this is an important guarantee for the reliability of research results.

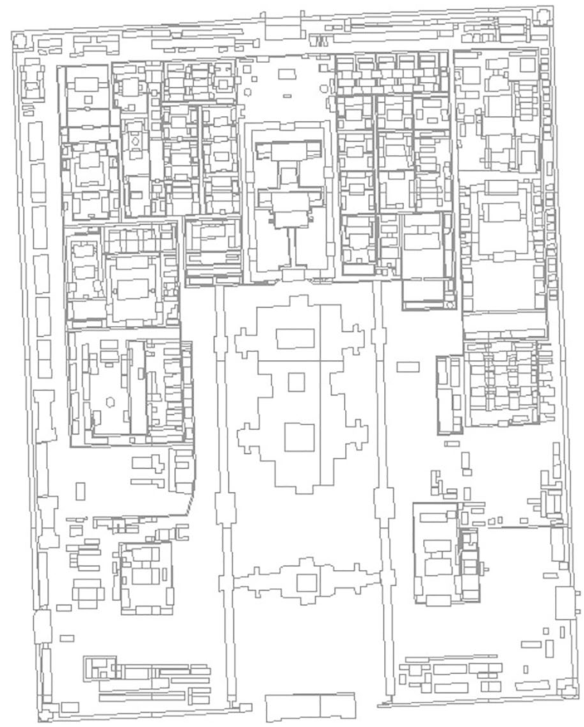
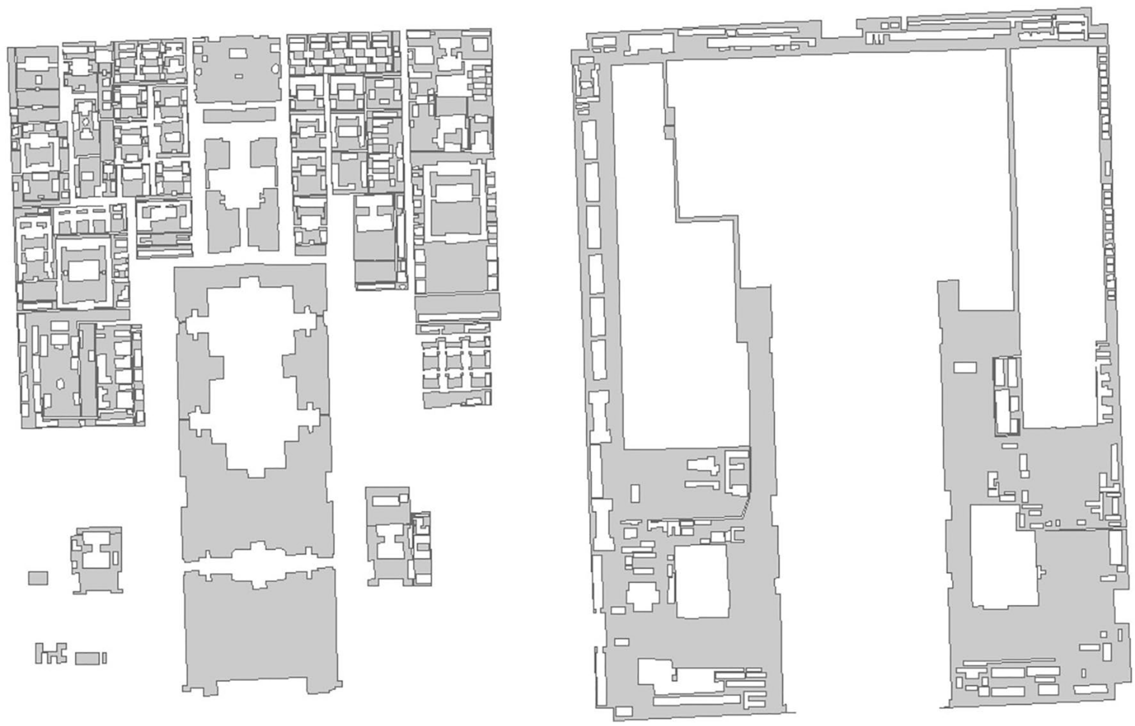


Fig. 4 Vector data of the Forbidden City

By creating a constrained Delaunay triangulation, dividing the triangle types, and generating skeleton line nodes, the skeleton lines for each sub-area were extracted. Using the skeleton line nodes generated in the previous steps, endpoints and intersections of the skeleton lines were extracted, as shown in Fig. 7a. Combined with the midpoints of the skeleton lines, a candidate set of viewpoints was obtained, as shown in Fig. 7b. Finally, viewpoint selection was performed on the candidate set, resulting in the selection of 46 viewpoints shown in Fig. 7c. The results of viewpoint selection and intermediate results are shown in Fig. 7. The values of the main parameters are listed in the Table 2.

Due to the fact that the values of the l_{TH1} and r parameters can be selected to a certain extent based on the specific situation of the architectural heritage area, it is necessary to consider changing these two parameters to explore the impact of parameter values on the selection results. For the first selection, the parameters l_{TH1} and r are set to 20 m; For the second selection, the parameters l_{TH1} and r are set to 25 m. The results of the first selection are shown in Fig. 7c, and the results of the second selection are shown in Fig. 8. The specific comparison results are shown in the Table 3.

Through the analysis of the viewpoint selection results after adjusting the parameter values, it can be concluded that parameter values are only related to the number of



(a) (b)

Fig. 5 Vector data of the Forbidden City. **a** Courtyard extraction results, **b** Road extraction results

表

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OBJECTID *	SHAPE *	SHAPE_Length	SHAPE_Area
4	面	714.398082	10488.071725
12	面	52.392201	136.339431
13	面	125.222995	869.865539
14	面	289.540021	1121.910068
15	面	114.437009	795.271204
16	面	812.836869	5637.877925
17	面	26.198	34.094047
18	面	788.922059	1912.112951
20	面	477.606149	2645.938478
21	面	126.410611	527.755929
22	面	129.058025	487.279144
23	面	200.413298	523.517618
24	面	133.759967	637.157713
25	面	145.464376	705.33117
26	面	22.733948	17.048034
27	面	227.785828	745.143573
28	面	428.752355	1132.254505
29	面	756.695687	1477.065614
31	面	519.150756	4253.458539
32	面	521.811081	1511.572818
33	面	4432.018879	22082.805639
34	面	369.587913	637.963941
35	面	705.869639	5377.170635
36	面	295.915223	2159.305928
37	面	306.77562	3346.670295
38	面	602.614096	820.356301
39	面	270.146582	1538.131634
40	面	312.372358	2216.194791
41	面	147.958505	1001.425524
42	面	456.12413	1028.284828
43	面	184.456006	507.46534
44	面	200.695536	535.425289

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Fig. 6 Courtyard extraction results

Fig. 7 The results of each stage of viewpoint selection. **a** Skeleton line extraction results, **b** Viewpoint candidate set, **c** Viewpoint selection results

Table 2 List of parameter value of viewpoint selection

Parameter symbols	Parameter values
l_{TH1}	20 m
l_{TH2}	1 m
r	20 m
S_{TH1}	1600 m^2
S_{TH2}	6400 m^2
w_{TH}	2

Fig. 8 The result of the second viewpoint selection method

viewpoints and is independent of the viewpoint position. In other words, the smaller the parameter, the more viewpoints are selected; It can also be considered that the first selection result is an increase in the number of viewpoints without changing the second selection result.

Validation of viewpoint selection results

To validate the accuracy of the viewpoint extraction results, a comparison was made with the viewpoint selection results using the direct selection method. The direct selection method is a significant approach for selecting viewpoints, as mentioned in [34]. Additionally, this

Table 3 List of parameter value of twice viewpoint selection

		Parameter symbols	Parameter values
Parameter value	l_{TH1}	20 m	25 m
	r	20 m	25 m
Number of viewpoints		46	39

method is well-suited for selecting viewpoints in courtyard layout type architectural heritage areas. Therefore, it was deemed appropriate to use this method as a benchmark for comparison.

1. Viewpoint selection using direct selection method

The direct selection method is based on analyzing important landscapes in architectural heritage areas, and directly selects the entrance of important landscapes as the viewpoint position. To apply this method to the Forbidden City, the first step involves identifying the key landscapes. These landscapes encompass the

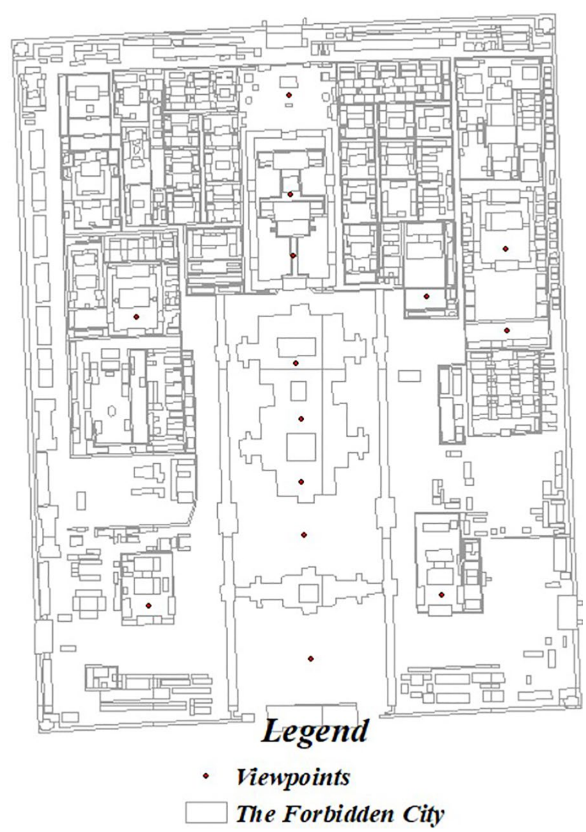

Fig. 9 The result of using direct selection method to select viewpoints

Meridian Gate, Hall of Supreme Harmony, Hall of Central Harmony, Hall of Divine Prowess, Hall of Preserving Harmony, Palace of Heavenly Purity, Palace of Earthly Tranquility, Palace of Tranquil Longevity, Imperial Garden, etc. By directly selecting the entrance positions of these scenic spots as viewpoint positions, a total of 14 viewpoints are established. The result of using direct selection method to select viewpoints is shown in Fig. 9.

2. Viewpoint selection results comparison

Upon analysis, the method proposed in this paper has the following advantages:

(1) The number of viewpoints obtained by this method is 3.5 times that of the direct selection method, covering 43% of the direct selection method's viewpoints. The viewpoints obtained by this method cover the 17 courtyards of the Forbidden City, more than the 12 courtyards covered by the direct selection method. Compared to the direct selection method, the distribution range of viewpoints obtained by this method is wider.

(2) Through an analysis of the viewshed, it can be seen that the viewshed range obtained by this method covers 96% of the Forbidden City architectural heritage area, significantly exceeding the 75% coverage achieved by the direct method. Compared to the directly selection method, this method provides a more comprehensive coverage of the viewpoint range. The viewshed range obtained via the direct selection method is illustrated in Fig. 10a, while the viewshed range derived from this method is shown in Fig. 10b. A comparison of the viewshed ranges obtained by both methods is presented in Fig. 10.

Conclusion

A quantitative a viewpoint selection method based on GIS spatial analysis is proposed. Correspondingly, key support is provided through algorithms for region division, constructing viewpoint candidate sets, and viewpoint selection. An example of viewpoint selection in the Forbidden City area shows that the region division method can accurately extract the spatial location of viewpoints. The viewshed coverage area in the architectural heritage area is as high as 96%. Comparative analysis

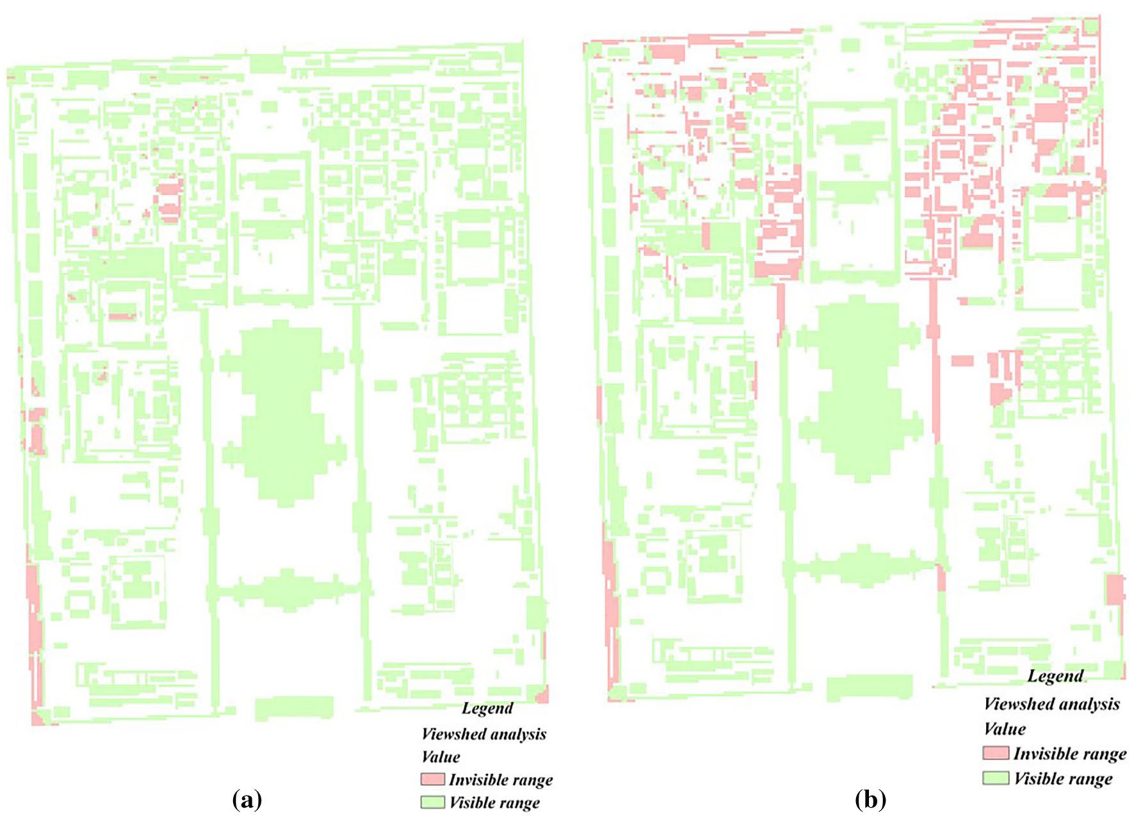

Fig. 10 The range of viewshed obtained by the two methods. **a** The range of viewshed obtained by directly selection method, **b** The range of viewshed obtained by this method

indicates that the viewpoints obtained by this method not onlyexhibit a broader distribution range but also offer a significantly larger viewshed coverage area than the direct selection method. This method only strives to provide a new viewpoint selection method, and this method attempts to achieve minimal human intervention. This method is suitable for researchers who use GIS as a data source and do not have more technical means to use as a reference. In reality, factors such as architectural heritage protection, local conditions, and even policies and weather can limit the application of high-tech solutions in certain heritage areas. Given that GIS data are widely accessible, our method may present new ideas for selecting viewpoints in these architectural heritage areas. Especially, our method highlights the principle of selecting viewpoints based on the characteristics of the building heritage protection. However, this method does have certain limitations, despite our best efforts to maximize the use of computer programs to minimize human intervention. Specifically, it is primarily applicable to architectural heritage with a courtyard layout and further research is required to adapt it to different types of architectural heritage.

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Author contributions
YH conceived the presented idea and put forward experimental suggestions. YF conducted and refined the analysis process and wrote the manuscript. All authors approved the final manuscript.

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Availability of data and materials
All data generated or analyzed during this study are included in this published article.

Declarations

Competing interests
The authors declare that they have no competing interests.

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