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The impact of city walls on urban expansion and structure of small historical cities: a Space Syntax analysis of Zhengding, China

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ABSTRACT

This study employs Space Syntax analysis to examine the urban expansion of Zhengding, a small historical city in northern China. Focusing on the impact of the city walls on urban form, spatial connectivity, and functional distribution, the research analyzes the city's growth at four key stages (1966, 1992, 2008, and 2024). The findings reveal a complex and evolving impact by the city walls, beyond that of a simple constraint. First, the walls mediated a unique "overflow before filled" expansion pattern, where partial demolitions guided expansion outward before the inner city was fully developed. Second, contradicting existing research, the city's Axial Synergy increased over time, revealing the walls' previously unappreciated function as a "stabilizer". Finally, the walls' impact is highly differentiated, creating divergent development logics inside and outside the city, as evidenced by the varying correlation between syntactic measurements and the distribution of commercial POIs. This study offers a refined methodological framework for analyzing the spatial structure of small historical cities and the impact of physical boundaries, providing insights for planning and heritage preservation policy, particularly on balancing development and heritage preservation.

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City walls; Space Syntax; urban expansion; small historical city; Zhengding

1. Introduction

Although city walls in historic cities have lost their defensive functions, they continue to influence urban form and development. This influence is particularly evident in Chinese historic cities, where city walls have been shown to shape the urban landscape (C. Wang et al. 2021) and affect the city's microclimate (Song et al. 2025). Most significantly, these physical boundaries constrain urban expansion (S. Wang et al. 2019) in these cities. Existing research on urban expansion using urban modeling has rarely focused on the impact of city walls. These models are usually built up upon socio-economic (Poelmans and van Rompaey 2010; Q. Zhang and Su 2016); and remote sensing data (Xiao et al. 2006; Z. Zhang et al. 2018), employing mathematical tools (e.g., logistic regression, cellular automata, etc.) to effectively explain past urban expansion and predict future trends (L. Li, Sato, and Zhu 2003; Poelmans and van Rompaey 2010). While they incorporate various driving and constraining forces of urban expansion, including the economy, demographic dynamics, topography, and policies, city walls have rarely been a primary consideration (L. Li, Sato, and Zhu 2003; Poelmans and van Rompaey 2010; Xiao et al. 2006; Q. Zhang and Su 2016). This omission is understandable for two main reasons. First, few contemporary cities still possess intact ancient city walls. Second, in large cities with remaining city walls, such as Xi'an (F. Wang and Gu 2023; X. Wang et al. 2018) and Nanjing (Chen et al. 2016; Qiao et al. 2019; C. Xu et al. 2007), the enclosed area has long been fully developed. The frontier of urban expansion has pushed far beyond these walls, diminishing their role as a significant constraining force and were thus not specifically focused in existing research on these metropolises.

However, in the context of small historic cities in China, city walls deserve particular attention, especially in cases where the built-up area did not fully occupy the space enclosed by the walls before the dramatic urban expansion in the latter half of the 20th century (Angel et al. 2011; S. Zhao et al. 2015). During this period, these small cities' built-up areas first gradually grew to fill the area enclosed by the city walls at a relatively slow pace and then overflowed through openings in the walls. The interaction between urban expansion and the physical boundary of the walls in this "fill-and-overflow" process has not yet been fully observed or described. Moreover, with a growing awareness of the value of built heritage and the rapid growth of heritage tourism, city walls in these small cities are increasingly being preserved or even reconstructed (Xie and Gu 2011; Z. Zhang, Yang, and Zhao 2003; Zhen et al. 2025). In this context, the key

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question remains unaddressed: how do city walls impact current and future urban expansion in these small cities? Therefore, understanding this unique interaction process is not merely an academic investigation, but also holds significant practical value for sustainable urban planning and heritage conservation in small Chinese historic cities currently undergoing similar transformations.

The traditional Conzenian school of urban morphology offers methods to investigate these questions. This school introduced the concept of the "fixation line" and the "fringe belt" approach to examine the dynamics related to physical boundaries during urban expansion (M. R. G. Conzen 1960). These concepts have been applied to small Chinese historic cities like Pingyao, revealing the unique urban fabric adjacent to city walls and its morphological evolution in history (M. P. Conzen, Gu, and Whitehand 2012; Whitehand and Gu 2017; Whitehand, Gu, and Susan 2011). However, such studies rely primarily on graphical and descriptive analyses and are therefore limited in their ability to explore how city walls impact spatial connectivity, traffic movement, and spatial functional patterns. A deeper analysis of these impacts therefore requires more precise spatial analysis tools.

Space Syntax, an analytical method based on spatial connectivity, is especially suitable for examining the urban expansion in small historic cities and the impact of city walls on spatial structures in this process. It can accurately describe the complexity of urban spatial configurations with physical boundaries, clearly identifying how these elements influence potential human movement, and quantitatively assessing aspects such as urban accessibility and connectivity (Hillier 1996; Hillier and Hanson 1984; van Nes and Yamu 2021). The method has been applied to reveal how spatial configurations evolved during urban expansion and how they influenced socioeconomic aspects, including pedestrian movements (Atakara and Allahmoradi 2021), commercial activities (Mara et al. 2024), tourist flows (Y. Li et al. 2016), and general urban dynamics (Chen 2022; Xia et al. 2019). Recent research on Chinese cases has demonstrated its effectiveness in describing how topography and water bodies have shaped urban street networks during their historical expansion (Huang, Shi, et al. 2025). When combined with other tools like GIS, Space Syntax can further examine the influence of urban expansion on the distribution and evolution of urban functions (Huang, Huang, et al. 2025). On a smaller scale, the Space Syntax measurements can facilitate specific analyses of the interaction between the urban water system and urban gardens (Yun and Liu 2023). The structural characteristics and evolution patterns revealed by Space Syntax can also inform and support contemporary urban planning and design practices, especially for urban regeneration and revitalization (Lyu et al. 2023; Yunitsyna, Shtepani, and Hasa 2024). Beyond analyzing different temporal cross-sections of a single city, Space Syntax can also be used to compare similar cities to identify more universal mechanisms in urban structure and expansion. For instance, van Nes (2021b) compared multiple cities in the UK and Germany to examine the influence of ring roads on the urban street network and commercial locations based on Space Syntax analysis. Similarly, Ge, Hou, and Xiao (2023) applied Space Syntax to different historical stages of 21 city centers in the UK, analyzing the effectiveness of various urban regeneration models in pedestrianizing the city centers.

This research applies Space Syntax approaches to Zhengding (正定), a small historic city in northern China (Figure 1). The city's urban evolution has been closely related to its city walls (Q. Liu 2024; Z. Liu, Ren, and Xie 2014; Ni 2016) and witnessed a typical "fill-and-overflow" process in the latter half of the 20th century. The objective is to examine this "fill-and-overflow" expansion in detail to achieve three goals: 1) to identify changes in the city's spatial structure at different stages; 2) to reveal how the city walls impacted these changes; and 3) to understand how this impact differed over time.

Specifically, this research selects four key stages in Zhengding's urban expansion and applies Space Syntax to analyze urban connectivity, Integration, and potential for human movement during the city's "fill-and-overflow" expansion. In addition, Points of Interest (POI) analysis (M Wang et al. 2021; L. Xu et al. 2024) is conducted to complement the Space Syntax analysis and provide a deeper understanding of the impact of city walls on the urban functions and activities.

2. Methods

This study adopts a comprehensive, three-step method. First, preliminary mapping and statistical analysis are conducted to observe the expansion of the urban built-up area in Zhengding. Then, space syntax methods are applied to analyze the spatial structure of the city in selected years through the syntactic measurements, both inside and outside the city walls, to identify the impact of the walls on the spatial structure. Finally, a POI analysis is used to assess the distribution of functions and activities under the impact of the city walls, complementing the space syntax analysis.

The analysis process is illustrated in Figure 2. This section will provide a detailed explanation of the specific methods, materials, and tools used in each step.

2.1. *Case study and materials: the walled city of Zhengding*

The walled city of Zhengding is an ideal case for this study's objectives. First, its urban evolution has been closely related to its city walls and witnessed a typical

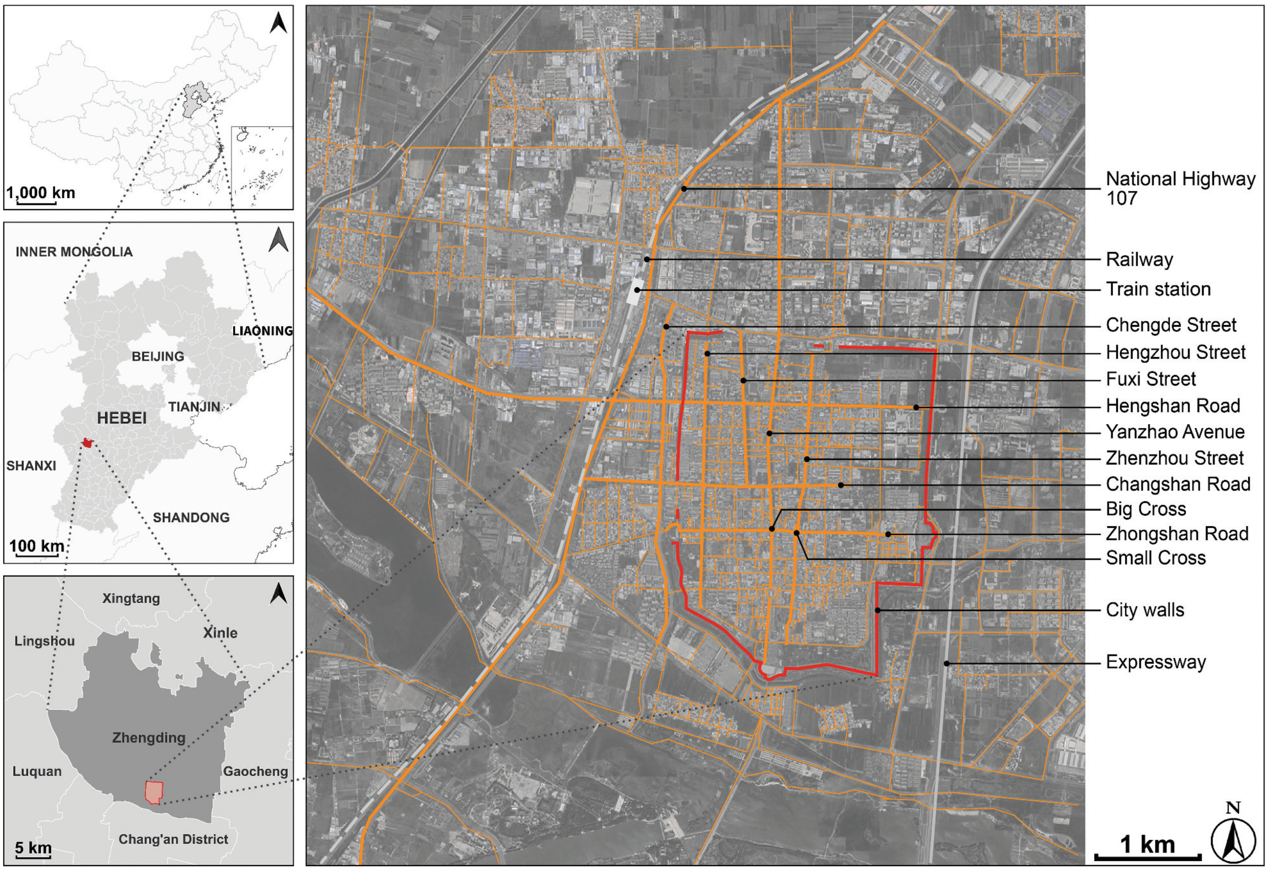

Figure 1. The location of Zhengding and its main urban elements in 2024. Source: the authors, based on orthophotos from Google Earth, 2024.

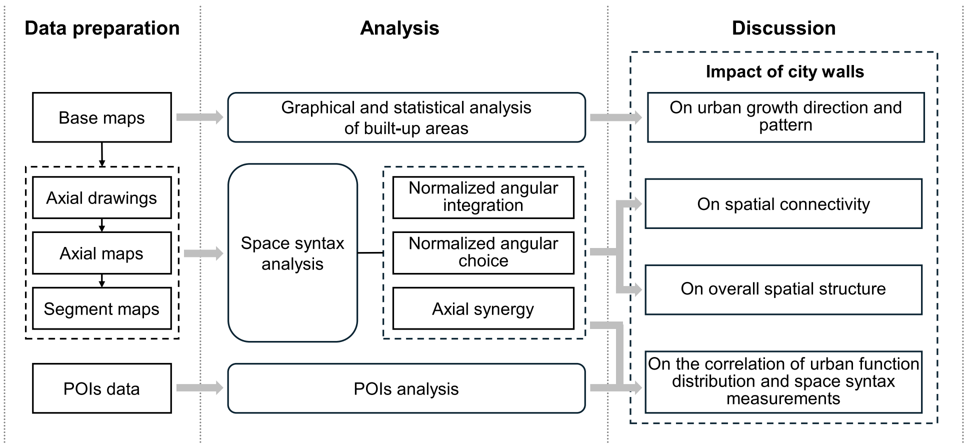

Figure 2. Analysis process of this paper. Source: the authors, 2024.

"fill-and-overflow" process in the latter half of the 20th century. Second, situated in the vast Huabei Plain in northern China, the city does not face significant topographical constraints on its expansion, allowing its evolution to better highlight the potential impact of city walls as a constraining force. The city was initially established as a military fortress in the 4th century and later evolved into a prominent regional center for both military and trade activities. The walled enclosure was expanded in the 8th and 15th centuries to encompass the area we see today (X. Zhao 2017).

The city walls and the major avenues together define the city's basic structure. The walls are approximately 12 kilometers in circumference, 10 meters high, and 7 meters thick. They were constructed from tamped earth and encased in large gray bricks (Y. Liu and Yu 2020). As shown in Figure 1, the walls' outline is roughly rectangular in the north with indented the southern corners. Four city gates are located on the east, west, north, and south sides. The positions of the east and west city gates align precisely and are connected by the east-west main avenue (now named

Zhongshan Road, see Figure 1); the north and south gates are offset and connected to the city center by two main north-south avenues (now named Yanzhao Avenue and Zhenzhou Street, respectively, see Figure 1). These three main avenues constitute the primary urban axes, which generally follow orthogonal directions. The three axes intersect at two crossroads in the city center, locally called the “Big Cross” and “Small Cross”, which have acted as the city center for centuries (Figure 1).

Zhengding’s city walls were partly demolished or collapsed during the industrialization and urbanization after the founding of the People’s Republic of China (PRC), when the walls lost their defensive functions and were left unmaintained. However, in 2013, the walls received special protection and restoration efforts after being listed as a “national priority protected site” by the State Council of PRC, and no further collapse or demolition has occurred since then. The municipal government initiated a large-scale restoration project on the walls that year, both for the purpose of heritage preservation and, more importantly, to establish them as an urban landmark to promote tourism (C. Xu 2018).

The city’s built-up area has never fully occupied the walled enclosure. It lost its status as a regional center in the early 20th century, resulting in the dramatic shrinkage of the built-up area. Nowadays, even though the built-up area has already pushed beyond the city walls, there are still some areas that are left vacant or used as farmland within the city walls (Q. Liu 2024).

This study selects four years, 1966, 1992, 2008, and 2024, as key temporal cross-sections to investigate the “fill-and-overflow” expansion process of Zhengding since the mid-20th century and the impact of the city walls in this process. These selections reflect both Zhengding’s urban development and, of course, the broader economic and urbanization trends across China. Each of these years marks a critical stage:

(1) 1966: This year marks a key point in the early urban expansion of Zhengding. It reflects the results of the intense post-war recovery and early socialist industrialization after the founding of the PRC. It is also the last year before the complete stagnation of urbanization during the decade of the Cultural Revolution (Gao 2005). The base map used for 1966 in this paper comes from orthophotos in the database of the United States Geographic Survey (USGS) (Earth Resources Observation and Science (EROS) Center). To correct for potential distortion in this old data source, necessary georeferencing was conducted using QGIS.
(2) 1992: This year reflects the achievements of urban construction during the first decade of China’s economic reform initiated in 1978. It also marks the final year before the Chinese society entered the era of rapid economic growth and urbanization symbolized by the “socialist market economy.” For Zhengding, the urban situation in 1992 also reflects construction driven by a tourism boom in the late 1980s. The 1992 base map used in this paper comes from the “Zhengding Gazetteer 1992” (Zhengding gazetteer editorial board 1992). Similarly, georeferencing was conducted to eliminate any potential distortions.
(3) 2008: This year marks the 30th anniversary of China’s economic reform. Additionally, it is also the last year before the “Three-Year Makeover”[1] policy accelerated Zhengding’s urbanization. The base map used for 2008 comes from the orthophotos available on Google Earth (Google LLC).
(4) 2024: This is the year of this study. After experiencing significant development during the “Three-Year Makeover” and the urban tourism initiatives starting in 2013, Zhengding’s built-up area has expanded dramatically once again. The base map used for 2024 also comes from the orthophotos available on Google Earth (Google LLC).

Using these base maps, this study first maps the built-up area of Zhengding in the four selected years in AutoCAD and provides a brief statistical analysis of the area inside and outside the city walls. When mapping the built-up area, villages surrounding the city walls but not directly connected to the central built-up areas were excluded, because they cannot be considered part of the urban built-up area in terms of spatial perception and resident activities. Some of these villages were later incorporated into the urban built-up area during the expansions in 2008 and 2024.

2.2. Space Syntax analysis

Space Syntax, introduced by Hillier and Hanson (1984), provides a powerful framework for analyzing spatial configurations and their influence on movement patterns, accessibility, and socio-economic activity. Utilizing tools like axial and segment maps, alongside measures such as Integration and Choice, it offers quantitative insights into the interplay between spatial arrangements and urban dynamics (Bafna 2003; Hillier and Hanson 1984). This methodology has been widely applied to study the expansion and transformation of

[1]In Chinese: “三年大变样”. This is the key word in the policy document “Several Opinions on Accelerating the Urbanization Process,” issued by the Hebei Provincial Government on December 10, 2007. This policy aimed to accelerate the urbanization process across the province. In the subsequent years, cities in Hebei Province initiated large-scale demolition of old buildings, development of new constructions, and urban expansion.

historic cities (Atakara and Allahmoradi 2021; Chen 2022; Mara et al. 2024; Xia et al. 2019).

2.2.1. Syntactic measurements

Space Syntax theory has developed various analysis modes and syntactic measurements. This study employs both Axial Analysis and Angular Segment Analysis modes to examine the spatial configuration of Zhengding. Axial Analysis, is the most traditional and widely applied analysis mode in Space Syntax (Meng and Zhang 2024). It represents the street network with axial maps (Hillier and Hanson 1984), where the calculation is performed on each axial line. Angular Segment Analysis is a relatively new mode that breaks the axial lines representing the street network at intersections into segments and incorporates segment length and angular weighting between segments into the calculation (Turner 2004; Ratti 2005). It more precisely captures the detailed variations in urban spatial structure, and therefore has been increasingly adopted in recent research (Meng and Zhang 2024).

Both Axial Analysis and Angular Segment Analysis yield various syntactic measurements, each describing different urban spatial features. Several measurements are selected in this research according to the research objectives, as detailed below:

In the Angular Segment Analysis mode:

- Normalized Angular Integration (NAIN): This is the normalized value of Angular Integration that measures how close each segment is to all others based on the sum of angular changes made on each route (Hillier and Iida 2005). It indicates the potential for "to-movement" within the system. The normalized value, NAIN, allows for better comparison across different systems (Hillier, Yang, and Turner 2012). This study uses global (R-n) NAIN to assess the overall accessibility of road segments throughout the city, both inside and outside the Zhengding city walls, which is a commonly approach for analyzing the overall structure of a city (Djenaihi et al. 2021; van Nes 2021a; Şahin Körmeçli 2023).
- Normalized Angular Choice (NACH): This is the normalized value of Angular Choice that is calculated by counting the number of times each street segment falls on the shortest path between all pairs of segments. It indicates the "through-movement" potential. The normalization of Angular Choice solves its paradox whereby segregated designs can yield higher values than integrated ones (Hillier and Iida 2005). Consequently, NACH is more effective and comparable across systems. This study uses global (R-n) NACH to examine the importance of road segments in terms of road network interconnections in the whole city, both inside and outside the city walls. Road segments with higher NACH are more important for traffic movement within the system (van Nes and Yamu 2021).

And, in Axial Analysis mode:

- Axial Synergy (AS): Axial Synergy measures the degree to which the internal structure of an area relates to the larger-scale system in which it is embedded (Hillier 1996). It is defined as the correlation between radius-3 and radius-n Integration in Axial Analysis. This study uses AS to examine whether the built-up areas inside and outside the Zhengding city walls are well integrated into the overall urban spatial structure. The stronger the AS in a given area, the better that area is integrated into the city's overall structure, exhibiting fewer structural distinctions from its surroundings (Chakraborty and Dey 2024).

2.2.2. Steps and tools of Space Syntax analysis

The Space Syntax analysis is carried out in two major phases: base map preparation and the calculation of syntactic measurements. The phases and steps are detailed below:

First, base map preparation:

(a) Mapping the street network from basemaps: Using AutoCAD, the road axes in the four years are mapped from their respective base maps. Prior to this, georeferencing is conducted in QGIS on the basemaps, particularly those from 1966 and 1992, to eliminate any potential distortions. Several types of inaccessible roads are excluded from the network: pathways that are too narrow for vehicular movement; internal roads that are not open to the general public; lanes within parks or greenways; and roads that are not open throughout the day, such as those within markets that are only accessible during operating hours.
(b) Generating axial and segment maps: The street network drawings are then imported into depthMapX (an open-source tool originally developed by the Space Syntax Laboratory from UCL (depthmapX development team 2020)), where they are converted into axial maps and then segment maps that can be directly used for Space Syntax calculations.

Second, the calculation of syntactic measurements:

(a) Angular Segment Analysis calculations: In depthMapX, the segment maps generated in the previous step are used to calculate the NACH and NAIN values with the custom attribute column function. The results are then represented on the segment maps using a color scale.

(b) Axial Analysis calculations: In depthMapX, the axial maps generated in the previous step are used to calculate the radius-3 and radius-n axial Integration values of each axis. The Integration value dataset and the axial map are then imported into QGIS (an open-source geographical information system tool (QGIS.org 2023)), where the data for each year is divided into two subsets: one inside the walls and one outside. Finally, open-source Python libraries (Pandas, SciPy, Matplotlib) are used for correlation analysis on the divided datasets to calculate the AS values of the built-up areas inside and outside the walls in each year and present the results in scatter plots.

2.2.3. Study areas selected for different measurements

This study selects a rectangular study area approximately 7.5 km wide and 8.3 km long (Figure 1), which encompasses all built-up areas inside and outside the Zhengding city walls in 2024. This area also covers the built-up areas in 1966, 1992, and 2008, as these were all smaller than the 2024 built-up area.

For analyzing NAIN and NACH, all axial lines or segments within the study area are included in the calculation. Although the built-up area is much smaller than the overall study area, every axial line or segment from outside the built-up boundaries influences the overall NAIN or NACH values. In the real world, these roads indeed affect movement and activities, making it necessary to include them in the analysis. Furthermore, maintaining the same geographical range ensures comparability across the four selected years, which is a common practice in similar existing studies (Ge, Hou, and Xiao 2023; Y. Li et al. 2016; van Nes 2021b).

When examining AS, only the axial lines within the built-up areas (both inside and outside the city walls) are included, rather than all axial lines within the aforementioned rectangular study area. This aligns with the purpose of this measurement. AS is used to analyze the relationship between specific areas and the overall city, and using this measurement indiscriminately for the entire study area or for non-built-up areas is not meaningful.

2.3. GIS-based POIs analysis

This study employs Points of Interest (POIs) analysis to extend the investigation of the walled city from spatial configurations to functional dimensions, specifically examining the impact of city walls on the aggregation of urban functions and activities. POIs represent geographic entities such as schools, shops, and restaurants, etc., offering precise data on names, coordinates, and attributes (M. C. Wang et al. 2021). POIs accurately reflect and predict the relationship between human activities and urban functions and spatial environments (Zhai et al. 2019). They have been utilized to identify functional areas, delineate urban aggregations, and plan tourism routes, highlighting their potential in mapping tourist preferences and optimizing facility layouts (Han, Jiao, and Xu 2017; Pop, Coros, and Balint 2017; Wu et al. 2014).

Existing studies indicate that NAIN values are correlated with the aggregation of urban POIs and related daily activities. Streets and roads with high levels of “to-movement” potential tend to have retail shops located along them (Hillier 1999; Larraz and García-Gómez 2020; van Nes 2021b; Y. Xu et al. 2020). However, it remains unclear whether this correlation persists in the presence of city walls. If not, to what extent do city walls distort this correlation between urban activities and spatial syntax measurements? This study uses POI analysis to address these questions.

Furthermore, as Zhengding continues to expand, some newly constructed roads appearing on the 2024 maps may exhibit high NAIN values, despite the absence of POIs along them. POI analysis thus serves as a critical validation tool to identify potential mismatches between syntactic predictions and actual patterns of daily activity aggregation.

The POI data in this study was collected from amap.com,[2] and then visualized as heatmap in QGIS based on kernel density estimation. POIs for several types of retail stores and restaurants in 2024 were selected as the primary focus, as they most directly reflect residents’ everyday activities.

3. Analysis and discussion

3.1. Understanding the general urban expansion

3.1.1. Analysis and results

Figure 3 shows the built-up areas and the city walls in the four selected years. Table 1 presents a statistical analysis of the built-up area for each year, including the respective areas inside and outside the city walls, as well as the ratio of the built-up area inside the city walls to the total land area within the walls. This figure and table clearly demonstrate that the total built-up area of Zhengding has continuously expanded over the past six decades, increasing from 3.4 km^2 in 1966 by over seven times to 27.9 km^2 in 2024. During this period, the built-up area inside the walls tripled, and the area outside grew over 20 times.

In 1966, following post-war reconstruction and initial socialist industrialization, urban expansion inside

[2]In Chinese: 高德地图. Amap.com is the most popular web mapping service in mainland China, developed by AutoNavi Software Co., Ltd.

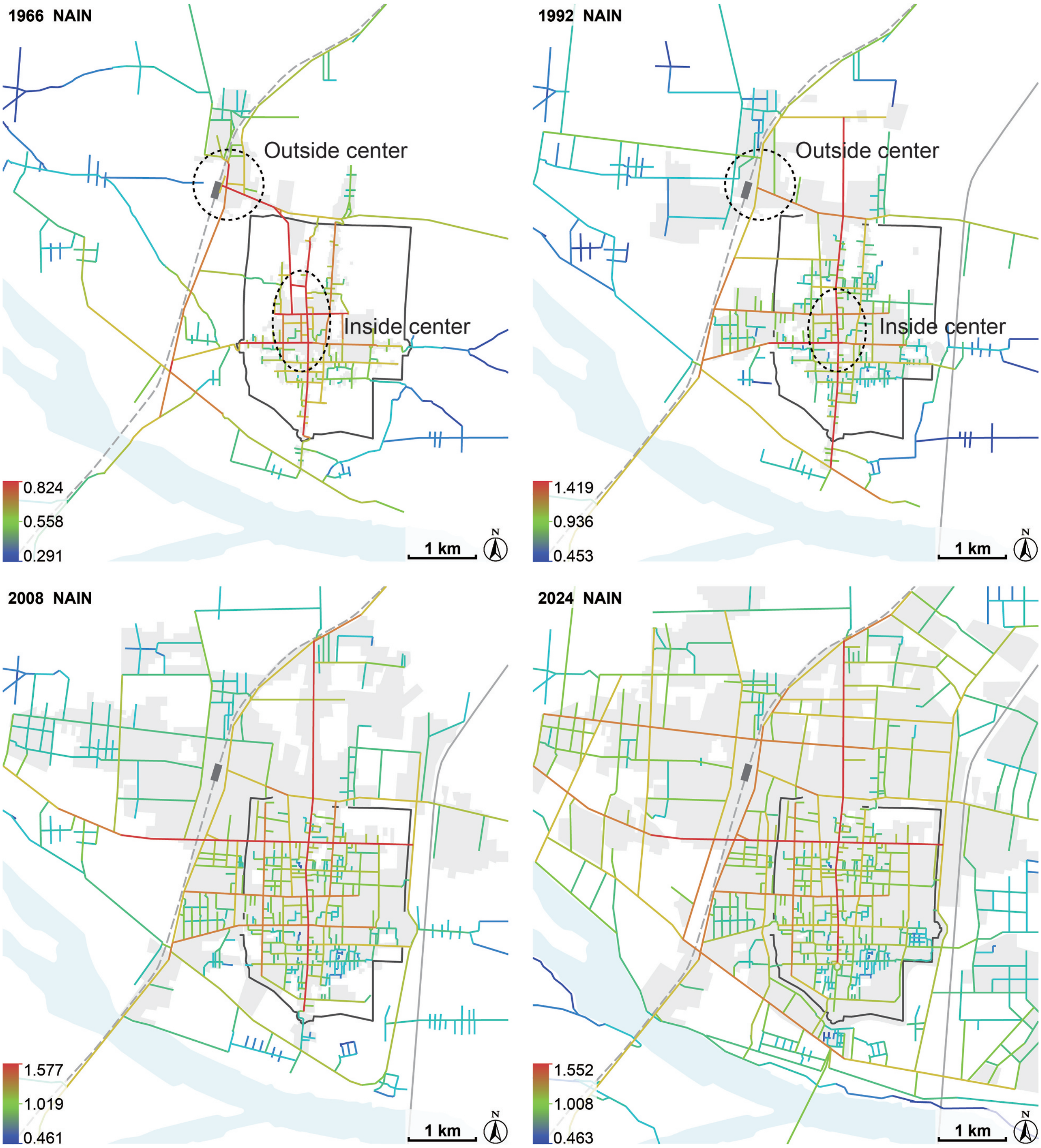

Figure 3. The results of NAIN analysis on Zhengding in 1966, 1992, 2008, and 2024, with the built-up area illustrated with gray in the background. Source: the authors, 2024.

Table 1. The built-up areas inside and outside the city walls in Zhengding, and the ratio of the built-up area inside the city walls relative to the total land area within the walls.

	Inside built-up areas			
Year	Area (km^2)	Built-up ratio	Outside built-up areas (km^2)	Total built-up areas (km^2)
1966	2.10	30.4%	1.27	3.37
1992	2.96	43.0%	3.67	6.64
2008	5.59	81.1%	13.34	18.94
2024	6.53	94.7%	21.39	27.93

the city walls was still centered on the main historical axes formed by several main roads, but it was far from filling the entire enclosure, with a "built-up ratio" of only about 30%. Subsequently, during periods of social turmoil such as the Great Leap Forward and the Cultural Revolution, Zhengding's expansion almost completely stopped, as was the case for many other Chinese cities, until the economic reforms that started at the end of 1978 marked a new phase of urban expansion. More than a decade later, by 1992, Zhengding's built-up area had expanded significantly compared to 1966. The most significant change was the partial demolition of the northern and western sections of the city walls, which allowed the built-up area within the walls to extensively "overflow" and directed the primary directions for subsequent urban expansion to the west and north. Following this, the rapid economic growth brought by the "socialist market economy" reforms further accelerated the city's expansion. By 2008, the built-up area inside the walls had filled over 80% of the enclosure, while the outside built-up area was more than twice the size of that inside. In the following decade, urban policies such as the "Three-Year Makeover" and the urban tourism initiatives continued to drive expansion. By 2024, the area outside the walls constituted the majority of the city's total built-up area. However, although the built-up area inside the walls in 2024 was more than three times its size in 1966, the enclosure was still not completely filled, with a built-up ratio of about 94%, leaving some areas vacant or in use as farmland.

In the maps from 1966 and 1992, a dual-center pattern is observable in Zhengding's built-up area, with the historical "Big Cross" and "Small Cross" as one center and the train station in the northwest outside the city as the other. Between these two years, the expansion inside the city walls mainly occurred along several axial roads, with almost no significant growth in the four corners. Later, from 1992 to 2008, the northwest corner inside the city walls was gradually filled and merged with the areas of growth outside the city walls to the west. From 2008 to 2024, the built-up area in the northern part outside the city walls saw the most significant growth, further driving the overall expansion of the city. Meanwhile, the northeast and southeast corners inside the city walls still remain undeveloped.

3.1.2 Discussion

Zhengding's expansion in the late 20th century presents a complete, quantifiable, and diachronic case study of the "fill-and-overflow" process. However, Zhengding's "fill-and-overflow" process also exhibits distinctive characteristics. While the city walls clearly acted as a typical fixation line, the fact that the area within this line was never completely filled, even after extensive overflows, differs from existing observations of fixation lines in other walled cities studied within the Conzenian framework, such as Alnwick, Como, Pingyao, and Nanjing (M. R. G. Conzen 1960; M. P. Conzen, Gu, and Whitehand 2012; Whitehand and Gu 2017). The expansion process after 1992 suggests that the primary reason for this difference lies in the preservation status of the city walls, which were breached early on, before large-scale overflow, yet were never entirely removed. With the partial demolition of the walls, urban expansion overflowed smoothly to the west and north, leaving several corners inside the walls behind. This contrast between Zhengding and other cases demonstrates not only the constraining effect of the city walls but also the potential effects of partially breaking through them. It suggests that once urban expansion finds an opportunity to overflow through the walls, the constraining effect of the remaining sections, particularly those far from the breaches, becomes even more pronounced. Thus, Zhengding's city walls, characterized by partial demolition, the preservation of other sections, and the "overflow before filled" phenomenon, offer a unique case study for urban morphology research.

This dynamic is further illustrated by the formation and dissolution of the "dual-center" structure, which also reflects the constraining effect of the city walls. The outside center was initially established around the train station, which was built in the 1920s as a hub for trade and transportation and attracted numerous buildings and facilities. This phenomenon of transport-led urban expansion is well-documented in the literature (Bertolini 2008; Long, Zheng, and Song 2018). However, the formation of this dual-center structure resulted from the physical disconnection between the train station and the old city center imposed by the city walls. Later, as the walls' constraints were partially removed, the breaches in the wall surpassed the train station to become the new and strongest guiding force for expansion. Between 1992 and 2008, roads cutting through the western and northern walls were extended, enhancing their traffic capacity and promoting further expansion in these directions, rather than centering on the train station. Meanwhile, the railway line running west of the city walls became a new "fixation line" constraining urban expansion. Its blocking effect was most evident between 2008 and 2024, during which it noticeably constrained further expansion towards the southwest.

In contrast, the eastern half of the city walls remained relatively intact and, together with the expressway to the east, constrained the city's eastward expansion, resulting in little direct spatial connection between the inside and outside. The southeastern and northeastern corners inside the walls were most affected by this constraining and disconnecting impact. The northeastern corner, isolated by the city walls and far from major tourist attractions, remained farmland until 2024. In the southeastern corner, although there was some expansion between 2008 and 2024, it was mainly driven by the policy agendas of tourism development, as this area contains key historical sites along Yanzhao Avenue and Zhongshan Road. Consequently, the southeastern corner was mainly transformed into large parks, greenways, and recreational facilities serving tourists rather than being developed into buildings.

3.2. Syntactic measurements in and out of the city walls

3.2.1. Analysis and results on NAIN and NACH

Figure 3 shows the results of the NAIN analysis for Zhengding. Notably, in 1966, segments in the northern part inside the city walls generally had higher Integration values than those in the southern part. Outside the city walls, the roads connecting the train station to the area inside the walls, along with the north-south national road in front of the train station, constituted a second center of high Integration. This outside center corresponds to the previously mentioned dual-center pattern of the built-up area. By 1992, the northward extension of Yanzhao Avenue gave it Integration values surpassing most other segments. As a result, the east-west roads crossing the city walls and intersecting this north-south axis also saw significant increases in their Integration values. At the same time, the Integration values of the roads outside the city walls and connecting the train station experienced a noticeable decline.

By 2008, the center of Integration had shifted further west and north, primarily due to the significant extension of Hengshan Road and the subsequent increase in its Integration value, which strengthened the connection between the areas inside and outside the walls. Meanwhile, Hengzhou Street, newly built in the western area inside the city walls, connected several east-west roads and also exhibited high Integration values. By 2024, the center of urban Integration had shifted even further north, primarily due to the continued improvement of the road network in the northern part outside the city walls, enhancing overall spatial connectivity. At the same time, the Integration value of National Highway 107 to the west outside the city walls, which connects two highly integrated east-west axes, saw a significant increase.

Figure 4 shows the results of the NACH analysis. In 1966, Yanzhao Avenue and Fuxi Street had very high Choice values, because they together formed the route connecting the two centers of the built-up area at the time, namely the train station and the "Big Cross". Additionally, National Highway 107, running parallel to the railway on the west outside the city walls, also exhibited very high Choice values. Overall, a dual-center pattern was observed, similar to that found in the NAIN and the built-up area analyses. By 1992, the "Big Cross" became the only noticeable core of Choice, and the roads connecting to the four city gates from here had noticeably higher Choice values than other roads, while the Choice values around the train station dropped significantly.

From 1992 to 2008, the center of Choice shifted north. This shift was primarily caused by the substantial extension of Hengshan Road, which became a new high-Choice axis. Meanwhile, the Choice values of the roads near the train station continued to decline. From 2008 to 2024, the center of Choice shifted further north as the Choice values of the road network in the northern part outside the city walls increased. Moreover, the Choice values of the roads in the south outside the city walls rose significantly due to new tourism-driven development.

3.2.2. Discussion on NAIN and NACH

NAIN (Normalized Angular Integration) and NACH (Normalized Angular Choice) are key measurements used to describe the accessibility and permeability of each segment in urban networks. Higher Integration values normally indicate that the area is more accessible and central to the city; higher Choice values indicate that the segment is a major route carrying more traffic flow (van Nes and Yamu 2021). The normalized Integration and Choice values are suitable for comparisons across different years (Ge, Hou, and Xiao 2023).

In 1966 and 1992, both NAIN and NACH analyses revealed a distinct dual-center structure, which, as previously discussed, was a clear manifestation of the city walls' disconnecting effect. In 1966, when the city walls were intact, the results showed two separate centers of high NAIN and NACH inside and outside the walls. The outside center, namely the train station area, stood out in the entire spatial structure at that time. This prominence stemmed from the constraining and disconnecting impact of the intact city walls, which rendered the area near the train station syntactically more accessible and convenient for traffic compared to the roads inside the city.

However, after 1992, the overall patterns of NAIN and NACH became significantly more dispersed. The structure shifted from distinct, cluster-like centers to a configuration centered on several linear arteries that breached the walls and connected the inside and outside. Notably, major roads that were newly extended after the partial demolition of the northern and western walls exhibited the highest NAIN and NACH values in the entire urban network, such as Yanzhao Avenue extended north by 1992 and Hengshan Road extended to connect the east and west by 2008. This dramatic transition from a structure defined by the walls' constraint to one defined by breaches in the walls highlights both the walls' initial constraining power and the profound impact of breaching them.

This contrast between constraint and breach is further evident in the disparity between the eastern and western halves inside the walls: NAIN and NACH

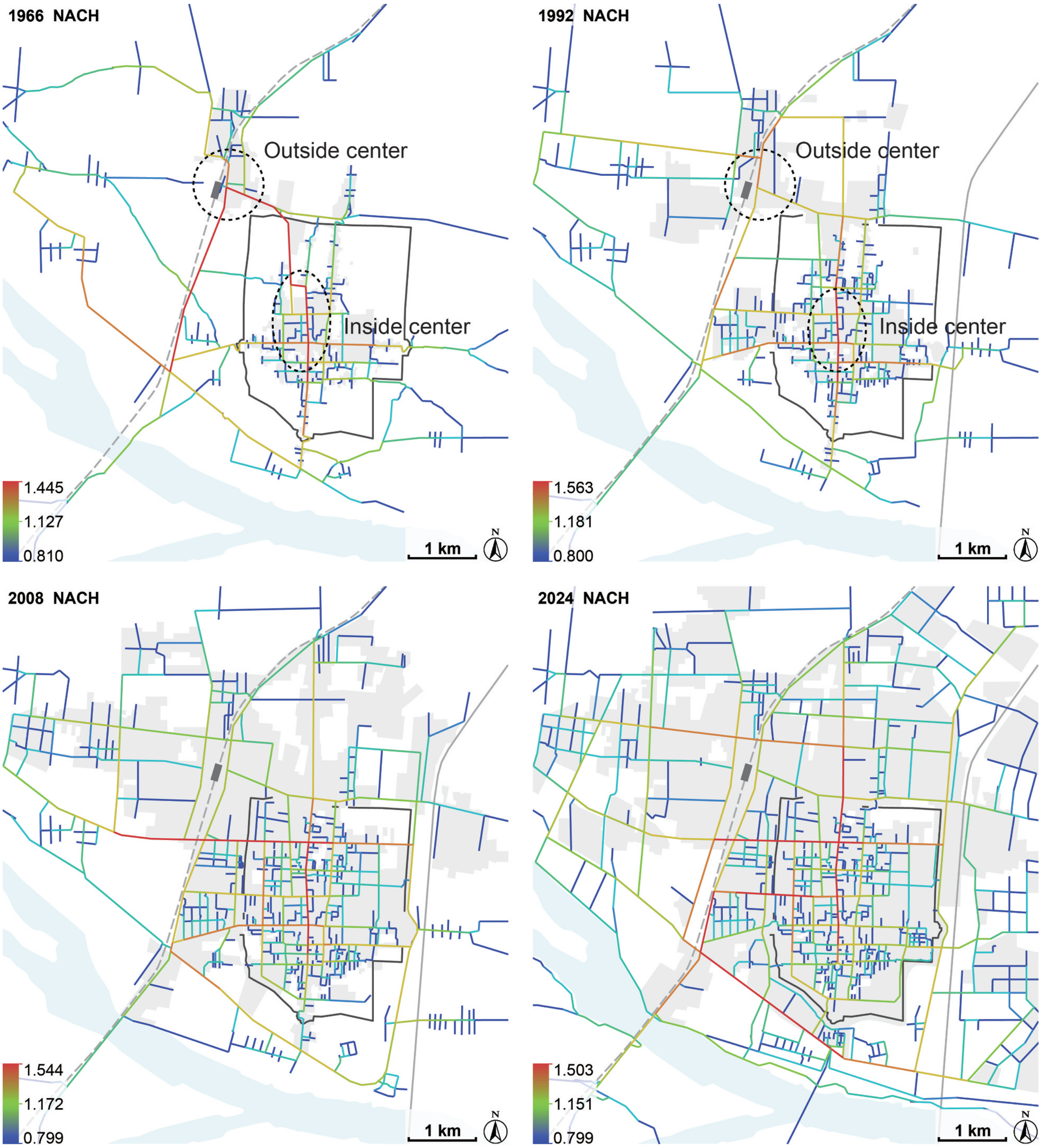

Figure 4. The results of NACH analysis on Zhengding in 1966, 1992, 2008, and 2024, with the built-up area illustrated with gray in the background. Source: the authors, 2024.

values in the western half are notably higher than those in the east. This disparity can be attributed to the greater number of openings in the western semicircle of the city walls, where many sections were demolished or collapsed. In contrast, the eastern half of the city walls remained largely intact with fewer openings, resulting in weaker connections between the inside and outside. Particularly, the southeast and northeast corners have consistently been the “lowlands” in terms of NAIN and NACH values, manifesting the persistent constraining and disconnecting impact of the walls in those locations. Nevertheless, the western half also manifests the constraining effect of the city walls in its corners despite the overall higher NAIN and NACH values. The NAIN values in the northwestern corner are relatively high, but its NACH values are lower than the neighboring areas, indicating that while the area is accessible, it experiences less through-traffic as a result of the relatively intact city walls at this corner.

The significant decline of the train station’s centrality was a direct consequence of this structural shift. By 1992, as parts of the western and northern city walls were demolished and multiple roads were extended through them, the connection between the inside and outside was greatly strengthened. As a result, the syntactic core of the city, in terms of both NAIN and NACH, shifted back inside the city walls, surpassing the syntactic advantages of the area around the train station.

Beyond these historical shifts, the formation of a new NAIN and NACH "hollow" near the South Gate between 2008 and 2024 demonstrates a new and more complex impact of the walls when they are intertwined with tourism-oriented policies. Tourism development projects, which centered on the South Gate as a hub for tourist attractions, reorganized the traffic flow around it, leading to a series of changes. On the one hand, the NAIN values decreased in the immediate vicinity of the gate, which would seemingly hinder tourist accessibility. On the other hand, the NACH values rose significantly in the roads approaching the South Gate area from outside the walls and along the southern section of Yanzhao Avenue, indicating their crucial role as corridors for channeling tourists to the periphery of the area. The corresponding decrease in NACH values within the area indicates a reduction in through-traffic within the gate area. All these changes suggest that the South Gate area is becoming an independent urban unit segregated from the surrounding city context: tourists can easily reach its periphery, while circulation within it operates as a self-contained system. This finding corroborates previous research on the impact of tourism development on Zhengding's urban structure (Q. Liu and Pezzetti 2022a, 2022b). Here, the roles of the city walls and the gate have transformed significantly. They are no longer a constraining factor but have become the core element of a touristic "city-within-a-city", which, together with tourism policies, exerts a new and complex impact on the surrounding urban area.

3.2.3. Analysis and results on AS

AS (Axial Synergy) is measured by the correlation between the local and global Integration of a specific urban area, typically quantified using the coefficient of determination R^2 (Hillier 1996). This measurement describes how well a given area is integrated into and synergizes with the overall spatial structure of the city. Specifically, an R^2 value lower than 0.5 indicates poor synergy, and a value greater than 0.7 suggests strong synergy between the area in question and the city's overall spatial structure (X. Li et al. 2017; Lyu et al. 2023).

This study calculates the Axial Synergy of the built-up areas inside and outside the city walls respectively, and their changes over the four years, which are illustrated in Figure 5 and Table 2. These figures show that the R^2 of the built-up area inside the city walls has consistently remained relatively high between 0.5 and 0.7, indicating that the built-up area inside the city walls has maintained a good Synergy with the overall built-up area. This suggests that the built-up area inside the city walls has been a well-integrated unit in the spatial structure, and decades of urban growth did not alter this status. Nevertheless, from 2008 to 2024, the inside R^2 value slightly decreased, suggesting that the intense expansion of the built-up area outside the walls may lead to a potential fragmentation between the inner and outer city areas in the future, although this tendency requires further observation.

In contrast, the R^2 value of the built-up area outside the city walls was only 0.074 in 1966, showing an extremely poor synergy. This indicates that the outside built-up area was almost an independent spatial unit, not well-integrated into the overall spatial structure. Between 1966 and 1992, the outside R^2 value rapidly rose above 0.5, signifying that the outside built-up area started to synergize with the overall spatial structure of the city. Since then, the outside R^2 value has continued to increase, but at a much slower rate.

3.2.4. Discussion on AS

The trend of Axial Synergy (AS) in Zhengding, both inside and outside the city walls, contrasts with findings from existing research. Previous studies have found that, as city size increases, the urban network tends to get more fragmented and the relationship between local areas and the global structure become less synergistic, leading to a decrease in the overall AS (Dalton 2011; Huang, Shi, et al. 2025). In Zhengding, however, the AS values for areas both inside and outside the walls increased significantly between 1966 and 2008, particularly for the outside area. This indicates that as Zhengding expanded, the relationship between its local parts and the overall urban structure became more, not less, coordinated. This unique trend is a key finding of this study.

The city walls played a crucial role in this unique process. The dramatic increase in AS for the built-up area outside the walls can be explained by a process of consolidation. In 1966, the outside built-up area was only a few scattered patches near the North Gate and the train station, with no clear morphological or functional connection among them, resulting in a naturally low AS value (R^2). By 1992 and 2008, following the breaching of the walls, the expanding built-up area increased substantially and became interconnected, gradually forming a cohesive area and leading to a significant rise in AS. Finally, by 2024, the built-up areas outside the walls have consolidated into a complete urban district that surrounds the walled historic core, comprising the majority of the city's area and featuring a well-connected internal structure and an AS level almost equal to that of the area inside the walls. However, it is worth noting that the growth rate of AS outside the walls significantly slowed after 2008, indicating a future trend consistent with existing

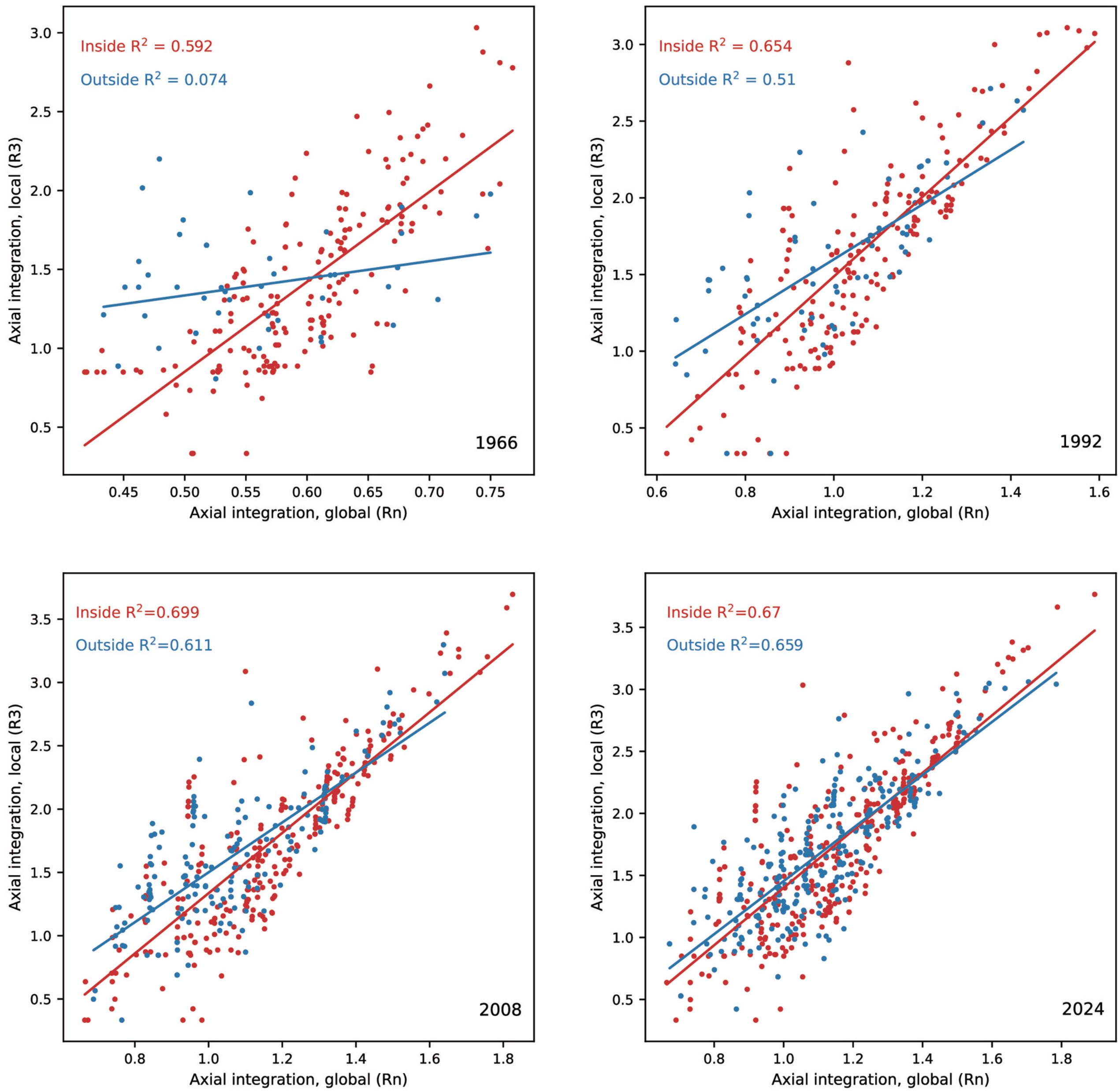

Figure 5. Scatter plots and regression analysis between radius-3 and radius-n Integration values of Zhengding across different years. Source: the authors, 2024.

Table 2. Axial Synergy (R^2 values) for Zhengding across different years. Source: the authors, 2024.

	Axial Synergy (R^2)	
Year	Inside	Outside
1966	0.592	0.074
1992	0.654	0.510
2008	0.699	0.611
2024	0.670	0.659

research, where AS decreases as the city continues to expand.

For the built-up area inside the walls, the consistently high AS can be attributed to the dual role of the city walls. From 1966 to 2008, although the inside built-up area expanded and its network became more complex, its growth did not become uncontrolled or fragmented, thanks to the constraining effect of the walls and the anchoring role of the historical urban axes. Instead, its gradual expansion maintained adequate internal connectivity and coherence, which explains the slight increase in its AS during this period. This unique process clearly demonstrates that the city walls function not only as a constraint on urban expansion but also as a "stabilizer" for the core area's morphological evolution in this walled city.

However, this increasing trend for the inner area showed a slight reversal between 2008 and 2024, which can be linked to the changes in the South Gate area due to tourism development, as discussed in Section 3.2.2. The formation of a relatively independent touristic "city-within-a-city" around the South Gate inevitably led to a decrease in the overall AS of the inner urban area compared to previous decades. This phenomenon that shifts in urban economic policy and new tourism-related developments lead to structural fragmentation deserves careful attention from planners and local policymakers.

3.3. Impact of city walls on the aggregation of POIs

3.3.1. Results

This study selects several types of retail and restaurant POIs, including supermarkets, convenience stores, personal care stores, Chinese restaurants, fast food restaurants, cold drink shops, and pastry shops. These POIs are closely related to residents' daily activities and are highly sensitive to spatial accessibility. The collected POI data was imported into QGIS to visualize their aggregation as a heatmap based on kernel density estimation.

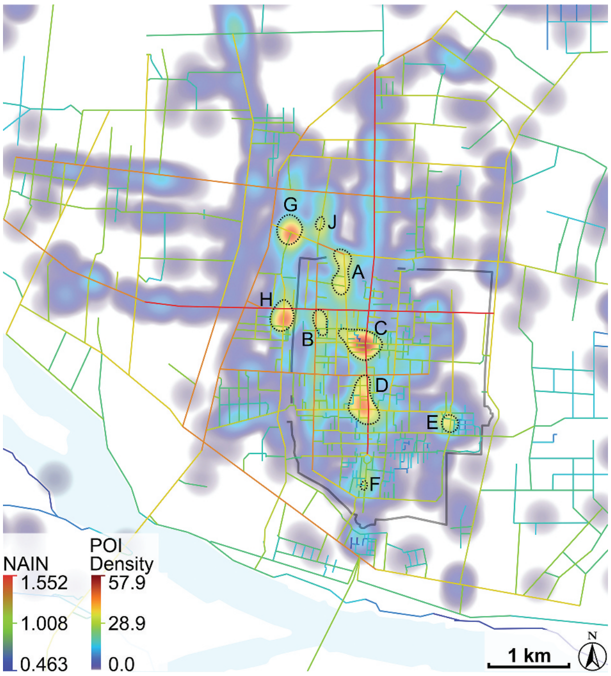

Figure 6. Heatmap of commercial POIs in the study area, overlaid with the 2024 NAIN map. Source: the authors, 2024.

The heatmap reveals several aggregation cores, which are defined as contiguous areas with a density of at least 50% of the maximum value and are labeled A-H and J in Figure 6. Inside the city walls, a large number of POIs are located along Yanzhao Avenue, especially in its mid-to-north sections (core C) and near the "Big Cross" (core D). Fuxi Street and Hengzhou Street form two relatively minor aggregation areas (core A and core B). Outside the walls, two significant aggregation cores are observed along the northern section of Chengde Street (core G and H).

The NAIN values of street segments associated with these cores are listed in Tables 3 and 4. Major aggregation cores, including A-D, G, H, and J, are located in areas with relatively high NAIN values. In contrast, areas with low NAIN values exhibit POI hollows, such as in the northwest and southeast corners inside the walls.

However, the POI aggregation did not present a universal correlation with NAIN values. There are several interesting exceptions worth noting in the heatmap: First, not all road segments with high NAIN values attract POI aggregation, especially along the extended northern section of Yanzhao Avenue and the western section of Hengshan Road. Second, the aggregation of POIs is more closely related to longitudinal roads. For instance, Changshan Road and Hengshan Road have relatively high NAIN values, but there are no significant aggregation cores observed along them. Third, there are small aggregation cores near the eastern city gate inside the city walls (core E), and inside the south city gate (core F), even though these locations have relatively low NAIN values.

3.3.2. Discussion

As stated in the methodology section, the goal of the POI analysis in this paper is to complement the Space Syntax analysis, observing whether the city walls

Table 3. NAIN values related to the POI aggregation cores inside the city walls. Source: the authors, 2024.

		Aggregation cores inside the city walls					
NAIN	Inside the city walls overall	Core A	Core B	Core C	Core D	Core E	Core F
Maximum	1.552	1.331	1.374	1.516	1.494	1.115	1.007
Minimum	0.470	1.005	1.094	0.470	0.763	0.656	0.820
Mean	1.058	1.219	1.187	1.098	1.208	0.883	0.945

Table 4. NAIN values related to the poi aggregation cores outside the city walls. Source: the authors, 2024.

		Aggregation cores outside the walls		
NAIN	Outside the walls overall	Core G	Core H	Core J
Maximum	1.552	1.323	1.549	1.131
Minimum	0.433	1.035	1.098	1.131
Mean	1.016	1.227	1.261	1.131

impact the positive correlation between syntactic measurements (mainly NAIN) and POI aggregation, a phenomenon widely found in existing research (Han, Jiao, and Xu 2017; M. C. Wang et al. 2021, Colaço and Abreu e Silva 2022; Mara et al. 2024). The aggregation cores observed in Zhengding are mostly connected to locations with high NAIN values, which is in line with existing research findings. However, the results also indicate several unexpected exceptions.

First, not all street segments with high NAIN values have POIs aggregated around them, especially those outside the city walls. The reason for this non-correlation is multifaceted. It can be attributed to the "time-lag" of changes in commercial activity compared to those in spatial structure. Although newly extended roads possess high NAIN and NACH values due to their strong spatial connectivity, such as the northern section of Yanzhao Avenue and the western section of Hengshan Road, their adjacent land has not yet been developed sufficiently to form aggregations of commercial activity.

The sparse distribution of POIs around National Highway 107 outside the walls is also noteworthy. Based on existing research findings, an aggregation core beyond the west city walls is expected along this highway, which has the highest NAIN values in the area. However, several factors make it an unsuitable site for commercial development: its proximity to the railway leaves little space for construction, and as a national-level traffic artery, it primarily serves high-speed regional traffic. Consequently, commercial development outside the city walls has aggregated towards Chengde Street, which, despite having only moderate NAIN values, possesses a more suitable urban context for commercial activities.

The second unexpected phenomenon is the overall pattern that POIs are more aggregated along longitudinal avenues than latitudinal ones. This phenomenon aligns with the city's overall development direction and the constraining impact of the city walls. First, the walled city's outline is longer in the north-south direction and narrower in the east-west direction. Second, the openings in the northern wall and the strong connection through the main avenues have provided more opportunities for the city to develop northward. The distribution of POIs, along with the NAIN and NACH patterns, suggests that in the current spatial structure of Zhengding, north-south movement is more critical than east-west movement. More importantly, this phenomenon manifests the new constraints of the railway on the west, the expressway on the east, and the river on the south, making the north the ideal direction for the city's future expansion.

Third, some unexpected POI aggregations inside the walls reflect Zhengding's increasing focus on tourism, a policy direction that is likely to persist in the foreseeable future. The minor POI aggregation cores in low-NAIN areas in the eastern and southern parts of the city are the results of tourism development (core E and F). The city's tourist attractions are mostly located inside the city walls, particularly along the southern section of Yanzhao Avenue and near the East Gate. Consequently, numerous commercial and dining establishments serving tourists have formed additional POI cores here. These areas, however, experience less daily activity involving local residents due to the constraining and disconnecting impact of the city walls. This situation, where POI aggregation is driven mainly by tourism, may lead to segregation between residents and tourists and the over-commercialization of built heritage, potentially jeopardizing the sustainable development of the industry.

All the aforementioned unexpected POI distributions that deviate from syntactic values demonstrate a methodological implication: although Space Syntax can accurately measure the physical connectivity of street spaces, the actual distribution of urban functions and activities is influenced by a multitude of factors. Top-down policy initiatives, the specific urban context of a street, and the distribution of other infrastructure can all impact the distribution of commercial and other urban functions. In a small but constantly expanding city like Zhengding, these factors can sometimes exert a more immediate and stronger influence than spatial configuration. This finding not only reveals the limitations of the Space Syntax method when used in isolation but also highlights the important complementary and validating role of POI analysis in this study.

4. Conclusion

This study employed a quantitative and diachronic approach that combines Space Syntax with POI analysis, to examine the dynamic impact of the city walls on Zhengding's "fill-and-overflow" expansion in the late 20th century. The findings reveal that the city wall is a dynamic urban element whose impact evolves and interacts with other urban forces. In addition to acting as a simple physical constraint, the city walls in Zhengding and their breaches have also functioned as a "stabilizer" preserving internal coherence, a force guiding new expansion, and a "catalyst" for contemporary, policy-driven development.

The key findings of this study, and their underlying causes, can be synthesized as follows:

- First, Zhengding presents a unique "overflow before filled" model, where large-scale overflow expansion occurred long before the enclosed area within the walls was completely filled, a phenomenon driven by the early and partial demolition of the western and northern walls. These breaches created high-potential corridors for development, guiding urban expansion outwards while leaving behind the inner corners constrained by the walls.

- Second, contrary to existing research, the city's Axial Synergy increased as it expanded, both inside and outside the city walls. The underlying cause of this result, particularly within the city walls, reveals the walls' previously underappreciated role as a morphological "stabilizer". By containing the expansion of the inside built-up area inside the walls, the walls prevented fragmented sprawl and preserved its internal spatial coherence.
- Finally, the walls' impact is highly differentiated and dynamic. This is demonstrated by the city's changing syntactic structure and the differing patterns of correlation between accessibility (NAIN) and commercial activity (POIs) inside and outside the walls, revealing that the walls' impact is contingent on their physical integrity and their complex interplay with top-down planning policies and new economic forces like tourism.

Theoretically, this research enriches the Conzenian approach of the "fixation line" by providing a unique case of partial breach and "overflow before filled". It also contributes the "stabilizer" concept as a new perspective on the function of historic physical boundaries. Methodologically, the proposed framework, combining Space Syntax with map and POI analysis, offers a more precise way to investigate the spatial structure of historic cities with physical boundaries. It extends traditional urban morphology studies that primarily rely on graphical and descriptive analysis and complements the limitations of Space Syntax when used in isolation.

The findings also offer several key policy implications. First, cities with preserved historical city walls should fully consider the constraining and disconnecting effects of the walls. Rigidly preserving walls may lead to spatial disconnection, while uncontrolled breaches may lead to uncontrolled urban sprawl and fragmentation for decades. Planners must be highly strategic about preserving or creating openings in historic walls, to balance heritage protection with contemporary connectivity needs. Furthermore, this study highlights the risks of development models that treat the walls solely as a tourism resource, as this can lead to the formation of isolated urban units, creating segregation between tourists and residents and potentially undermining urban vitality and sustainability.

The methodological framework and policy insights from this study can also be applied to cities facing other forms of spatial constraints imposed by physical boundaries, such as topographical barriers, rivers, or major transportation infrastructure. Particularly, in small cities like Zhengding, such constraints can significantly influence spatial configuration and the distribution of urban functions. The framework proposed in this study may therefore serve as a useful tool for identifying the impacts of these constraints and informing urban planners and policymakers.

Although this study provides valuable insights, it does have limitations. First, as a single case study, its findings are specific to Zhengding and may be influenced by local factors. Second, our POI analysis relies on data from a single year, 2024. While this provides a valuable contemporary snapshot of urban functions and commercial activities, it does not capture their historical evolution, which may not fully align with the long-term development of the city's spatial structure. Therefore, future research could expand the application of this framework to a broader range of small historical cities to test the generalizability of these findings. A particular direction for future work would be a longitudinal study of the emerging "Zhengding New District" to the east, which is excluded from this study's area because it is still in construction. It would be valuable to analyze how this large-scale top-down planned development interacts with the historical urban structure. Additionally, it would be beneficial to combine socio-economic data (e.g., land value, demographics) with GIS and qualitative methods to deepen the understanding of the impact of city walls on the economic and social development of historic cities, ultimately promoting their sustainable development.

Author contributions statement

QL conceived and designed the research, collected data, performed the Space Syntax analysis, and drafted the manuscript. GS participated in the analysis and interpretation of results and revised the manuscript. KL contributed to the research concept, supervised the research and revised the manuscript. All authors read and approved the final manuscript.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Angel, S., J. Parent, D. L. Civco, A. Blei, and D. Potere. 2011. "The Dimensions of Global Urban Expansion: Estimates and Projections for All Countries, 2000–2050." *Progress in*

Planning 75 (2): 53–107. https://doi.org/10.1016/j.progress.2011.04.001.
Atakara, C., and M. Allahmoradi. 2021. "Investigating the Urban Spatial Growth by Using Space Syntax and GIS—A Case Study of Famagusta City." *ISPRS International Journal of Geo-Information* 10 (10): 638. https://doi.org/10.3390/ijgi10100638.
Bafna, S. 2003. "Space Syntax: A Brief Introduction to Its Logic and Analytical Techniques." *Environment & Behavior* 35 (1): 17–29. https://doi.org/10.1177/0013916502238863.
Bertolini, L. 2008. "Station Areas as Nodes and Places in Urban Networks: An Analytical Tool and Alternative Development Strategies." In *Railway Development: Impacts on Urban Dynamics*, edited by F. Bruinsma, E. Pels, P. Rietveld, H. Priemus, and B. van Wee, 35–57. Heidelberg: Physica-Verlag HD.
Chakraborty, B., and P. Dey. 2024. "Spatial Characterisation of Blighted Urban Areas Using Space Syntax Analysis: The Case of Historic City Centre of Kolkata, India." *Geojournal* 89 (5). https://doi.org/10.1007/s10708-024-11221-4.
Chen, J. 2022. "The Research Evolution and Frontier Analysis of Historical Districts in Ancient Villages by Space Syntax." *Formosa Journal of Science and Technology* 1 (6): 739–756. https://doi.org/10.55927/fjst.v1i6.1567.
Chen, J., J. Gao, F. Yuan, and Y. D. Wei. 2016. "Spatial Determinants of Urban Land Expansion in Globalizing Nanjing, China." *Sustainability* 8 (9): 868. https://doi.org/10.3390/su8090868.
Colaço, R., J. de Abreu, and E. Silva. 2022. "Exploring the Role of Accessibility in Shaping Retail Location Using Space Syntax Measures: A Panel-Data Analysis in Lisbon, 1995–2010." *Environment & Planning B: Urban Analytics & City Science* 50 (5): 1345–1360. https://doi.org/10.1177/23998083221138570.
Conzen, M. P., K. Gu, and J. W. R. Whitehand. 2012. "Comparing Traditional Urban Form in China and Europe: A Fringe-Belt Approach." *Urban Geography* 33 (1): 22–45. https://doi.org/10.2747/0272-3638.33.1.22.
Conzen, M. R. G. 1960. *Alnwick, Northumberland: A Study in Town-Plan Analysis*. London: George Philip & Son.
Dalton, N. S. C. 2011. "Synergy, Inteligibility and Revelation in Neighbourhood Places." Doctoral thesis, University College London. https://discovery.ucl.ac.uk/id/eprint/1334117 .
depthmapX development team. 2020. depthmapX. https://github.com/SpaceGroupUCL/depthmapX/ .
Djenaihi, W.-M., N. Zemmouri, M. Djenane, and A. van Nes. 2021. "Noise and Spatial Configuration in Biskra, Algeria—A Space Syntax Approach to Understand the Built Environment for Visually Impaired People." *Sustainability* 13 (19): 11009. https://doi.org/10.3390/su131911009.
Earth Resources Observation and Science (EROS) Center. In *Declassified Satellite Imagery - 1*, U.S. Geological Survey.
Gao, S. 2005. "The Chinese Urbanization Process Since 1949: Review and Introspection." *Journal of Hunan University of Science and Engineering* 26 (3): 126–132. https://doi.org/10.3969/j.issn.1673-2219.2005.03.029.
Ge, T., W. Hou, and Y. Xiao. 2023. "Study on the Regeneration of City Centre Spatial Structure Pedestrianisation Based on Space Syntax: Case Study on 21 City Centres in the UK." *Land* 12 (6): 1183. https://doi.org/10.3390/land12061183.
Google, L. L. C. 2024. "Google Earth." Accessed December 29, 2024. https://www.google.com/earth/.
Han, Y., L. Jiao, and G. Xu. 2017. "Correlation Analysis of Road Structure and Commercial Agglomeration in Wuhan City." *Progress in Geography* 36 (11): 1349–1358. https://doi.org/10.18306/dlkxjz.2017.11.004.
Hillier, B. 1996. *Space Is the Machine: A Configurational Theory of Architecture*. Cambridge: Cambridge University Press. https://discovery.ucl.ac.uk/id/eprint/3881/.
Hillier, B. 1999. "Centrality as a Process: Accounting for Attraction Inequalities in Deformed Grids." *Urban Design International* 4 (3–4): 107–127. https://doi.org/10.1080/135753199350036.
Hillier, B., and J. Hanson. 1984. *The Social Logic of Space*. Cambridge University Press.
Hillier, B., S. Iida. 2005. "Network and Psychological Effects in Urban Movement." In *Spatial Information Theory: International Conference, COSIT 2005*, edited by D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, and M. Naor, et al. 475–90 3693. Vol. 3693. Berlin Heidelberg: Berlin, Heidelberg: Springer. September 14–18, 2005, *Ellicottville, NY, USA*, *Proceedings*.
Hillier, B., T. Yang, and A. Turner. 2012. "Normalising Least Angle Choice in Depthmap: And How It Opens Up New Perspectives on the Global and Local Analysis of City Space." *Journal of Space Syntax* 3 (2): 155–193. https://discovery.ucl.ac.uk/id/eprint/1389938.
Huang, Y., Y. Huang, Y. Chen, J. Song, S. Yang, L. Huang, L. Zheng, and Y. Gao. 2025. "The Evolution and Construction of Shan-Shui Cities: Evidence from the Ancient City of Hangzhou from the Sixth to the Twenty-First Century via Geographical Information Systems and Space Syntax." *Frontiers in Earth Science* 13:13. https://doi.org/10.3389/feart.2025.1551117.
Huang, Y., Z. Shi, Y. Chen, K. Zhou, Z. Ying, L. Zheng, and S. Yang. 2025. "Urban Form Evolution and Transformation of Traditional Water Towns Based on Space Syntax and GIS: Evidence from Ancient Wenzhou City (16th to the 20th Century)." *Frontiers in Earth Science* 13:13. https://doi.org/10.3389/feart.2025.1520643.
Larraz, B., and E. García-Gómez. 2020. "Depopulation of Toledo's Historical Centre in Spain? Challenge for Local Politics in World Heritage Cities." *Cities* 105:102841. https://doi.org/10.1016/j.cities.2020.102841.
Li, L., Y. Sato, and H. Zhu. 2003. "Simulating Spatial Urban Expansion Based on a Physical Process." *Landscape and Urban Planning* 64 (1): 67–76. https://doi.org/10.1016/S0169-2046(02)00201-3.
Li, X., Z. Lv, Z. Zheng, C. Zhong, I. H. Hijazi, and S. Cheng. 2017. "Assessment of Lively Street Network Based on Geographic Information System and Space Syntax." *Multimedia Tools & Applications* 76 (17): 17801–17819. https://doi.org/10.1007/s11042-015-3095-2.
Li, Y., L. Xiao, Y. Ye, W. Xu, and A. Law. 2016. "Understanding Tourist Space at a Historic Site Through Space Syntax Analysis: The Case of Gulangyu, China." *Tourism Management* 52:30–43. https://doi.org/10.1016/j.tourman.2015.06.008.
Liu, Q. 2024. "Sustainable Production of Public Space in Small Historic Cities in China." Doctoral thesis, Politecnico di Milano. https://hdl.handle.net/10589/221092 .
Liu, Q., and L. Pezzetti. 2022a. "Role of Public Spaces Between Built Heritage and Living City: the case of Changle Gate in Zhengding, China." In *Book of Proceedings: AESOP 2022 Congress 'Space for Species: Redefining Spatial Justice'*, 217–225. https://proceedings.aesop-planning.eu/index.php/aesopro/article/view/27.
Liu, Q., and L. Pezzetti. 2022b. "Tourism-boosting rebuilding of historic buildings and urban form: the case study of Yanghe Tower and its urban morphology in Zhengding, China." In Annual Conference Proceedings of the XXVIII International Seminar on Urban Form, edited by AFeliciotti and M. Fleischmann, 634–641. Glasgow: University of

Strathclyde Publishing. https://strathprints.strath.ac.uk/80470/.

Liu, Y., and P. Yu. 2020. "略论正定城墙历史变迁及唐五代时期正定城的三城格局 (On the historical changes of Zhengding city wall and the three-city layout of Zhengding city in Tang and Five Dynasties)." *Wenwu Chunqiu* (3): 45–53.

Liu, Z., D. Ren, and H. Xie. 2014. "Protection and Development of Historical Landscape of Ancient City Wall in Zhengding, Hebei Province." *China Homes* (5): 178. https://doi.org/10.3969/j.issn.1674-3954.2014.15.158.

Long, F., L. Zheng, and Z. Song. 2018. "High-Speed Rail and Urban Expansion: An Empirical Study Using a Time Series of Nighttime Light Satellite Data in China." *Journal of Transport Geography* 72:106–118. https://doi.org/10.1016/j.jtrangeo.2018.08.011.

Lyu, Y., M. I. Abd Malek, N. H. Ja'afar, Y. Sima, Z. Han, and Z. Liu. 2023. "Unveiling the Potential of Space Syntax Approach for Revitalizing Historic Urban Areas: A Case Study of Yushan Historic District, China." *Frontiers of Architectural Research* 12 (6): 1144–1156. https://doi.org/10.1016/j.foar.2023.08.004.

Mara, F., A. Chiara, D. Federica, and C. Valerio. 2024. "The Spatial Roots of Urban Growth: Modelling Urban Dynamics with Space Syntax." In *Computational Science and Its Applications – ICCSA 2024 Workshops*, edited by O. Gervasi, B. Murgante, C. Garau, D. Taniar, A. M. A. C. Rocha, and M. N. F. Lago, 61–76 14817. Vol. 14817. Cham: Springer Nature Switzerland.

Meng, D., and J. Zhang. 2024. "The Evolution of Space Syntax Over the Past Two Decades: Evidence from China." *Journal of Asian Architecture & Building Engineering*: 1–19. https://doi.org/10.1080/13467581.2024.2399739.

Ni, C. 2016. *古城正定 (The ancient city of Zhengding).Series of Preservation of Cultural Heritages and Urban Planning*. Shanghai: Orient Pulishing Center.

Poelmans, L., and A. van Rompaey. 2010. "Complexity and Performance of Urban Expansion Models." *Computers, Environment and Urban Systems* 34 (1): 17–27. https://doi.org/10.1016/j.compenvurbsys.2009.06.001.

Pop, C., M. M. Coros, and C. Balint. 2017. "Romanian Rural Tourism: A Survey of Accommodation Facilities." *Studia Universitatis Babeş-Bolyai Negotia*: 71–126. https://doi.org/10.24193/subbnegotia.2017.2.05.

QGIS.org. 2023. QGIS Geographic Information System. https://qgis.org/.

Qiao, W., J. Gao, Y. Guo, Q. Ji, J. Wu, and M. Cao. 2019. "Multi-Dimensional Expansion of Urban Space Through the Lens of Land Use: The Case Study of Nanjing City, China." *Journal of Geographical Sciences* 29 (5): 749–761. https://doi.org/10.1007/s11442-019-1625-y.

Ratti, C. 2005. "Suggestions for Developments in Space Syntax." In *Space Syntax 5th International Symposium: Proceedings*, edited by A. van Nes, 13–17. Delft: Techne Press. June. https://www.spacesyntax.net/symposia/ .

Şahin Körmeçli, P. 2023. "Analysis of Walkable Street Networks by Using the Space Syntax and GIS Techniques: A Case Study of Çankırı City." *ISPRS International Journal of Geo-Information* 12 (6): 216. https://doi.org/10.3390/ijgi12060216.

Song, D., S. Niu, L. Chen, A. Wang, X. Shi, X. Zhou, L. Yang, and X. Jin. 2025. "Influence of Historical City Walls on the Water Cooling Effects in Summer." *Urban Climate* 59:102310. https://doi.org/10.1016/j.uclim.2025.102310.

Turner, A. 2004. "Depthmap 4: A Researcher's Handbook." https://discovery.ucl.ac.uk/id/eprint/2651 .

van Nes, A. 2021a. "Spatial Configurations and Walkability Potentials. Measuring Urban Compactness with Space Syntax." *Sustainability* 13 (11): 5785. https://doi.org/10.3390/su13115785.

van Nes, A. 2021b. "The Impact of the Ring Roads on the Location Pattern of Shops in Town and City Centres. A Space Syntax Approach." *Sustainability* 13 (7): 3927. https://doi.org/10.3390/su13073927.

van Nes, A., and C. Yamu. 2021. *Introduction to Space Syntax in Urban Studies*. Cham: Springer International Publishing.

Wang, C., W. Yang, Y. Zhu, and Y. Ren. 2021. "Analysis of the Impact of Ancient City Walls on Urban Landscape Patterns by Remote Sensing." *Landscape & Ecological Engineering* 17 (1): 29–39. https://doi.org/10.1007/s11355-020-00428-5.

Wang, F., and N. Gu. 2023. "Exploring the Spatio-Temporal Characteristics and Driving Factors of Urban Expansion in Xi'an During 1930–2014." *International Journal of Urban Sciences* 27 (1): 39–64. https://doi.org/10.1080/12265934.2022.2085152.

Wang, M., J. Yang, W.-L. Hsu, C. Zhang, and H.-L. Liu. 2021. "Service Facilities in Heritage Tourism: Identification and Planning Based on Space Syntax." *Information* 12 (12): 504. https://doi.org/10.3390/info12120504.

Wang, S., Y. Jiang, Y. Xu, L. Zhang, X. Li, and L. Zhu. 2019. "Sustainability of Historical Heritage: The Conservation of the Xi'an City Wall." *Sustainability* 11 (3): 740. https://doi.org/10.3390/su11030740.

Wang, X., F. Xiao, Y. Zhang, L. Yin, M. Lesi, B. Guo, and Y. Zhao. 2018. "Thirty-Year Expansion of Construction Land in Xi'an: Spatial Pattern and Potential Driving Factors." *Geological Journal* 53 (S1): 309–321. https://doi.org/10.1002/gj.2987.

Whitehand, J. W. R., and K. Gu. 2017. "Urban Fringe Belts: Evidence from China." *Environment & Planning B: Urban Analytics & City Science* 44 (1): 80–99. https://doi.org/10.1177/0265813515608849.

Whitehand, J. W. R., K. Gu, and M. W. Susan. 2011. "Fringe Belts and Socioeconomic Change in China." *Environment & Planning B, Planning & Design* 38 (1): 41–60. https://doi.org/10.1068/b36104.

Wu, R., H. Zhang, J. Zhang, X. Chen, S. Zhang, and B. Yan. 2014. "Micro-Scale Spatial Structure and Spatial Associations of Urban Historical and Cultural Tourism Destinations: A Case Study of Confucius Temple, Nanjing." *Geographical Research* 33 (12): 2427–2436. https://doi.org/10.11821/dlyj201412019.

Xia, C., A. Zhang, H. Wang, and A. G. Yeh. 2019. "Predicting the Expansion of Urban Boundary Using Space Syntax and Multivariate Regression Model." *Habitat International* 86:126–134. https://doi.org/10.1016/j.habitatint.2019.03.001.

Xiao, J., Y. Shen, J. Ge, R. Tateishi, C. Tang, Y. Liang, and Z. Huang. 2006. "Evaluating Urban Expansion and Land Use Change in Shijiazhuang, China, by Using GIS and Remote Sensing." *Landscape and Urban Planning* 75 (1): 69–80. https://doi.org/10.1016/j.landurbplan.2004.12.005.

Xie, F., and K. Gu. 2011. "Urban Morphology and Tourism Planning: Exploring the City Wall in Pingyao, China." *Journal of China Tourism Research* 7 (2): 229–242. https://doi.org/10.1080/19388160.2011.576938.

Xu, C. 2018. "正定城墙及南门瓮城城台保护与展示利用 (Protection and display of Zhengding city wall and south gate barbican platform)." *Wenwu Chunqiu* (3): 46–51. https://doi.org/10.13635/j.cnki.wwcq.2018.03.007.

Xu, C., M. Liu, C. Zhang, S. An, W. Yu, and J. M. Chen. 2007. "The Spatiotemporal Dynamics of Rapid Urban Growth in the Nanjing Metropolitan Region of China." *Landscape Ecology* 22 (6): 925–937. https://doi.org/10.1007/s10980-007-9079-5.

Xu, L., Y. Liu, J. Shen, J. Tan, and A. Hutter. 2024. "Evaluation of Commercial Space Accessibility in Tourist Town: A Case Research of Maotai Town in China." *Frontiers of Architectural Research* 14 (4): 965–982. https://doi.org/10.1016/j.foar.2024.10.010.

Xu, Y., J. Rollo, D. S. Jones, Y. Esteban, H. Tong, and Q. Mu. 2020. "Towards Sustainable Heritage Tourism: A Space Syntax-Based Analysis Method to Improve Tourists' Spatial Cognition in Chinese Historic Districts." *Buildings* 10 (2): 29. https://doi.org/10.3390/buildings10020029.

Yun, J., and H. Liu. 2023. "Spatial Syntax Analysis of the Evolution of the Water System and Garden Distribution Relationship in Suzhou: 13th–20th Centuries." *Buildings* 13 (7): 1703. https://doi.org/10.3390/buildings13071703.

Yunitsyna, A., E. Shtepani, and K. Hasa. 2024. "Socioeconomic Performance of In-Between Open Spaces in a Post-Socialist City of Tirana, Albania." *Frontiers of Architectural Research* 13 (4): 858–875. https://doi.org/10.1016/j.foar.2024.03.001.

Zhai, W., X. Bai, Y. Shi, Y. Han, Z.-R. Peng, and C. Gu. 2019. "Beyond Word2vec: An Approach for Urban Functional Region Extraction and Identification by Combining Place2Vec and POIs." *Computers, Environment and Urban Systems* 74:1–12. https://doi.org/10.1016/j.compenvurbsys.2018.11.008.

Zhang, Q., and S. Su. 2016. "Determinants of Urban Expansion and Their Relative Importance: A Comparative Analysis of 30 Major Metropolitans in China." *Habitat International* 58:89–107. https://doi.org/10.1016/j.habitatint.2016.10.003.

Zhang, Z., F. Liu, X. Zhao, X. Wang, L. Shi, J. Xu, S. Yu, et al. 2018. "Urban Expansion in China Based on Remote Sensing Technology: A Review." *Chinese Geographical Science* 28 (5): 727–743. https://doi.org/10.1007/s11769-018-0988-9.

Zhang, Z., X. Yang, and R. Zhao. 2003. "A Study of the Recreation Space Reconstruction Based on Closed Corridor: Taking the Jingzhou Ancient City for an Example." *Chinese Landscape Architecture* 19 (11): 66–68. https://doi.org/10.3969/j.issn.1000-6664.2003.11.024.

Zhao, S., D. Zhou, C. Zhu, Y. Sun, W. Wu, and S. Liu. 2015. "Spatial and Temporal Dimensions of Urban Expansion in China." *Environmental Science and Technology* 49 (16): 9600–9609. https://doi.org/10.1021/acs.est.5b00065.

Zhao, X. 2017. "Image Reconstruction of the Zhengding Ancient City." *Journal of National Museum of China* 6:6–22.

Zhen, M., X. She, W. Xia, R. Lu, Z. Geng, D. Shang, M. Zhang, and K. Nan. 2025. "Comparative Study of Outdoor Thermal Comfort: Residents vs. Tourists at Xi'an Ming Dynasty Ancient City Wall Scenic Area." *Building & Environment* 267:112195. https://doi.org/10.1016/j.buildenv.2024.112195.

Zhengding gazetteer editorial board. 1992. *正定县志 (Zhengding gazetteer)*. Beijing: China City Press.