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Ageing–heritage spatial mismatch across ten Chinese historic cities: A spatial analysis of walking accessibility under mobility constraints

Xi Zhijiang[1]
Universiti Sains Malaysia
Norfarizah Mohd Bakhir[1]
farizah@usm.my
Universiti Sains Malaysia

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Ageing–heritage spatial mismatch across ten Chinese historic cities: A spatial analysis of walking accessibility under mobility constraints

Abstract

Protected heritage is fixed in place, but population ageing is spatially uneven. In historic cities, this raises a practical question: whether older residents can reach protected cultural resources on foot from where they live. We examine this spatial mismatch across ten Chinese historic-city jurisdictions by combining gridded estimates of the population aged 65 and over with nationally protected heritage locations and pedestrian networks. Population-weighted accessibility is estimated under different walking-time and speed scenarios, while spatial mismatch is measured as the exposure of high-concentration older-population areas to heritage access deficits. Heritage abundance does not necessarily translate into good pedestrian access for older residents. At a 30-minute threshold and a walking speed of 0.9 m/s, median population-weighted access is 11.1%, while median deficit exposure in high-concentration older-population areas reaches 71.0%. These patterns remain stable across alternative grid resolutions and network treatments. Heritage supply alone therefore provides an incomplete picture of age-friendly cultural access.The approach offers a policy-relevant spatial screening framework for identifying priority areas where more detailed route, public-space and site-level accessibility assessment is warranted.The estimates describe potential access rather than actual visits.

Keywords*:* population ageing; protected cultural heritage; walking accessibility; cumulative opportunity; spatial mismatch; historic cities

1. Introduction

Population ageing changes urban accessibility in practice. A destination that appears close may require a longer walk once street configuration and walking speed are considered. Research on age-friendly environments has therefore moved beyond counting amenities toward the conditions under which older people can reach them (Plouffe and Kalache, 2010; Van Cauwenberg et al., 2011; Rosso et al., 2011; Cerin et al., 2013; Buffel and Phillipson, 2016; Zhou et al., 2017; Herbolsheimer et al., 2020; van Hoof et al., 2021; Akinci et al., 2022; Stearns et al., 2023). Geographical studies likewise show that travel assumptions, street networks and analytical scale alter walking-time catchments (Dunning et al., 2023; Li and Wang, 2024; Ng et al., 2024; Liu et al., 2024; Deng et al., 2025; Wei et al., 2026; Wu et al., 2026).

Protected cultural heritage presents a particular problem. Hospitals, shops and bus stops can be relocated or duplicated; protected buildings, archaeological sites and historic districts cannot. Their locations reflect earlier settlement processes, while the geography of ageing continues to change. Routes, entrances and public space can be improved, although historic paving, level changes and conservation requirements constrain intervention (Ioannidis and Vozikis, 2007; Shin, 2010; Zhao et al., 2020; Jimenez Martin et al., 2022; Das Mahapatra et al., 2023; Zhang et al., 2023; Fan et al., 2024; Treccani et al., 2026).

Site-level heritage accessibility is better documented than the residential geography of access (Koustriava and Koutsmani, 2023). Which older residents live beyond a feasible walk to protected resources, and where are they concentrated? Cultural infrastructure is unevenly distributed: Brook (2016) linked geographical access to museum and gallery attendance in London, alongside social stratification. Our population-weighted analysis asks about opportunity before preferences or participation can be observed; it does not presume that all residents wish to visit each site.

Accessibility relates opportunities to the effort required to reach them (Handy and Niemeier, 1997; Geurs and van Wee, 2004). We use a cumulative-opportunity measure, not individual space-time prisms. Time geography motivates the explicit time budget and the recognition that movement capability changes its effective reach (Hägerstrand, 1970; Miller, 1991, 1999; Kwan, 1998). Later-life activity-space work cautions against equating chronological age with a fixed walking capacity (Schönfelder and Axhausen, 2003; Hirsch et al., 2014, 2016; Cornwell and Cagney, 2017; Hasanzadeh et al., 2021; Plaut et al., 2021; Crane et al., 2023). Walking speed is therefore a scenario parameter (Dunning et al., 2023; Deng et al., 2025; Lei et al., 2026).

China offers a useful setting. The Seventh Census counted 190.6 million people aged 65 or above in 2020, accounting for 13.5% of the national population, while the national immovable-heritage system contains thousands of designated units across different settlement types (National Bureau of Statistics of China, 2021; Ye et al., 2023, 2024). Historic-city jurisdictions vary in administrative extent, protected-resource density and the overlap between old urban cores and present-day residential concentrations.

We ask how pedestrian access to nationally protected heritage varies across ten jurisdictions when older residents' locations are represented explicitly; how sensitive the estimates are to mobility, network, grid and population-calibration assumptions; and where high concentrations of older residents coincide with low opportunity. The applied spatial contribution lies in integrating

established network-accessibility methods with census-calibrated age surfaces and a consistent heritage opportunity set across multiple historic-city jurisdictions, while making mobility, network and scale assumptions explicit. This comparative framework is intended to support spatial diagnosis and policy prioritisation where ageing populations and fixed cultural opportunities are poorly aligned. We do not rank heritage quality, infer cultural preference or equate modelled access with visits.

2. Conceptual framework

2.1 From heritage presence to effective spatial opportunity

Heritage inventory and effective access differ. Resources may be concentrated far from older residents or separated from them by a circuitous network. A smaller inventory may provide better local opportunity where residences and destinations coincide. Accessibility thus depends on the arrangement of people, destinations and routes, not on site counts alone (Handy and Niemeier, 1997; Geurs and van Wee, 2004; Rodrigue et al., 2023).

2.2 Time budgets, mobility constraints and cumulative opportunity

We ask whether at least one protected-heritage cluster lies within a stated network-time budget. Time geography motivates the attention to time and capability but is not the estimator: we have no individual schedules, coupling constraints or personal prisms. Nor does chronological age imply one gait speed (Bohannon and Andrews, 2011; Akinci et al., 2022). We compare several speeds to show how a fixed time budget covers different network distances.

2.3 Ageing–heritage spatial mismatch

Ageing–heritage spatial mismatch is the co-location of high concentrations of older residents and low modelled walking access to protected heritage. It measures exposure to an opportunity deficit, not observed exclusion (Lucas, 2012; Brook, 2016). Access is calculated for population cells and aggregated to a 1-km grid. We count older residents in high-demand cells who lack a reachable destination; the jurisdiction outcome divides that count by all residents aged 65+. The map uses an additional rule: at least half of a high-demand cell's older population lacks access. It does not imply that every resident of such a cell is inaccessible. Figure 1 summarises this analytical workflow.

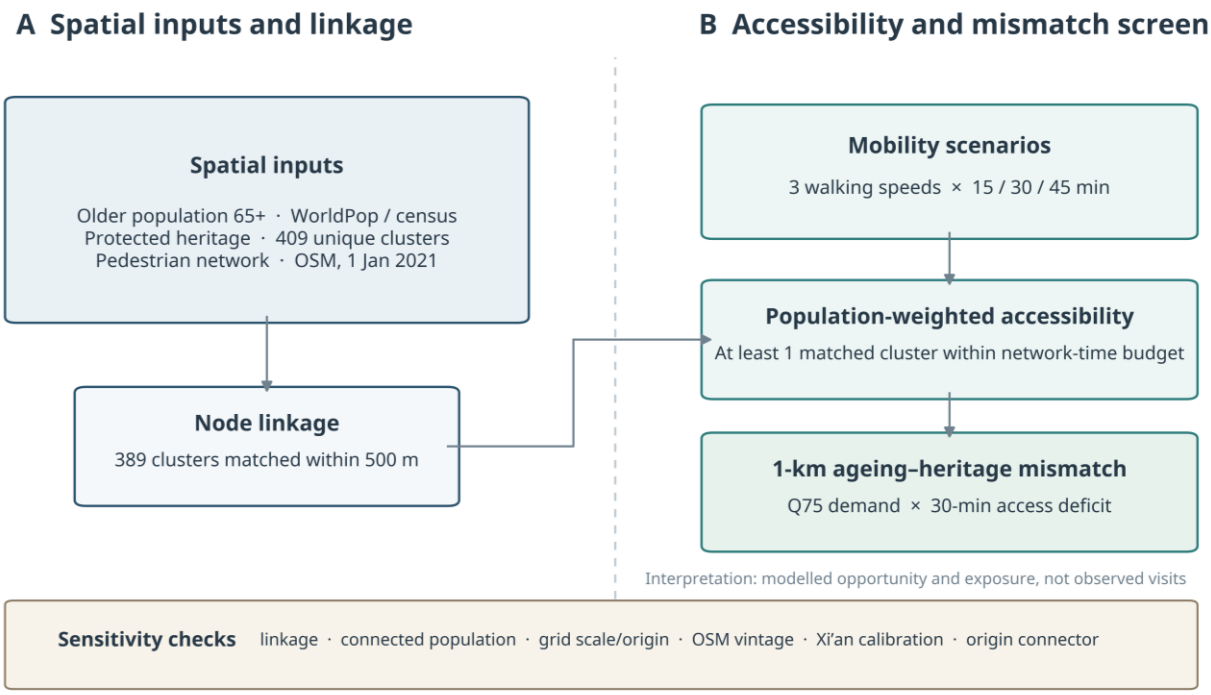


Fig 1. Analytical framework for the population-weighted heritage-access screen. The 409 unique eligible clusters are linked to the 2021 walking network; 389 match within 500 m. Walking-speed and time-budget scenarios enter before access is calculated. Mismatch combines access with the older-population distribution; the listed checks assess sensitivity rather than produce access.

3. Data and methods

3.1 Study design and cases

Ten jurisdictions were selected because each had a usable 2020 census reporting unit, age-structured population surface, geocoded national heritage records, administrative boundary and archived 2021 pedestrian network: Beijing, Xi'an, Suzhou, Luoyang, Quanzhou, Chengdu, Pingyao, Lijiang, Xinghua and Kaifeng. They span different reporting scales, older-population sizes and heritage inventories. This criterion-based sample tests a common workflow across contrasting conditions; it does not estimate a national average.

We matched GADM 4.1 boundaries as closely as possible to 2020 census reporting units (GADM, 2022). Several therefore include extensive peripheral or rural territory. Table 1 describes these contrasts and Figure 2 locates the cases.

Table 1. Case-selection contrasts and baseline network diagnostics. The table describes the final criterion-based sample; it is not a population-representative design.

City	Reporting scale	65+ pop.	Matched heritage	Heritage /100k	Unserved (%)
Beijing	Municipality	2,912,060	131	4.50	5.5
Xi'an	Prefecture/sub-prov.	1,228,144	51	4.15	5.2
Suzhou	Prefecture	1,585,701	55	3.47	3.9
Luoyang	Prefecture	915,231	32	3.50	19.8
Quanzhou	Prefecture	790,577	37	4.68	14.9
Chengdu	Prefecture/sub-prov.	2,851,183	38	1.33	7.9
Pingyao	County	63,948	16	25.02	21.9
Lijiang	Prefecture	132,894	9	6.77	18.5
Xinghua	County-level city	287,981	4	1.39	19.7
Kaifeng	Prefecture	684,965	16	2.34	26.5

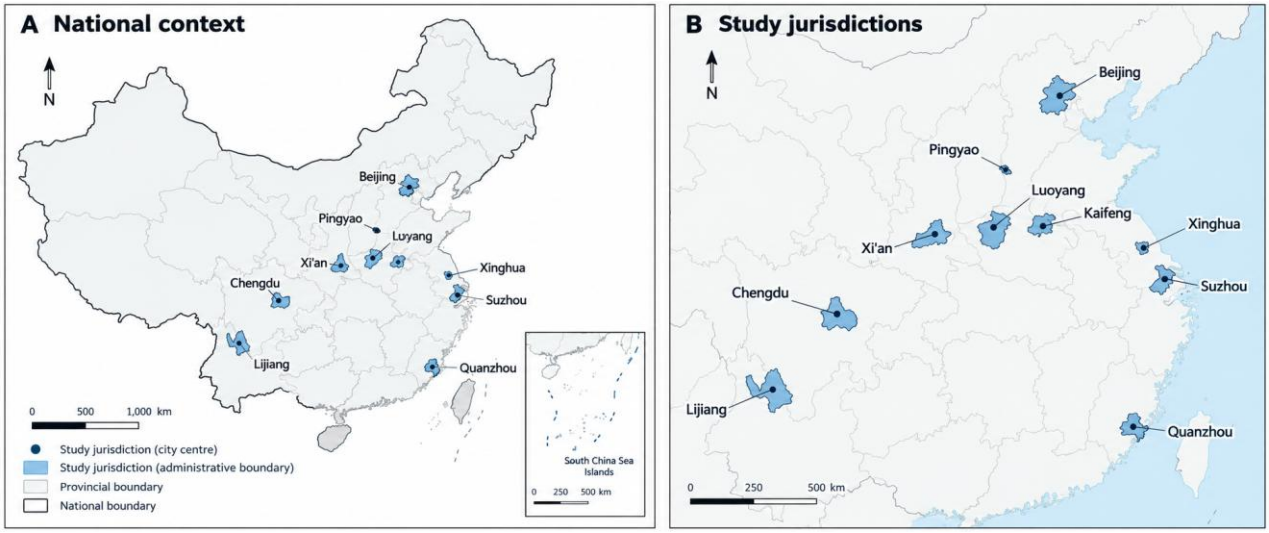


Fig 2. Location of the ten study jurisdictions in China. Jurisdiction boundaries are harmonised to GADM 4.1 administrative units used for demographic matching. Source coordinates are WGS84 (EPSG:4326); the map is displayed in a Lambert conformal conic projection. Scale bar in kilometres. Map lines delineate study areas and do not necessarily depict accepted national boundaries.

3.2 Protected-heritage opportunity set

Heritage locations derive from the published 5,058-unit dataset for the eight State Council designation batches (Ye et al., 2023, 2024). The ten-case extract held 436 records. We checked duplicates, coordinates and adopted jurisdiction boundaries. Of three records outside those boundaries, two lay 0.09 and 0.62 km beyond them and were retained under the documented

tolerance. A Luoyang record geolocated about 80 km away in Shanxi was excluded rather than assigned a conjectural coordinate. Co-located designation records were clustered, leaving 409 unique input destinations; 389 matched the 2021 graph within 500 m. Each matched cluster is one unweighted opportunity. The set excludes lower-level listings, unlisted heritage and the areal experience of historic districts.

3.3 Older-population distribution and census calibration

We used WorldPop China's 2020 constrained age-and-sex surfaces (R2025A v1, approximately 100 m; Bondarenko et al., 2025), summing the relevant layers for ages 65+. WorldPop supplies the within-jurisdiction distribution; Seventh Census totals calibrate it. Unscaled WorldPop 65+ totals were 7.4–7.9% below census values in nine scope-compatible jurisdictions, whose cells were scaled uniformly to the official totals. Xi'an differed by 13.0%, and its census reporting extent does not match the adopted GIS boundary. We retained its unscaled surface rather than force a total from another extent onto it, and report a nine-case sensitivity analysis.

3.4 Pedestrian network and accessibility computation

The primary pedestrian network was built from the archived Geofabrik/OpenStreetMap (OSM) China snapshot dated 1 January 2021, which closely matches the 2020 census and WorldPop baseline in time (Geofabrik GmbH, 2021). OpenStreetMap is widely used for network analysis, but volunteered mapping can vary in coverage and attribute completeness (Haklay and Weber, 2008; Haklay, 2010; Barrington-Leigh and Millard-Ball, 2017; Boeing, 2017). We excluded motorways, motorway links, trunk roads, trunk links, raceways, construction, proposed, abandoned and platform features. Links explicitly tagged as no/private pedestrian access or use_sidepath were also removed unless a permissive pedestrian tag overrode the general restriction.

Heritage points and populated cells were assigned to their nearest routable nodes under a 500-m maximum snap distance; 250- and 1,000-m linkage checks describe network coverage. Cells beyond 500 m, or linked to components with no matched heritage node, remain in the population denominator as network-unserved. The shortest-path calculation then runs between the assigned nodes. It does not add the off-network distance from the cell to its node or from a heritage point to its node. These connectors are not mapped walking paths. An origin-only straight-line addition provides a partial sensitivity check; it cannot validate the actual first or last segment.

We convert node-to-node distance to time at 0.9 m/s (3.24 km/h, reduced-mobility scenario), 4.0 km/h (1.11 m/s, baseline planning scenario) and 1.2 m/s (4.32 km/h, faster reference). The scenarios represent neither fixed age-group gait speeds nor observed route times (Bohannon and Andrews, 2011; Dunning et al., 2023; Deng et al., 2025; Lei et al., 2026). For jurisdiction c, time threshold T and speed v, population-weighted access is:

$$A_{(c)}(T,v) = [\Sigma_i P_i I(d_i / v \leq T)] / [\Sigma_i P_i]$$

Here P_i is the 65+ population in cell i, d_i is node-to-node shortest-path distance to the nearest matched cluster, and $I(\cdot)$ marks whether the threshold is met. We report 15-, 30- and 45-minute access; the primary outcome is the share with at least one reachable cluster.

3.5 Spatial mismatch and sensitivity analysis

We aggregate population and access to a regular 1-km grid. The upper quartile (Q75) of 65+ population among populated cells defines high demand separately within each jurisdiction. Primary deficit exposure counts residents in those cells without 30-minute access at 0.9 m/s and divides by the jurisdiction's total 65+ population. Figure 5 additionally marks high-demand cells where at least 50% of older residents lack access. The reduced-speed scenario is a screen for constrained walking reach, not a classification of individuals.

We examined Q80 and Q90 demand thresholds, 45-minute reach, removal of network-unserved population with Q75 recalculated, a 500-m grid, a 1-km grid shifted 500 m in both axes, and exclusion of Xi'an (Openshaw, 1984). We also added each origin's straight-line snap distance to its node-to-node distance before recalculating 30-minute access and Q75 exposure. That addition is a lower bound for the origin connector only; it leaves the destination connector out. These checks show dependence on modelling choices, rather than identifying one uniquely correct specification.

3.6 Robustness checks and statistical tests

To assess network-vintage sensitivity, we repeated the model with provincial OSM extracts dated 21 September 2026, holding the population, heritage set, boundaries, filters, snap rule and speeds fixed. OSM changes reflect both roads and mapping activity, so this is not a longitudinal estimate of physical access. No field timing or independent routing benchmark was available; the comparison tests rank stability, not absolute travel-time validity.

With ten cases, inference remains limited. We report the magnitude of the speed contrast rather than test its direction, which follows mechanically from the cumulative threshold model.

Spearman correlations describe OSM-vintage ranks and the associations of heritage supply with access and mismatch. We repeat relevant summaries without Xi'an. We do not fit a city-level multivariable model with n=10. Table 2 summarises the data sources, spatial roles and analytical treatments used in the analysis.

Table 2. Data sources, spatial role and analytical treatment.

Component	Source / year	Spatial role	Treatment
Older population	WorldPop R2025A v1, 2020, ~100 m	65+ spatial exposure	Nine jurisdictions census-calibrated; Xi'an retained raw because reporting scope differs
Population census	Seventh National Population Census, 2020	Validation totals and ageing shares	Matched to available city/county reporting units
Protected heritage	Ye et al. national 5,058-unit dataset	Fixed cultural opportunities	436 source records → 409 unique clusters; 389 matched the 2021 graph within 500 m
Administrative boundary	GADM 4.1	Census matching and raster clipping	Jurisdiction boundaries kept consistently, including peripheral territory
Pedestrian network	OpenStreetMap/Geofabrik, 1 Jan 2021	Primary shortest-path network	500-m snap rule; 15/30/45-min accessibility; three speed scenarios
Mismatch grid	Regular 1-km grid	High-demand / low-access exposure	Q75 primary; Q80/Q90, 45-min, 500-m and shifted-grid checks
Robustness network	Provincial OSM extracts, 21 Sep 2026	Network-vintage sensitivity	All non-network inputs and routing rules held constant

4. Results

4.1 Data validation and network quality

Of 409 eligible clusters, 389 matched the 2021 graph within 500 m. The median city match rate was 96.2% (84.2% in Luoyang to 100% in Lijiang and Xinghua). The median network-unserved share of the 65+ population was 16.7%, ranging from 3.9% in Suzhou to 26.5% in Kaifeng. These residents remain in primary denominators; Section 4.5 assesses this choice.

Population weights reproduce official 65+ totals in nine scope-compatible jurisdictions, from 63,948 in Pingyao to 2.91 million in Beijing. Xi'an contributes 1.228 million from the unscaled WorldPop surface because its census benchmark covers a different extent.

4.2 Walking-speed assumptions materially change access

At 0.9 m/s, the median share of residents aged 65+ with at least one protected-heritage opportunity is 4.1% within 15 minutes, 11.1% within 30 minutes and 17.0% within 45 minutes. The ten cases are far from uniform. Thirty-minute access ranges from 7.1% in Xinghua and 7.2% in Quanzhou to 35.7% in Pingyao; Beijing and Xi'an reach 14.0% and 14.4%, respectively. Heritage inventory size by itself does not reproduce this ordering.

Changing the assumed walking speed shifts access in every jurisdiction, as the cumulative-threshold model entails. At 30 minutes, the cross-city median is 11.1% at 0.9 m/s, 14.1% at 4.0 km/h and 15.2% at 1.2 m/s. Moving from 0.9 m/s to 4.0 km/h adds a median 2.95 percentage points, with city-level gains of 2.52–6.67 points. Figure 3 reports the reduced-mobility result used in the primary mismatch screen.

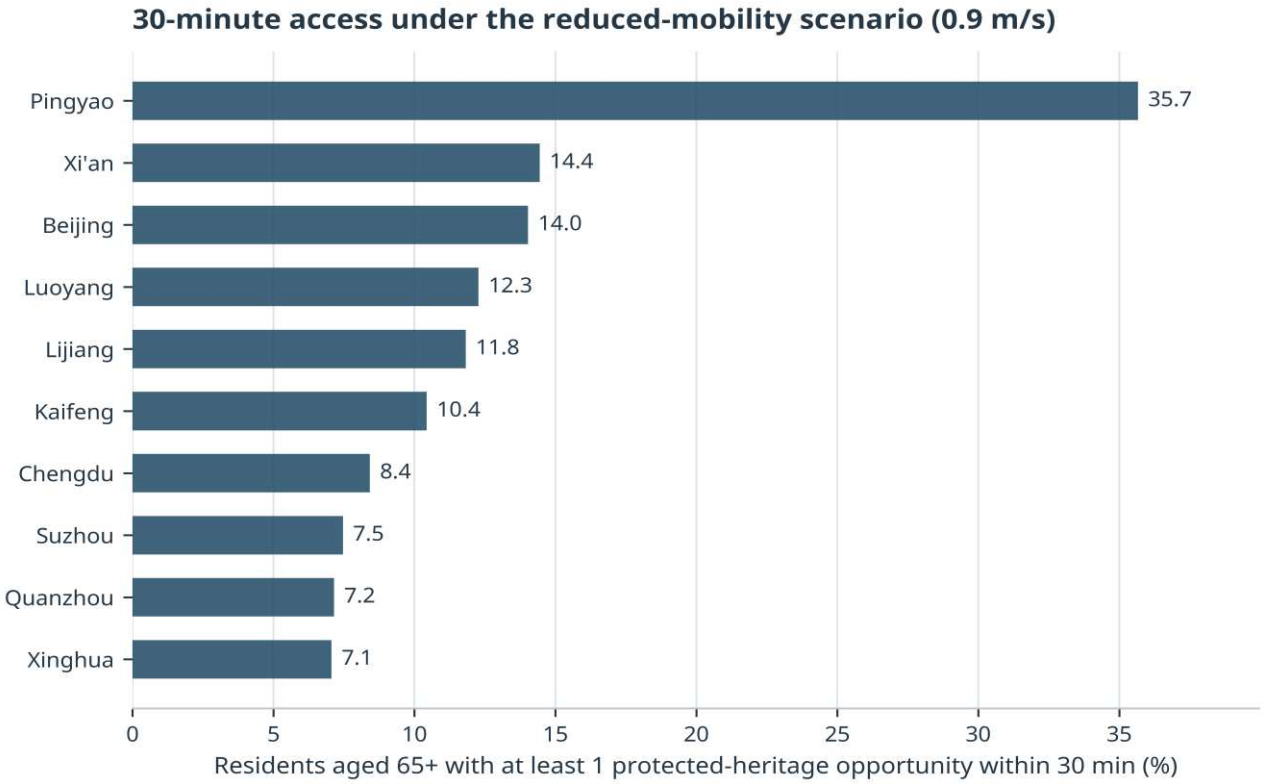


Figure 3. Population-weighted 30-minute accessibility to at least one protected-heritage cluster under the reduced walking-speed scenario (0.9 m/s).

4.3 High-demand areas remain widely exposed to low heritage access

Low accessibility overlaps extensively with local concentrations of older residents. Under the primary Q75 definition and a 30-minute threshold at 0.9 m/s, the median deficit-exposure share is 71.0% of the jurisdiction's total 65+ population. Values span 50.4% in Pingyao to 80.8% in

Lijiang; Quanzhou (79.8%), Luoyang (75.3%) and Beijing (74.9%) are also high. This is not simply a consequence of the conservative speed assumption. At the 4.0 km/h baseline, the corresponding median remains 67.8%. Extending the reduced-mobility time budget to 45 minutes lowers it to 64.4%, but a sizeable deficit remains.

As expected, the absolute percentage depends on where 'high demand' is drawn. Tightening the threshold from Q75 to Q80 lowers the median 30-minute deficit exposure from 71.0% to 67.1%; at Q90 it falls to 52.1%. The ordering across cities is much more stable than the magnitude itself: Q75 and Q90 exposure values remain strongly rank-correlated (Spearman $\rho=0.915$, $p<0.001$). Comparisons across studies should therefore report the demand threshold explicitly rather than treating mismatch as a threshold-free quantity. Figure 4 shows the resulting cross-jurisdiction distribution under the primary Q75 definition.

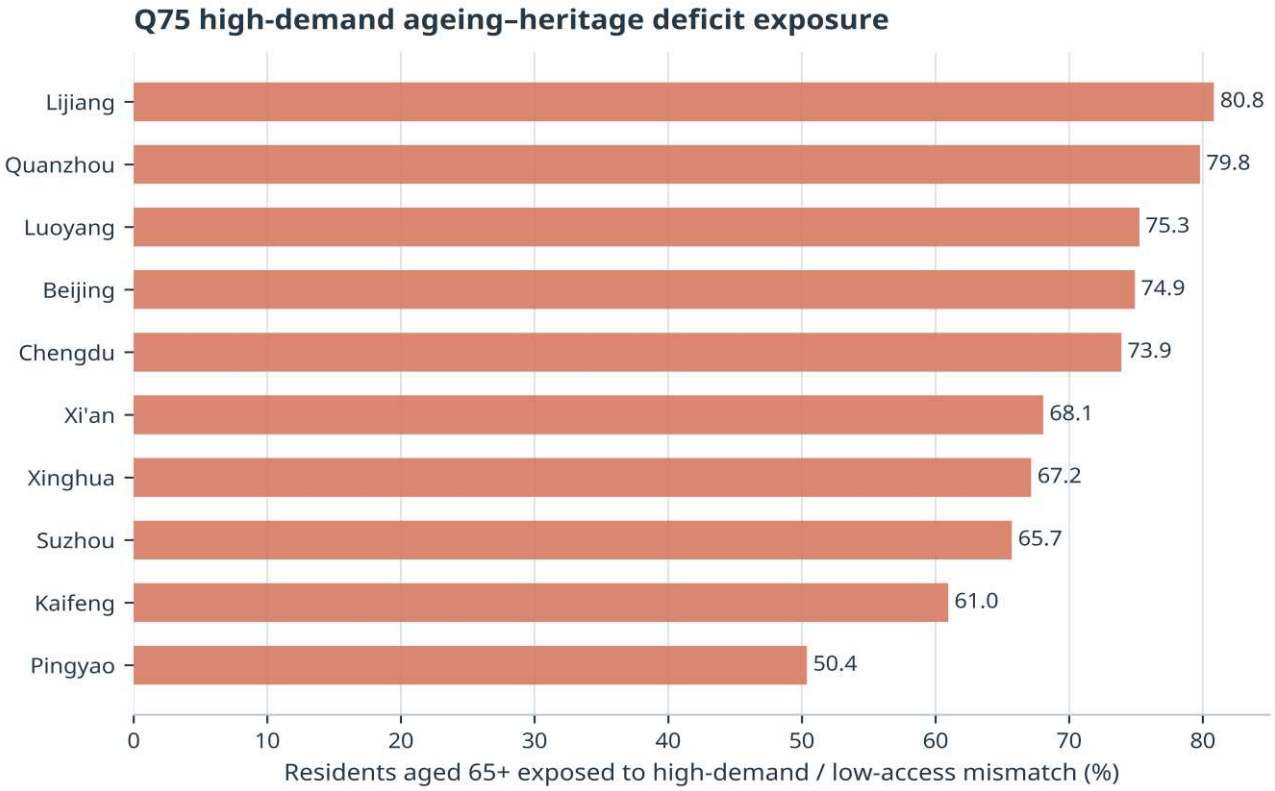


Fig 4. Deficit exposure under the primary Q75 high-demand definition: share of the total 65+ population who live in high-demand 1-km cells and individually lack a protected-heritage opportunity within 30 minutes at 0.9 m/s.

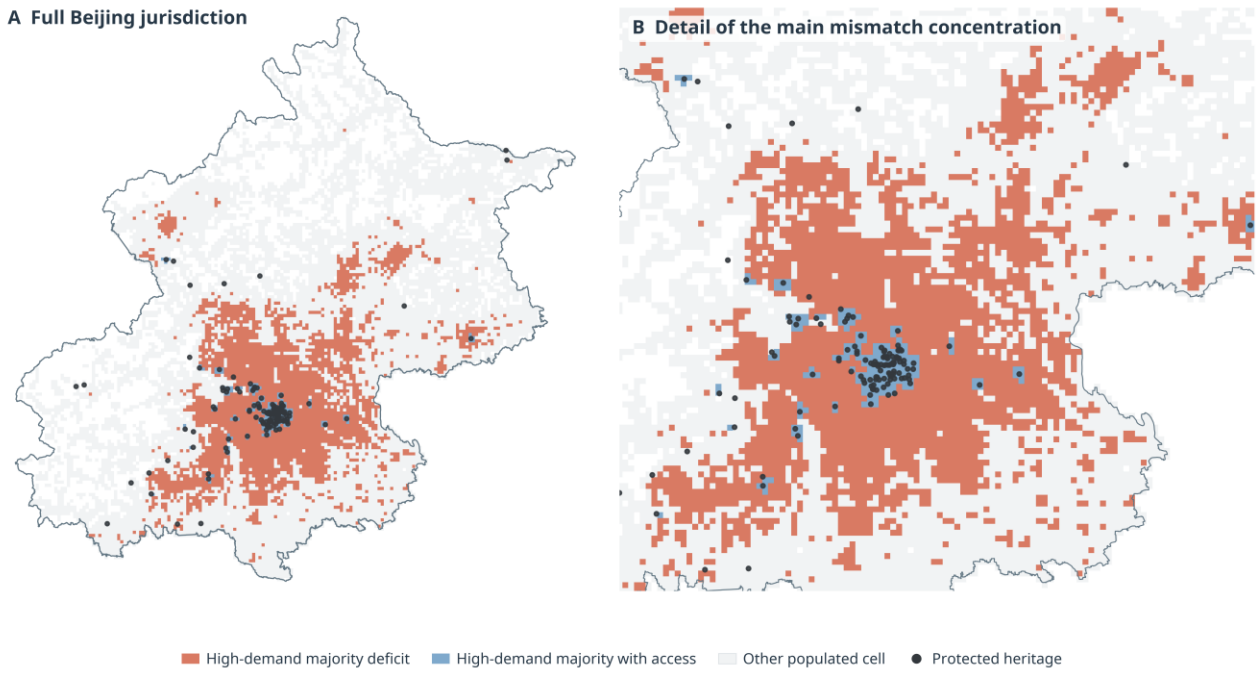


Fig 5. Beijing example of the final 1-km ageing–heritage mismatch classification. High-demand cells are defined by the within-jurisdiction upper quartile of 65+ population; the red majority-deficit class contains cells in which at least 50% of the 65+ population lacks a protected-heritage opportunity within 30 minutes at 0.9 m/s.

4.4 Heritage counts and effective opportunity in this sample

In these ten selected jurisdictions, heritage counts do not closely track population-weighted access. Matched cluster counts correlate weakly with 30-minute access at 0.9 m/s (Spearman $\rho=0.207$, $p=0.567$) and Q75 deficit exposure ($\rho=0.061$, $p=0.868$). Clusters per 100,000 residents aged 65+ correlate only weakly with deficit exposure ($\rho=0.248$, $p=0.489$). Small n and contrasting jurisdiction sizes preclude a general claim of no association; the results show why the position of sites relative to residents matters alongside inventory size. This relationship is visualised in Figure 6.

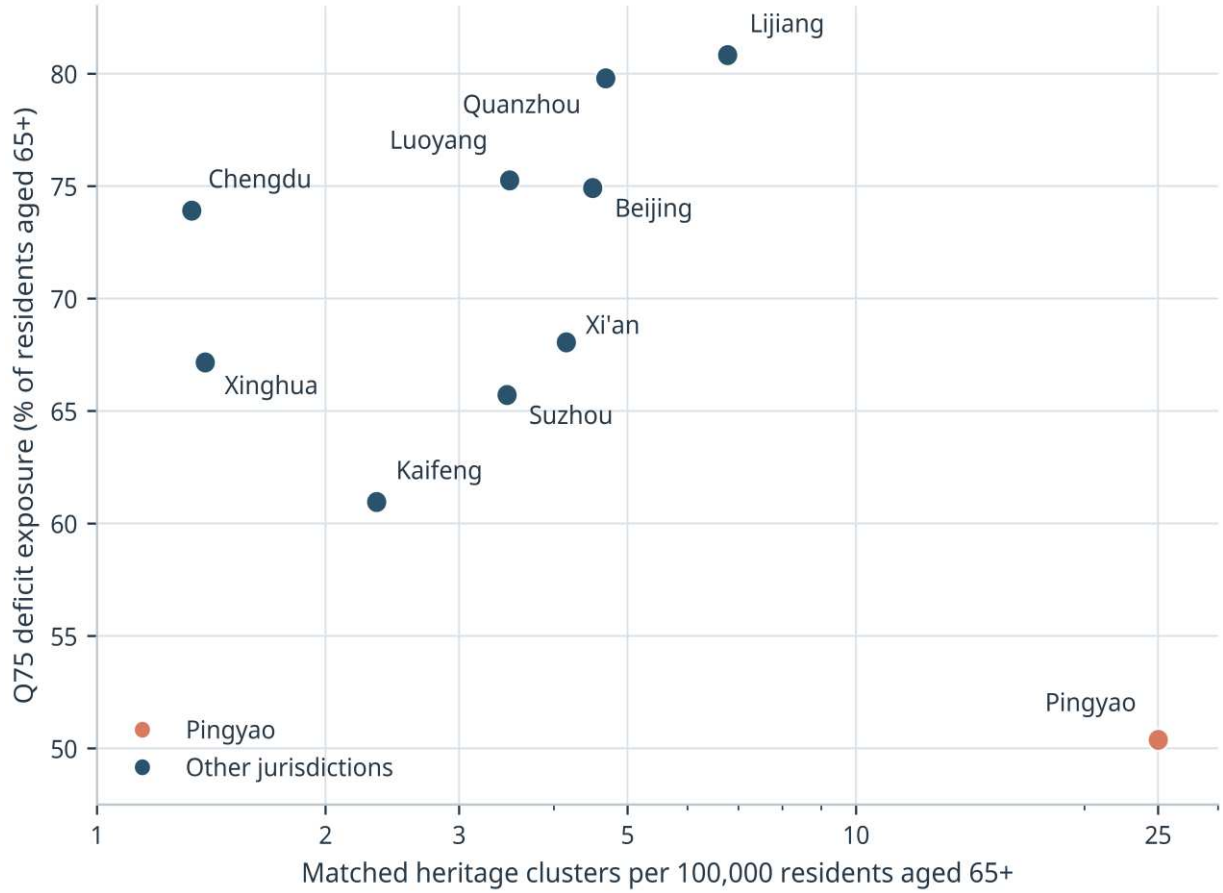


Fig 6. Matched heritage-cluster density and Q75 ageing–heritage deficit exposure across the ten cases. The horizontal axis uses a logarithmic scale to display the density outlier alongside the other cases. Site counts alone do not describe the arrangement of opportunities relative to residents.

4.5 Mismatch is robust to linkage and grid diagnostics

Excluding network-unserved residents from both numerator and denominator and recalculating Q75 yields a median deficit exposure of 71.6%, compared with 71.0% in the primary model. Median access among network-served residents is 14.3%. As a separate connector check, adding each cell's straight-line distance to its assigned node lowers median 30-minute access at 0.9 m/s from 11.1% to 10.5% and raises median Q75 deficit exposure from 71.0% to 71.9%. This calculation omits the destination connector and does not represent an audited walking route.

Grid specification has a small effect on the cross-city summary. A 500-m grid gives median Q75 exposure of 72.7% (Spearman ρ=0.976 against the 1-km values; median absolute city difference 1.59 percentage points). Shifting the 1-km origin by 500 m yields 71.0% and ρ=1.000, with a median absolute difference of 0.11 points. Individual values can still be scale-sensitive.

Without Xi'an, median 30-minute access at 0.9 m/s is 10.4% rather than 11.1%, and Q75 exposure is 73.9% rather than 71.0%. The count–mismatch association remains small (ρ=0.059, p=0.881), and 2021–2026 access ranks remain aligned (ρ=0.967, p<0.001). Table 4 summarises these diagnostic sensitivity checks.

4.6 Accessibility ranking is stable across OSM network vintages

The 2026 OSM network produces a similar comparative pattern. For 30-minute access, 2021–2026 ranks correlate at ρ=0.976 (p<0.001) under both 0.9 m/s and 4.0 km/h. At 0.9 m/s the median absolute city change is 0.24 percentage points, with a maximum of 1.53 points. This stability concerns the reported node-based measure; it is not external validation of walking time.

Network-quality indicators change more. The unserved-share rank correlation is ρ=0.830 (p=0.003), while the median absolute city change is 4.48 percentage points and five cases change by over five points. Added network connectivity may change linkage status without moving the full-population access percentage much. Both indicators should be retained. Figure 7 shows the 2021–2026 city-level comparison, and Table 3 summarises the core city-level accessibility, mismatch and network-vintage results.

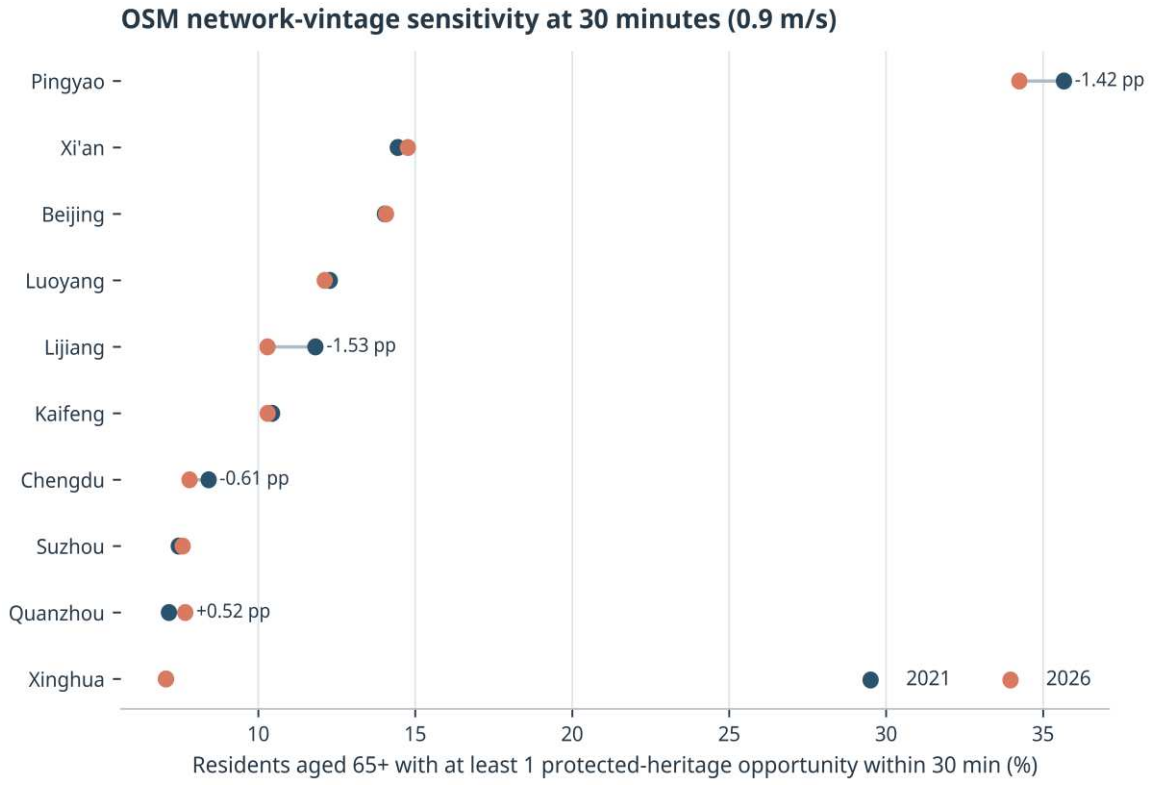


Fig 7. Sensitivity of 30-minute reduced-mobility accessibility to OpenStreetMap network vintage. Population, heritage opportunities, boundaries, routing rules and walking speed are held constant; the comparison is not a longitudinal estimate of real-world accessibility change.

Table 3. Core accessibility, mismatch and network-vintage robustness results.

City	30m 0.9 (%)	30m 4.0 (%)	45m 0.9 (%)	Q75 mismatch (%)	Unserved (%)	Δ access 2026 (pp)
Beijing	14.0	17.5	21.3	74.9	5.5	+0.04
Xi'an	14.4	19.8	26.1	68.1	5.2	+0.32
Suzhou	7.5	10.0	13.3	65.7	3.9	+0.12
Luoyang	12.3	16.6	20.5	75.3	19.8	-0.16
Quanzhou	7.2	9.7	12.7	79.8	14.9	+0.52
Chengdu	8.4	11.1	14.3	73.9	7.9	-0.61
Pingyao	35.7	42.3	46.9	50.4	21.9	-1.42
Lijiang	11.8	14.8	17.9	80.8	18.5	-1.53
Xinghua	7.1	9.6	12.6	67.2	19.7	-0.01
Kaifeng	10.4	13.3	16.0	61.0	26.5	-0.14

Note: *Δ access is the 2026 OSM result minus the 2021 OSM result while all non-network inputs and model rules are held constant.*

Table 4. Diagnostic sensitivity checks for the primary Q75 mismatch result.

Check	Specification	Key result	What it shows
Primary	1-km grid; Q75; 30 min; 0.9 m/s	Median mismatch 71.0%	Reference estimate
Demand threshold	Q80 / Q90	67.1% / 52.1%	Magnitude changes, ordering remains stable
Connected population	Remove unserved; recalculate Q75	Median mismatch 71.6%	OSM linkage failure does not create the main result
Grid scale	500-m grid	Median 72.7%; ρ=0.976 vs 1 km	Comparative pattern is stable; some city values shift
Grid origin	1-km grid shifted 500 m	Median 71.0%; ρ=1.000	Negligible origin effect
Xi'an exclusion	Nine-case summary	Mismatch 73.9%; count–mismatch ρ=0.059	Known calibration exception does not drive conclusions
OSM vintage	2021 vs 2026	30-min rank ρ=0.976	Access ordering is robust; network-quality diagnostics are more sensitive
Origin connector	Add straight-line origin-to-node distance	Median access 10.5%; mismatch 71.9%	Partial bound; destination connector and route quality

Check	Specification	Key result	What it shows
			remain unknown

5. Discussion

5.1 Mobility assumptions reshape the geography of heritage opportunity

A fixed time threshold covers different network distances at different speeds. Across all ten cases, slower assumed movement contracts 30-minute access; the median loss from 4.0 km/h to 0.9 m/s is just under three percentage points. Comparable sensitivity to mobility assumptions has been reported for access to other urban resources (Dunning et al., 2023; Li and Wang, 2024; Ng et al., 2024; Deng et al., 2025; Lei et al., 2026). Here, a fixed national heritage opportunity set is evaluated against the residential geography of older people using an established accessibility algorithm.

Time geography helps interpret the role of capability and time budgets. Because we observe no individual schedules or space-time prisms, the empirical measure remains cumulative opportunity under alternative network-time assumptions.

5.2 Mismatch identifies exposure, not cultural exclusion

A median 71.0% of the 65+ population lives in Q75 cells and lacks modelled 30-minute access at 0.9 m/s. This is exposure, not a measure of cultural or social exclusion. We do not observe preferences, opening hours, trip chaining, family support or other travel modes. The result identifies places for closer assessment before such behavioural factors are considered.

Accessibility-based planning can combine low access with concentrations of a target population to screen for priority areas (Rodrigue et al., 2023). The analysis also adds population geography to work on uneven cultural participation (Brook, 2016). We cannot infer effects on loneliness, attachment or wellbeing from modelled proximity (Fancourt and Steptoe, 2018, 2019; Liu et al., 2023). Those questions require evidence of actual routes, site use and social outcomes.

5.3 National protection points capture only part of the historic environment

Inventory size and effective access are distinct, but the inventory used here is also incomplete. National Key Cultural Relic Protection Units form the only common national opportunity set across the cases. Provincial and municipal listings, unlisted traditional fabric, walls, streetscapes

and area-based historic-town experiences are excluded (Zhang, 2022; National People's Congress, 2024).

The omission may matter more in Pingyao and Lijiang, where heritage is experienced as a continuous urban landscape (UNESCO, 2011; Bandarin and van Oers, 2012). A point-based model can understate such ambient opportunity relative to cities with more discrete destinations. Our estimates concern nationally protected clusters only. Future work could compare point, polygon and network representations and add lower-level heritage registers.

5.4 Diagnostic checks separate substantive mismatch from data artefacts

Removing unserved population, changing grid scale or origin, and omitting Xi'an leave the cross-city mismatch pattern broadly intact. The origin-connector check moves median exposure by less than one percentage point, although Pingyao's access falls by 2.98 points. It is only a partial bound: the straight-line connection may be impassable, and the destination-to-network segment remains omitted. Local travel-time claims therefore require route validation.

The OSM-vintage check concerns comparative stability, not absolute network accuracy. City access ranks change little, while unserved shares change more. OSM evolves through physical change and mapping activity (Haklay, 2010; Barrington-Leigh and Millard-Ball, 2017; Boeing, 2017). Field routes or independent routing engines would be useful benchmarks, particularly where network-unserved shares are high.

5.5 Policy relevance, planning implications and limits of transferability

For policy and planning, age-friendly heritage access should be assessed through the spatial relationship between older residents and protected places rather than through heritage counts alone. At the meso scale, Q75 cells identified in Section 4.3 locate concentrations of older residents with weak 30-minute walking access and can support the spatial prioritisation of route and public-realm audits. They identify where further assessment is most warranted rather than prescribing interventions. At the local scale, Lijiang and Quanzhou have high mismatch (80.8% and 79.8%) despite 6.77 and 4.68 matched clusters per 100,000 residents aged 65+, directing attention to route continuity and access from homes. Xinghua has only four matched clusters and 67.2% mismatch; walking improvements around those sites may have limited reach without other modes. Pingyao combines the lowest mismatch (50.4%) with the highest matched-cluster density (25.02 per 100,000) and 30-minute access (35.7%). Its configuration is not a template for other cities. The screen identifies where detailed audits of paving, gradients, crossings, entrances, toilets

and conservation constraints are warranted (Ioannidis and Vozikis, 2007; Jimenez Martin et al., 2022; Das Mahapatra et al., 2023; Fan et al., 2024; Treccani et al., 2026).

The selected jurisdictions are not a probability sample and differ greatly in area; some contain extensive rural territory. Walking is only one mode, protected status does not ensure public opening, and older residents differ in health and preference (ICOMOS China, 2015; van Hoof et al., 2021; Ma et al., 2022; Stearns et al., 2023; Horstmann et al., 2026). The network model does not represent route surface, crossings, slope or the off-network connectors as walkable paths. Its transferability also awaits testing beyond these ten jurisdictions and the Chinese designation system. Institutional coordination between heritage-conservation and ageing-policy authorities lies beyond the scope of the present spatial model and would require a separate governance-focused research design. We therefore interpret the results as a comparative screen for nationally protected heritage opportunity under explicit assumptions.

6. Conclusion

Across ten jurisdictions, 409 unique heritage clusters were eligible and 389 matched the 2021 walking graph within 500 m. At 0.9 m/s, median 30-minute access among residents aged 65+ is 11.1%, compared with 14.1% at 4.0 km/h. Mobility assumptions change who falls within the modelled catchment.

Under the primary Q75 definition, median deficit exposure is 71.0% of the older population. It remains 71.6% after excluding network-unserved residents and 72.7% on a 500-m grid; removing Xi'an yields 73.9%. An origin-connector lower-bound check gives 71.9%. In this small and deliberately varied sample, heritage counts alone do not track effective opportunity.

The 2026 network preserves the 2021 city access ordering closely, although linkage shares are less stable. These diagnostics support the comparative pattern but do not validate actual walking routes, site entry or cultural participation. The practical contribution is a transparent spatial screening framework that locates areas where protected resources and ageing populations are poorly connected, providing an evidence base for prioritising subsequent route, public-realm, multimodal and site-level assessment.

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