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A Spatial Typology of University Campus Areas in Cold-Climate Cities: Evidence from Three Cities in Northeast China

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Abstract

Campus–city relationships are important for optimising campus areas in cold-climate cities. Existing classifications are largely based on location, openness, or spatial layout, but rarely distinguish combinations of campus–city spatial relationships. From a campus-area perspective, this study develops a spatial typology framework. It examines 53 samples in Harbin, Changchun, and Shenyang, treating the campus proper and its proximate urban area within 1000 m as a unified analytical unit. The study combines multilevel spatial characterisation with correlation, factor, and cluster analyses. The results show that four factors explain 61.25% of the variance before rotation and correspond to four dimensions: spatial interaction support, morphological difference, transport accessibility, and built-up intensity difference. Factor-score clustering identifies four types: interaction-dominant, transport-accessible, connection-imbalanced, and peripherally isolated. The silhouette coefficient averages 0.311, and the adjusted Rand index (ARI) averages 0.869 across resamples. All four occur in each city. Type composition does not differ significantly, but spatial distributions vary. Four winter-relevant spatial indicators load on three of these factors, representing spatial conditions potentially relevant in winter rather than measured climate effects. The typology extends classification from individual attributes to combinations of campus–city spatial relationships, supporting comparative research and type-specific regeneration.

Keywords: university campus; campus area; campus–city relationship; spatial typology; cold-climate city

1. Introduction

As urban development shifts towards the regeneration of existing built-up areas, campus–city relationships have become an important issue in the spatial optimisation of cold-climate cities [1]. Universities are no longer relatively self-contained educational institutions. By concentrating and sharing knowledge, human capital, and public resources, they increasingly participate in urban processes, thereby strengthening campus–city connections [2]. Accordingly, the research perspective needs to extend beyond the campus interior to encompass both the campus proper and its proximate urban area. The expansion of higher education in China has driven the rapid development of new campuses and university towns, creating a multi-period campus landscape alongside established campuses [3–5]. The degree of spatial connection between campuses and their surrounding urban areas varies considerably. Cold-climate conditions further affect the effectiveness of

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these connections in winter, as low temperatures and snow make non-motorised travel and walking more difficult [6].

Comparing campus–city relationships across campuses requires treating the campus proper and its proximate urban area as a unified analytical unit. Typological analysis can then be used to identify recurring spatial patterns. In this study, "campus-area space" refers to this combined spatial unit, in which the campus proper and its proximate urban area interact through spatial connections. This definition draws on Regional Architecture, whose regional perspective emphasises continuous interaction between buildings and their external environment [7–9]. Regional architecture provides a relational analytical approach for this study, characterised by amplification of vision, structural priority, and coordination of internal and external factors. This approach extends the scope of analysis from the campus proper to its proximate urban area. It identifies structural relationships across spatial levels and examines the connections, differences, and correspondences between campus and urban spaces. Previous campus studies have focused mainly on internal spatial form and quality of use, including urbanity, greening, and campus life [10]. As research has extended beyond campus boundaries, greater attention has been paid to physical and functional connections between campuses and cities. These studies show that campus size, location, and the surrounding urban environment can influence campus–city relationships [11,12]. Typological studies have used multiple morphological features, separately or in combination, to classify urban fabrics [13] and identify campus plot types [14,15]. Other studies have compared spatial perception across urban types [16]. Research in cold-climate contexts further shows that low temperatures and snow affect walking, accessibility, and space use [17].

Despite growing attention to campus–city relationships, three major limitations remain in identifying patterns of campus-area spatial relationships. First, existing studies often examine campus–city connections at a local level, with limited attention to the campus proper and its proximate urban area as an integrated whole [18,19]. Second, existing campus classifications are largely based on attributes such as location, degree of openness, or spatial layout, producing categories such as inner-city–peripheral, open–closed, and dispersed–compact [2,20,21]. These classifications give limited attention to differences in campus–city relationships arising from combinations of multiple spatial conditions. Third, research on campuses in cold-climate contexts has focused mainly on internal campus space and its use. Less attention has been paid to spatial conditions that may be particularly relevant to campus–city connections in winter [17,22]. To address these gaps, this study integrates campus–city relationships across spatial levels into comparable relational configurations. These configurations are then used to identify campus-area types. This approach differs from existing classifications that focus on individual campus–city interfaces, morphological characteristics, or accessibility. Within this relational framework, winter-relevant spatial conditions are treated as contextual features.

This study examines university campus areas in Harbin, Changchun, and Shenyang. It aims to identify differences in how spatial relationships between the campus proper and its proximate urban area are combined and to develop a typology of campus–city spatial relationships in cold-climate cities. Three interrelated research questions guide the study:

RQ1: What are the characteristics of the spatial relationships between the campus proper and its proximate urban area?

RQ2: What dominant dimensions can be identified from these spatial relationship characteristics, and how do the winter-relevant spatial indicators relate to these dimensions?

RQ3: What basic types can be identified from different combinations of spatial characteristics, and what cross-city differences do they exhibit?

To address these questions, this study develops a multilevel framework that incorporates winter-relevant spatial indicators to characterise campus-area space. Correlation, factor, and cluster analyses are used to identify dominant spatial dimensions and campus-area types. The identified types are then examined through representative cases to characterise their spatial features. Their composition and spatial distribution are further compared across the three cities.

2. Study Areas and Methods

2.1. Study Areas and Sample Units

2.1.1. Study Areas

The study was conducted in Harbin, Changchun, and Shenyang (Figure 1a). All three cities are located in Northeast China, with substantial concentrations of higher education institutions and diverse spatial distributions of university campuses. The study areas were selected based on two main considerations.

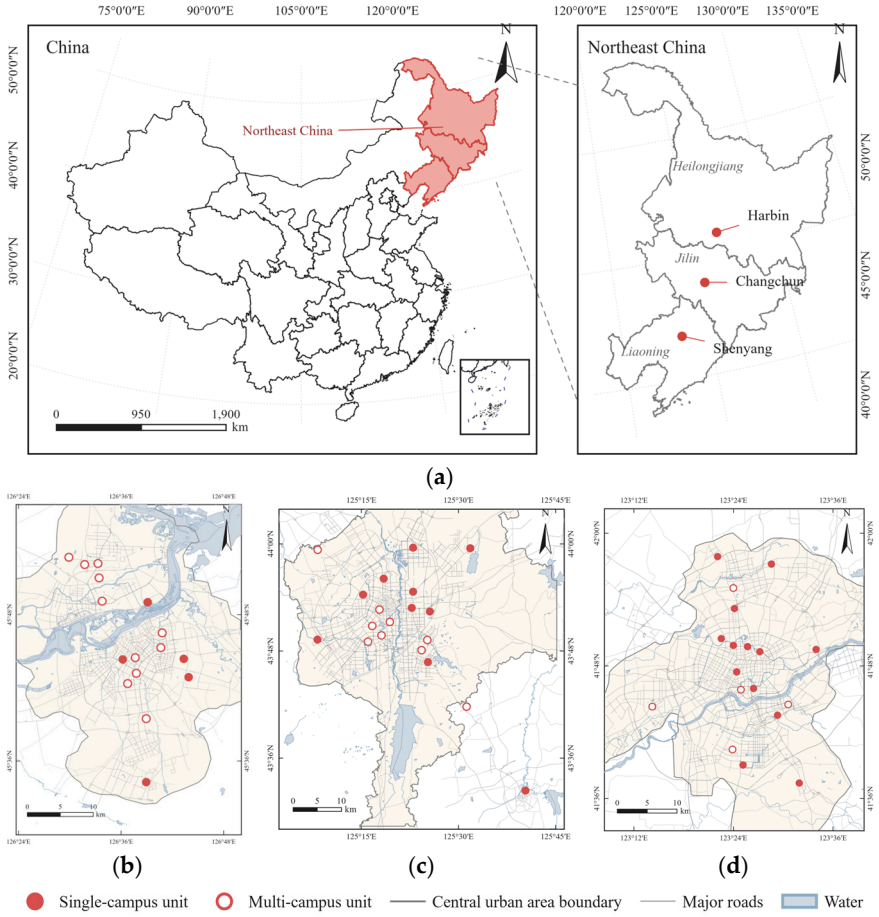


Figure 1. Location of the study cities and spatial distribution of campus-area sample units. (**a**) Study-area location; (**b**) Harbin; (**c**) Changchun; (**d**) Shenyang.

(1) Similar cold-climate conditions. All three cities experience prolonged winter conditions characterised by low temperatures, cold winds, snow cover, and icy surfaces.

(2) Differences in urban development and university distribution. The three cities differ in their development trajectories, urban expansion patterns, and spatial distribution of universities. In Harbin, universities are largely concentrated in traditional urban areas and established educational and cultural districts. Changchun shows a pattern of university concentration in the central urban area alongside peripheral university towns. Shenyang,

by contrast, is characterised by established campuses in the central urban area and multiple university clusters at the periphery.

The shared cold-climate conditions and contrasting urban spatial contexts provide a comparative basis for identifying the basic spatial types of university campus areas and their cross-city differences.

2.1.2. Campus Selection and Sample Unit Construction

Campuses in the three cities that support undergraduate teaching, research, or comprehensive academic functions were used as the basic spatial objects. Campus-area sample units were then constructed based on their spatial distribution. A university refers to the institutional entity. A campus is defined as a physically distinct unit with an independent site boundary. A sample unit is the analytical unit used for subsequent indicator calculation and type identification. A university may comprise multiple campuses. A sample unit may consist of one or more campuses.

(1) Campus selection. Campus selection was based on undergraduate higher education institutions listed in the 2026 National List of Higher Education Institutions [23]. Higher vocational colleges, technician colleges, independent research bases, and continuing-education facilities were excluded. Campuses that were inactive, were under construction, or had boundaries that could not be reliably determined were also excluded. Spatially separate campuses belonging to the same university were treated as distinct campuses when each had an independent site boundary. This procedure identified 103 campuses across 79 undergraduate higher education institutions.

(2) Sample unit construction. Following the identification of individual campuses, single-campus and multi-campus sample units were established through a consistent map-based assessment of spatial proximity and major spatial barriers between campuses. Single-campus sample units were defined for spatially separate campuses. Nearby campuses separated by major barriers, such as express transport corridors, railways, or rivers, were also treated as separate units. Multi-campus sample units were formed by grouping closely spaced campuses with distinct boundaries and no major spatial barriers between them. This grouping was intended to avoid repeated measurement of substantially overlapping surrounding urban areas. Once the sample units were defined, the proximate urban area of each unit was delineated by extending 1000 m outward from the boundaries of its constituent campus or campuses. The indicators were then calculated for each sample unit. Using Harbin as an example, Figure 2 illustrates sample-unit delineation together with the composition of single-campus and multi-campus units. The 103 campuses were ultimately grouped into 55 initial sample units: 16 in Harbin, 19 in Changchun, and 20 in Shenyang. The constituent campuses of the 53 samples included in the final analysis are listed in Table A1.

(3) Analysis extent and valid sample determination. Each sample unit comprised the campus proper and its proximate urban area, defined by a 1000 m Euclidean buffer extending outward from the campus boundaries. The campus proper reflected internal spatial organisation. The proximate urban area was used to characterise the supporting conditions provided by surrounding roads, the built environment, public transport, and urban functions. The 1000 m extent was based on the typical scale of a 15-min walking neighbourhood [24]. It also drew on the approximately 1 km campus surroundings adopted in previous studies of campuses and university towns [25,26]. This extent served as a consistent measurement scale for proximate urban areas to ensure comparability across samples. It did not represent the actual walking catchment delineated along the road network. Actual walking catchments may vary with seasonal walking conditions, spatial barriers, campus size, and street-network morphology. After checks for spatial data com-

pleteness and anomalies, 54 of the 55 initial sample units were suitable for the analysis of relationships among spatial characteristics. One of these samples had insufficient data for some indicators. The subsequent multivariate analyses therefore included 53 samples to derive the spatial dimensions and identify spatial types. Their spatial distribution across the three study cities is shown in Figure 1b–d, and their composition is summarised in Table 1.

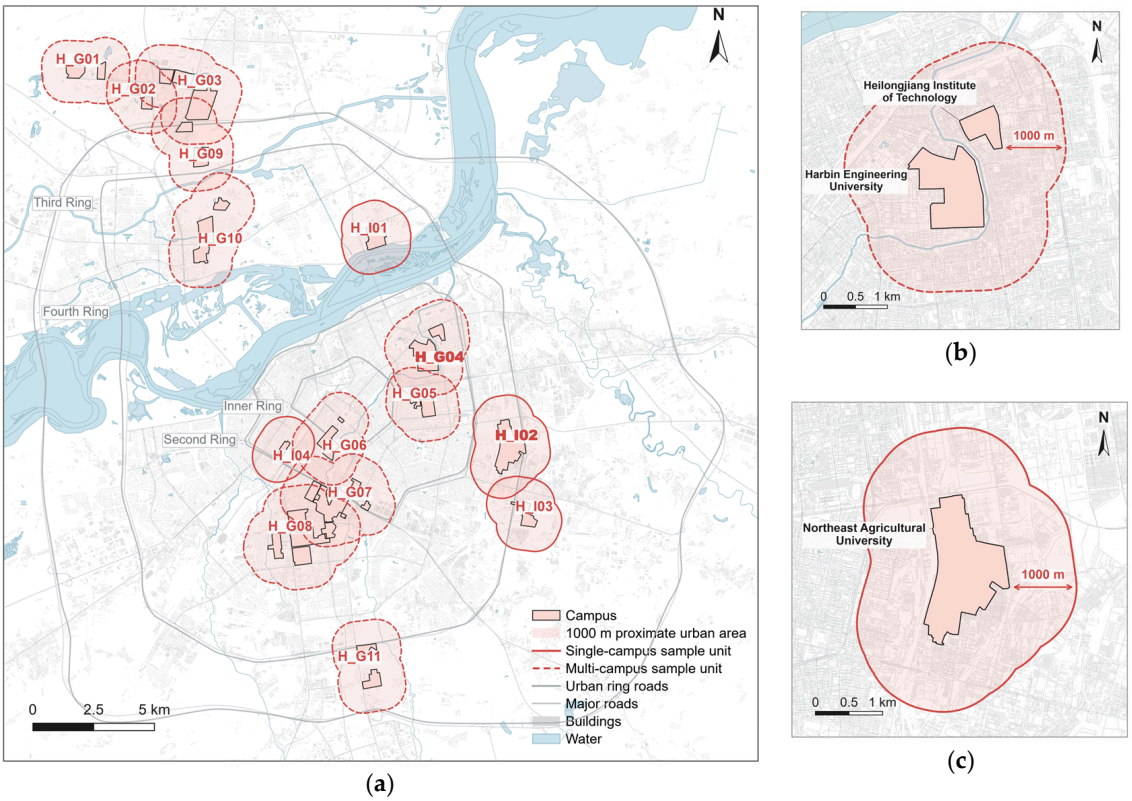


Figure 2. Sample-unit delineation and composition in Harbin. (**a**) Sample-unit delineation; (**b**) multi-campus sample unit (H_G04); (**c**) single-campus sample unit (H_I02).

Table 1. Composition of campus-area sample units across the three study cities.

City	Campuses	Initial Sample Units	Valid Sample Units	Single-Campus Units (IDs)	Multi-Campus Units (IDs)
Harbin	33	16	16	H_I01–H_I05 (n = 5)	H_G01–H_G11 (n = 11)
Changchun	41	19	19	C_I01–C_I10 (n = 10)	C_G01–C_G09 (n = 9)
Shenyang	29	20	18	S_I01–S_I09, S_I11, S_I13–S_I15 (n = 13)	S_G01–S_G05 (n = 5)
Total	103	55	53	28	25

2.2. Research Methods

This study combined spatial analysis, statistical analysis, and comparative case analysis. Figure 3 illustrates the three-stage analytical workflow: multilevel spatial characterisation of campus areas; spatial feature synthesis and type identification; and interpretation of spatial types and cross-city comparison.

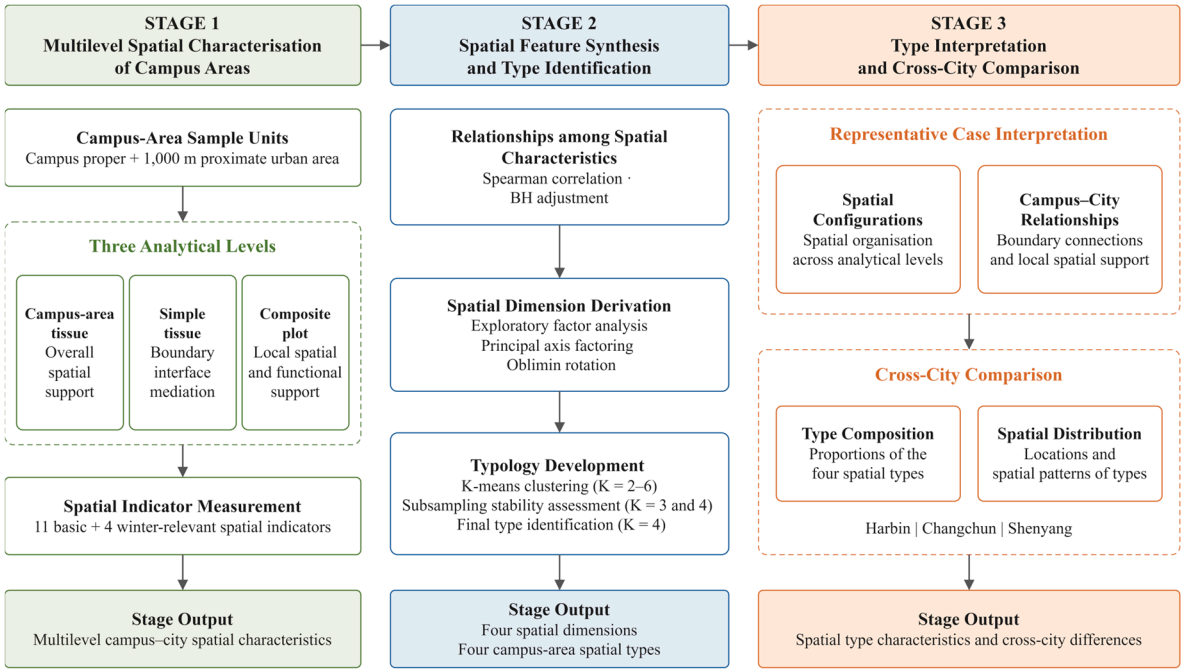


Figure 3. Research workflow of the study.

2.2.1. Multilevel Spatial Characterisation of Campus Areas

Campus–city spatial relationships involve overall structure, boundary interfaces, and local spatial configurations. They cannot be adequately characterised at a single scale or through individual spatial elements. Previous urban morphology studies have emphasised the characterisation of the built environment across multiple elements and scales, including streets, plots, buildings, and land use [27–29]. Based on the "part–whole" hierarchical relationship in morphological typology [30], campus-area space was divided into three analytical levels: campus-area tissue, simple tissue, and composite plot. Spatial indicators were then used to quantify the relational characteristics at each level. This multilevel characterisation translated the relational perspective of regional architecture into a measurable analytical approach. The three analytical levels were used to identify structural relationships within each campus area. At these levels, relational indicators characterised the connections, differences, and correspondences between the campus proper and its proximate urban area. These relationships were further examined in subsequent statistical analyses.

(1) Spatial level division. At the campus-area tissue level, the campus proper and its proximate urban area were treated as an integrated spatial unit. This level examined the overall spatial support between the campus and the surrounding built environment, road network, plot morphology, and public transport. At the simple tissue level, the analysis focused on the campus boundary, adjoining streets, and internal and external roads. It assessed whether the surrounding urban network could connect across the boundary and extend into the campus. At the composite plot level, the analysis examined local combinations of built space, open space, and functional facilities on both sides of the campus boundary. It assessed how these combinations supported activities and service connections across the boundary. The three levels progressed from overall to local conditions and together formed a relational sequence of 'overall spatial support–boundary interface mediation–local spatial and functional support'. Figure 4 illustrates the spatial extents and progression of the three levels in H_G05.

(2) Spatial indicator selection. Indicator selection followed four principles: spatial-level correspondence, relational relevance, relative comparability, and winter relevance. Each

indicator was assigned to a specific spatial level and measurement object. The indicators were selected to capture relationships between the campus proper and its proximate urban area. All subsequent measurements were conducted at the sample-unit level. Comparable quantitative measures, including densities, proportions, coverage rates, and relative campus–city ratios, were prioritised to reduce the influence of differences in campus size, morphology, and urban location on comparisons across samples. Type identification was not based on the number of campuses within each sample unit. Single-campus and multi-campus sample units could therefore be compared on a consistent measurement basis. Among these indicators, PTA, WTD, and NISC were measured using pedestrian network distances to characterise pedestrian connections. This network-based measurement differs from the 1000 m Euclidean extent used to delineate the proximate urban area.

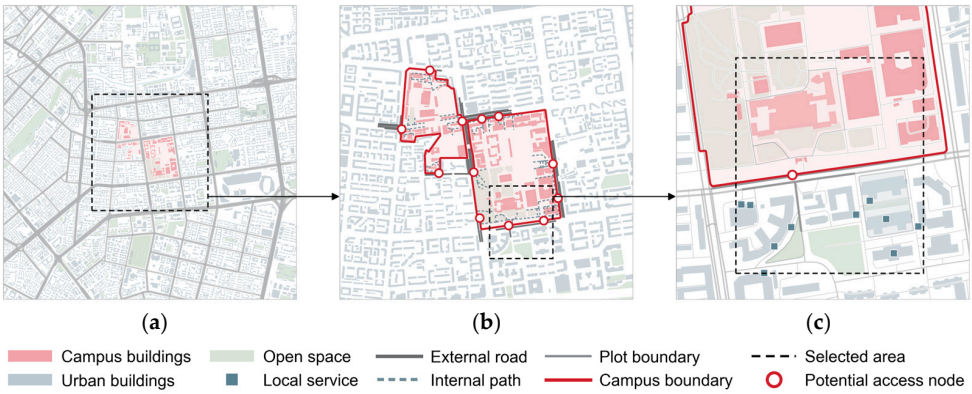


Figure 4. Extents and progression of the three spatial levels in H_G05. (**a**) Campus-area tissue; (**b**) simple tissue; (**c**) composite plot.

Based on these principles, a multilevel system of 15 spatial indicators was developed, including 11 basic indicators and 4 winter-relevant spatial indicators (Table 2). The basic indicators characterised spatial morphology, road traffic conditions, and functional configuration under normal conditions. Winter-relevant spatial indicators captured static spatial characteristics that may be more important in winter. These included campus–city open-space separation, pedestrian access distance to public transport, boundary detours, and nearby indoor services. The winter relevance of these indicators was based on previous research. This study did not directly observe winter behaviour, microclimatic exposure, snow conditions, or seasonal mobility. Accordingly, these indicators supplemented the characterisation of basic spatial relationships and were not treated as direct measures of cold-climate effects. Operational definitions, key measurement parameters, and decision rules are provided in Appendix A.2 Table A2.

2.2.2. Spatial Feature Synthesis and Type Identification

Spatial feature synthesis and type identification were conducted in three steps: association analysis, spatial dimension derivation, and type development.

First, correlation analysis was used to identify relationships among campus-area characteristics across different spatial levels. Spearman's rank correlation was applied to test monotonic associations among the 15 spatial indicators. The Benjamini–Hochberg procedure was used to adjust for multiple testing. Similar multi-indicator association analyses have been applied to studies of built-environment and functional characteristics around university campuses [31]. Correlation analysis was used to identify associations across spatial levels. It also examined relationships between basic and winter-relevant spatial indicators. These associations were interpreted as statistical relationships rather than evidence of climatic effects or causality.

Table 2. Multilevel spatial indicator system for campus areas in cold-climate cities.

Spatial Level	Analytical Focus	Indicator Type	Indicator	Measurement	Calculation
Campus-area tissue	Overall spatial support	Basic spatial indicators	BEC	Measures the continuity of the proximate built-up environment adjoining the campus	$BEC_i = \frac{\max_{B_{ij} \in B_i^{adj}} A(B_{ij})}{\sum_{B_{ij} \in B_i} A(B_{ij})}$
			R_AR	Measures the ratio of campus plot area to the mean area of surrounding urban blocks	$R_{AR,i} = \frac{A(C_i)}{\overline{A}_{pi}}$
			R_CO	Measures the ratio of campus compactness to the mean compactness of surrounding urban blocks	$R_{CO,i} = \frac{CO_{Ci}}{\overline{CO}_{pi}}, CO(X) = \frac{4\pi A(X)}{(L(X))^2}$
			R_BD	Measures the ratio of campus building coverage to that of the proximate urban area	$R_{BD,i} = \frac{BD_i^C}{BD_i^U}$
			RND	Measures the density of the road network in the proximate urban area	$RND_i = \frac{\sum_{r \in R_i} L(r)}{A(U_i)}$
			PTA	Measures the proportion of campus-boundary sample points with access to at least one public transport stop within the specified walking-network distance	$PTA_i = \frac{\sum_{j=1}^{m} I_{ij}^{PTA}}{m}$
		Winter-relevant spatial indicators	OGD	Measures the mean open-space gap between the campus boundary and the continuous urban built-up area	$OGD_i = \frac{\sum_{j=1}^{m} d_{ij}^{OGD}}{m}$
			WTD	Measures the mean walking-network distance from potential campus access nodes to the nearest public transport stop	$WTD_i = \frac{\sum_{j=1}^{r_i} d_{ij}^{WTD}}{r_i}$
Simple tissue	Boundary interface mediation	Basic spatial indicators	BC	Measures the density of potential access nodes that connect the internal and external path systems	$BC_i = \frac{N(G_i)}{L_i}$
			BSC	Measures the proportion of the campus boundary adjoining continuous urban streets	$BSC_i = \frac{\sum_{j=1}^{q} I_{ij}^{BSC} L(l_{ij})}{L_i}$
		Winter-relevant spatial indicators	BDD	Measures the upper-tail detour distance along the campus boundary from boundary sample points to the nearest potential access node	$BDD_i = Q_{0.90}\left\{\min_{g \in G_i} d_{\partial C}(s_{ij}, g)\right\}_{j=1,\ldots,m}$
Composite plot	Local spatial and functional support	Basic spatial indicators	OSA	Measures the extent to which open spaces on both sides of the campus boundary are directly adjacent	$OSA_i = \frac{\sum_{j=1}^{q} I_{ij}^{OSA} L(l_{ij})}{L_i}$
			FM	Measures the diversity and evenness of functional types in the proximate urban area	$FM_i = -\frac{\sum_{k=1}^{K} p_{ik} \ln(p_{ik})}{\ln(K)}$
			FCD	Measures the difference in functional composition between the campus and the proximate urban area	$FCD_i = \frac{1}{2} \sum_{k=1}^{K} \lvert p_{ik}^C - p_{ik}^U \rvert$
		Winter-relevant spatial indicators	NISC	Measures the proportion of campus-boundary sample points with access to major indoor services within the specified walking-network distance	$NISC_i = \frac{\sum_{j=1}^{m} I_{ij}^{NISC}}{m}$

Abbreviations: BEC, built-environment continuity; R_AR, relative plot area; R_CO, relative compactness; R_BD, relative building coverage; RND, road-network density; PTA, public transport accessibility; OGD, open-space gap distance; WTD, walking distance to public transport; BC, boundary connectivity; BSC, boundary–street continuity; BDD, boundary detour distance; OSA, open-space adjacency; FM, functional mix; FCD, functional composition difference; NISC, nearby indoor service coverage.

Second, exploratory factor analysis was used to derive the dominant dimensions of spatial variation among campus areas. After confirming data suitability, common factors were extracted using principal axis factoring. Oblimin rotation was then applied to allow for potential correlations among the spatial dimensions. The number of dimensions was determined based on eigenvalues, the scree plot, and the interpretability of the resulting spatial structure. Each dimension was then interpreted from an architectural perspective based on its high-loading indicators and the campus–city spatial relationships they represented. To assess the robustness of the four-factor structure, we conducted a sensitivity analysis by excluding the three indicators with the lowest communalities (FM, FCD, and BSC). The remaining 12 indicators were reanalysed using the same factor extraction and rotation procedures, with four factors retained. We then compared their primary factor assignments and main high-loading indicator groups with the original solution.

Finally, K-means clustering was applied to standardised factor scores to identify groups of samples with similar combinations of spatial characteristics. This approach was informed by previous quantitative studies of campus-space classification [32,33]. Candidate solutions from K = 2 to K = 6 were compared in terms of cluster separation, within-cluster variation, and cluster size. The K = 3 and K = 4 solutions were further assessed through subsampling-based stability analysis because their mean silhouette coefficients were very similar. In each of 1000 iterations, 80% of the 53 samples were randomly selected without replacement and reclustered. The adjusted Rand index (ARI) was used to assess overall clustering stability, while the Jaccard similarity coefficient was used to assess the stability of individual clusters. Sample-level assignment consistency was also calculated to identify boundary samples with relatively low stability. Final sample assignments were determined directly by the selected K-means clustering solution, without adjustment based on spatial interpretation.

The analysis was repeated at 800 m and 1200 m to assess the sensitivity of type identification to spatial extent. The 53 sample units and their composition remained unchanged. For each alternative buffer, the affected indicators were recalculated using the original procedures. Factor analysis and K-means clustering were then performed using the 1000 m baseline procedures. Four factors were extracted, and K was fixed at 4. Factor loading patterns and sample cluster assignments were compared across the three buffer extents to assess the stability of the four-type structure identified at 1000 m.

2.2.3. Interpretation and Cross-City Comparison of Spatial Types

Following type identification, sample spatial maps were prepared using consistent rules. Representative cases were then used to interpret the spatial relationship characteristics of each type. The identified spatial types were then mapped across Harbin, Changchun, and Shenyang. Type composition among the three cities was assessed using the Fisher–Freeman–Halton exact test. Spatial distribution was then compared based on the mapped type patterns.

2.3. Data Sources and Processing

2.3.1. Data Sources

The data used in this study were obtained from three main sources.

(1) Institutional and campus data. Institutional and campus information was cross-checked against the Ministry of Education's list of higher education institutions, official university websites, Amap, and remote-sensing imagery.

(2) Morphological and environmental data. Campus boundaries, road networks, building footprints, green spaces, and water bodies were obtained from Amap. These data

were used to establish the morphological base for the campus proper and its proximate urban area. They were also used to calculate road, building, plot, and open-space indicators.

(3) Public transport and functional data. Points of interest (POIs) obtained from Amap included bus stops, rail transit stations, and commercial, daily-life, public, healthcare, cultural and sports facilities, as well as educational and research services. The facility POIs were used to characterise the functional configuration of the proximate urban area [34]. Together with public-transport POIs, they were used to measure transport connections and functional support conditions. Figure 5 illustrates the main datasets used for spatial indicator measurement, using H_I02 as an example.

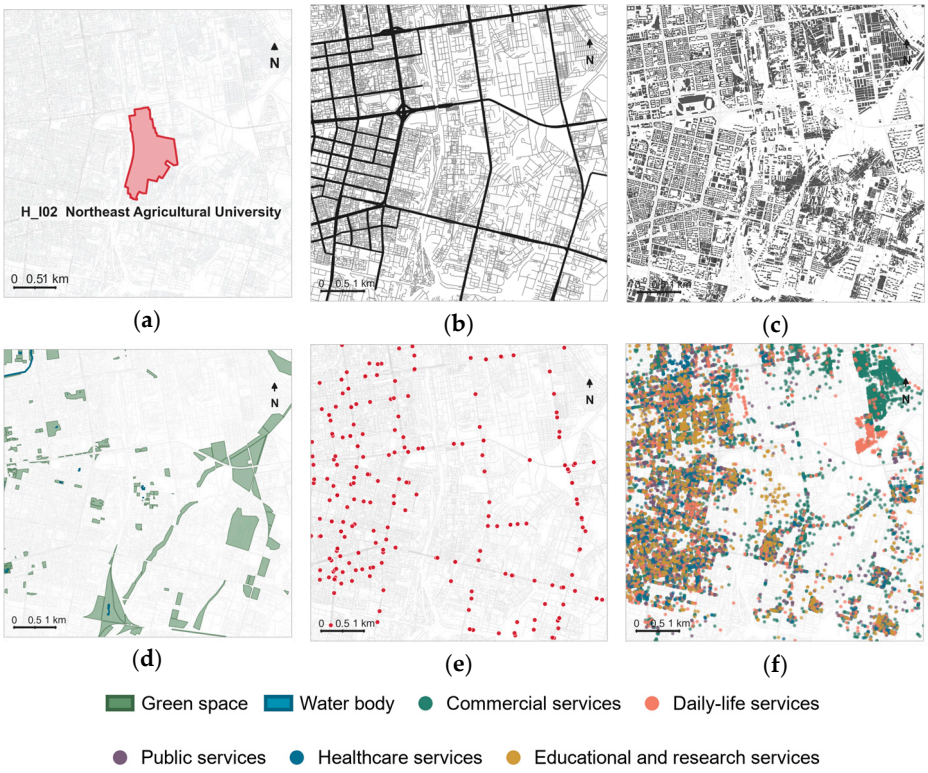


Figure 5. Main spatial data layers for campus-area analysis. (**a**) Campus boundary; (**b**) road network; (**c**) building footprints; (**d**) green spaces and water bodies; (**e**) public transport stops; (**f**) facility POIs.

2.3.2. Data Processing

Raw spatial data for all samples were corrected and standardised using consistent procedures. A 7 km × 7 km data-acquisition window was centred on the geometric centroid of each sample unit to ensure full coverage of the predefined analysis extent. The window was used only for data acquisition and did not alter the analysis extent used for indicator calculation. Amap data were converted from GCJ-02 to WGS 84 and projected into the corresponding metric coordinate system. Subsequent processing included standardising sample IDs, spatial clipping, geometry repair, duplicate removal, and functional reclassification of POIs. POIs were reclassified primarily using the Amap typecode field. The original categories were consolidated into eight functional categories. The mid_type field was used to refine classifications requiring further differentiation. Records that could not be reliably mapped were excluded from the calculation of functional composition indicators. The same classification rules were applied across all three cities. The Amap spatial data archived in the project database were inventoried, standardised, and subsequently processed using consistent procedures in July 2026.

Processed spatial data were indexed by sample ID. Indicators were then calculated according to the predefined analysis extents and measurement rules. Road-network distances,

boundary distances, areas, and lengths were measured in a consistent metric projected coordinate system. The results were verified through visual inspection of spatial outputs, data-completeness checks, and outlier screening.

3. Results

3.1. Relationships Among Campus-Area Spatial Characteristics

Correlation analysis revealed significant cross-level associations among campus-area tissue, simple tissue, and composite plot characteristics (Figure 6). These associations were primarily reflected in three relationships: continuity between the overall urban structure and local campus space, correspondence between spatial morphology and proximate urban functions, and correspondence between basic spatial connections and winter-relevant spatial indicators.

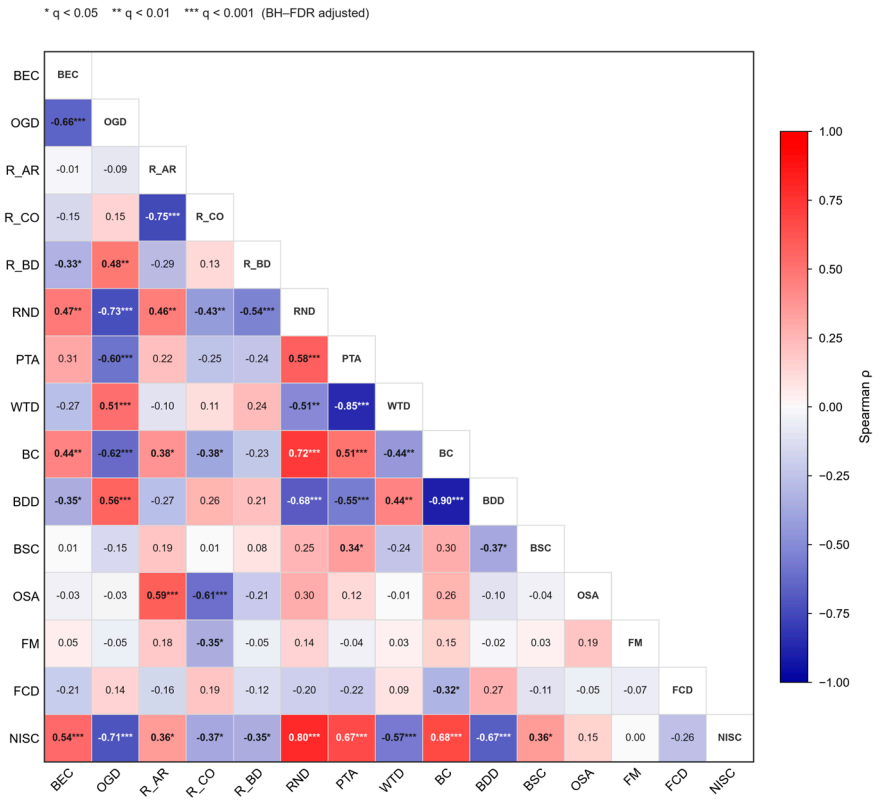


Figure 6. Spearman correlation matrix of the 15 spatial indicators.

3.1.1. Continuity Between Proximate Urban Structure and Local Campus Space

Proximate urban structure was closely associated with local campus space, primarily through the continuous correspondence between surrounding spatial conditions and campus boundary access. RND was strongly and positively correlated with BC ($\rho = 0.723$) and negatively correlated with BDD ($\rho = -0.681$), while OGD was negatively correlated with BC ($\rho = -0.619$). These relationships indicated that denser proximate road networks and smaller campus–city open-space separations generally corresponded to greater campus boundary connectivity and shorter boundary detours.

3.1.2. Correspondence Between Spatial Morphology and Proximate Urban Functions

Spatial morphology was clearly associated with proximate urban functions, although the strength of these relationships varied across spatial characteristics. RND was strongly and positively correlated with NISC ($\rho = 0.802$), while BEC was positively correlated with NISC ($\rho = 0.538$) and OGD was negatively correlated with NISC ($\rho = -0.709$). These rela-

tionships indicated that denser road networks, greater continuity of the built environment, and smaller campus–city separations were generally associated with greater nearby indoor service coverage.

Campus plot morphology was also associated with the adjacency of open spaces on either side of the campus boundary. R_AR was positively correlated with OSA ($\rho = 0.588$), whereas R_CO was negatively correlated with OSA ($\rho = -0.607$), indicating that larger, less compact campuses generally had greater open-space adjacency. However, BC was only weakly and negatively correlated with FCD ($\rho = -0.319$), suggesting that stronger boundary connectivity did not necessarily imply closer functional correspondence between the campus and its proximate urban area.

3.1.3. Correspondence Between Basic Spatial Connections and Winter-Relevant Spatial Indicators

Basic spatial connections were clearly associated with winter-relevant spatial indicators, particularly through relationships involving transport conditions and campus boundary access. RND was negatively correlated with WTD ($\rho = -0.506$), while PTA was positively correlated with NISC ($\rho = 0.670$) and negatively correlated with BDD ($\rho = -0.553$). These relationships indicated that better road and public transport conditions were generally associated with shorter walking connections to public transport, less boundary detouring, and greater access to nearby indoor services.

Walking distance to public transport was also associated with campus boundary access. WTD was positively correlated with BDD ($\rho = 0.442$) and negatively correlated with BC ($\rho = -0.438$), indicating that longer walking connections to public transport were generally associated with greater boundary detours and poorer campus boundary access.

3.2. Key Spatial Dimensions and Type Identification

3.2.1. Key Spatial Dimensions

The shared variation across the multilevel indicators was captured by four cross-level dimensions: spatial interaction support, morphological difference, transport accessibility, and built-up intensity difference. The Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity indicated that the data were suitable for exploratory factor analysis (KMO = 0.724; $\chi^2(105) = 430.556$, $p < 0.001$). Four factors were retained based on the eigenvalue distribution, rotated loading structure, and spatial interpretability. The resulting solution showed four relatively clear loading patterns with distinct spatial meanings. Indicators related to boundary access and spatial interaction, relative morphological differences, public transport access, and built-up intensity differences and associated spatial characteristics loaded primarily on Factors 1–4, respectively. The four-factor solution accounted for 61.25% of the total variance before rotation. The four dimensions were named based on their factor-loading patterns and architectural interpretation (Table 3).

Table 3. Pattern loadings for the four-factor solution.

Factor	Positive Indicators	Negative Indicators
Factor 1: Spatial interaction support	BC (0.877), NISC (0.441), BSC (0.365)	BDD (−0.856), FCD (−0.414)
Factor 2: Morphological difference	R_CO (0.845)	R_AR (−0.843), OSA (−0.727), FM (−0.283)
Factor 3: Transport accessibility	PTA (1.009)	WTD (−0.833)
Factor 4: Built-up intensity difference	R_BD (0.729), OGD (0.664)	BEC (−0.541), RND (−0.480)

Note: Pattern loadings after Oblimin rotation are reported. Positive and negative loadings indicate the direction of association with each factor rather than better or worse spatial conditions. The cumulative unrotated extracted variance of the four-factor solution was 61.25%; the corresponding unrotated variance estimates are reported in Table A3.

The sensitivity analysis yielded a KMO value of 0.745, and Bartlett's test of sphericity was significant ($\chi^2(66) = 402.396$, $p < 0.001$). Eleven of the 12 indicators retained their original primary factor assignments. The key high-loading indicator groups also remained similar to those in the original analysis. Together, these results indicate that the core four-factor structure was largely stable in this sensitivity analysis.

The four dimensions represented distinct aspects of campus–city spatial relationships. Spatial interaction support concerned boundary access, detour distance, and nearby service provision under proximate urban conditions. Morphological difference captured relative contrasts in plot scale, plan form, and open-space organisation between the campus and surrounding urban fabric. Transport accessibility combined public transport coverage with walking distance from campus access points to nearby stops. Built-up intensity difference characterised relative variation in building coverage, built-environment continuity, road-network density, and campus–city open-space separation. The four winter-relevant spatial indicators loaded onto these dimensions rather than forming a separate common factor.

3.2.2. Type Identification

The combinations of the four spatial dimensions differentiated the samples into four groups (Figure 7). Based on the factor configurations and interpretation of spatial relationships, these groups were identified as the interaction-dominant, transport-accessible, connection-imbalanced, and peripherally isolated types.

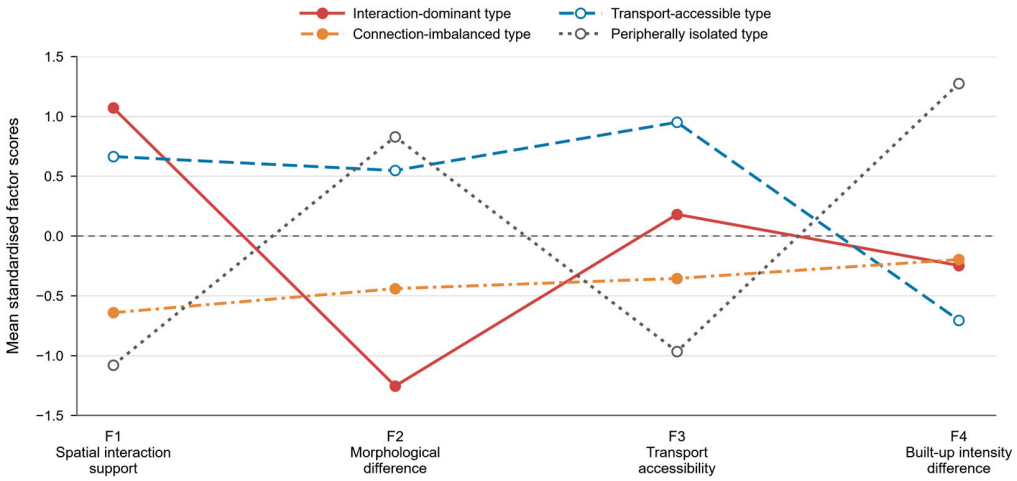


Figure 7. Mean standardised factor scores of the four spatial types.

Among the candidate clustering solutions, K = 4 had a mean silhouette coefficient of 0.311, close to 0.317 for K = 3 (Table 4). However, K = 4 had a lower Davies–Bouldin index (1.131 vs. 1.234). WCSS decreased by a further 20.9%, and the four clusters were relatively balanced in size (11, 16, 14, and 12). The main change was that the 20 samples in one K = 3 cluster were split evenly between two K = 4 clusters. The other two clusters remained largely unchanged. These two K = 4 clusters differed mainly in spatial interaction support and morphological difference. Their cluster centres for these two dimensions were (1.070, −0.654) and (−1.255, −0.422), respectively. Thus, K = 4 distinguished factor configurations that had been combined in the K = 3 solution.

Resampling analysis showed comparable overall stability for the K = 3 and K = 4 solutions. Across 1000 subsampling iterations, their mean ARI values were 0.864 and 0.869, respectively. The corresponding 2.5th–97.5th percentile ranges were 0.368–1.000 and 0.599–1.000. For K = 4, the mean Jaccard similarity coefficients ranged from 0.845 to 0.936 across the four clusters, indicating high resampling consistency. A few boundary samples showed relatively low assignment stability, but their assignments were not adjusted. De-

tailed overall and cluster-level resampling stability results are provided in Table A4. Based on these comparisons, K = 4 was retained. The final assignments of all 53 samples were determined directly by the K = 4 clustering solution. Spatial relationship interpretation was used only to characterise and name the types (Table 5).

Table 4. Comparison of candidate clustering solutions.

K	Mean Silhouette Coefficient	Davies–Bouldin Index	WCSS Reduction from Previous K (%)	Minimum Cluster Size	Assessment
2	0.311	1.186	—	21	Substantial merging of types
3	0.317	1.234	27.1	15	Some distinct factor configurations merged
4	**0.311**	**1.131**	**20.9**	**11**	**Additional factor configuration distinguished**
5	0.302	1.028	15.0	6	Small cluster emerged
6	0.311	1.068	14.8	6	Further fragmentation of types

Table 5. Assignment of the 53 campus-area samples to the four spatial types.

Cluster	Spatial Type	*n*	Harbin	Changchun	Shenyang
K1	Interaction-dominant type	11	H_G03, H_G04, H_G07, H_G08	C_G01, C_G02, C_G03, C_G04	S_I02, S_G01, S_G02
K2	Transport-accessible type	16	H_I04, H_G02, H_G05, H_G06	C_I01, C_I02, C_I03, C_I05, C_I06, C_I10, C_G05	S_I01, S_I03, S_I05, S_I07, S_I15
K3	Connection-imbalanced type	14	H_I02, H_I03, H_G01, H_G09, H_G10	C_I04, C_G06, C_G07	S_I09, S_I11, S_I14, S_G03, S_G04, S_G05
K4	Peripherally isolated type	12	H_I01, H_I05, H_G11	C_I07, C_I08, C_I09, C_G08, C_G09	S_I04, S_I06, S_I08, S_I13
Total		53	16	19	18

Sensitivity analysis showed that the four-factor structures at 800 m and 1200 m were broadly consistent with the 1000 m baseline. The same 53 sample units were used at all three scales. The K = 4 clustering results at 800 m were identical to those at 1000 m (ARI = 1.000). Agreement remained high at 1200 m (ARI = 0.811), with 49 of the 53 samples retaining their original cluster assignments. Overall, the four-cluster structure remained stable across the tested buffer extents.

3.3. Characterisation of the Four Spatial Types

The interaction-dominant type comprised 11 samples (20.8%). It was characterised by high spatial interaction support and low morphological difference, while transport accessibility and built-up intensity difference remained close to the overall average. Its defining feature was the presence of multiple points of correspondence among proximate roads, campus boundary access, and local services. H_G07 comprised Northeast Forestry University, Harbin Normal University (Jiangnan Campus), Heilongjiang University of Chinese Medicine, and Harbin University of Science and Technology (East Campus). The four campuses were embedded in a continuous urban road network formed by Hexing Road, Heping Road, Sandadongli Road, and adjacent streets. Multidirectional boundary access points created multiple connections to the surrounding road network, producing a spatial structure of "dispersed layout–road-network linkage–multiple access points" (Figure 8a).

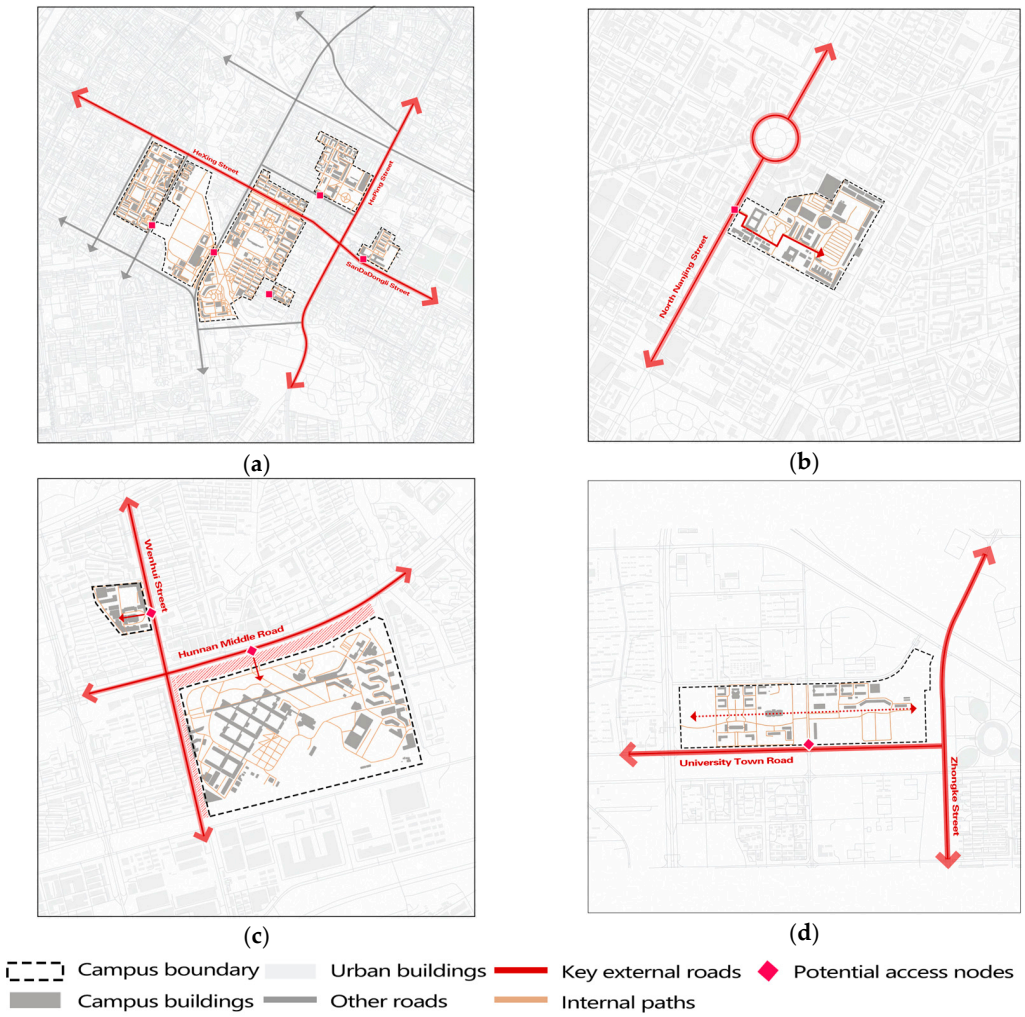


Figure 8. Representative cases of the four spatial types. (**a**) Interaction-dominant—H_G07; (**b**) transport-accessible—S_I03; (**c**) connection-imbalanced—S_G03; (**d**) peripherally isolated—C_I07.

The transport-accessible type comprised 16 samples (30.2%), the largest share among the four types. Transport accessibility was its most prominent dimension, while spatial interaction support and morphological difference were also above the overall average. Public transport coverage was extensive, and walking distances from public transport stops to campus access points were short. At specific boundary locations, these access points connected directly to the main internal paths. S_I03 corresponded to China Medical University. The campus was well served by public transport. Along Nanjing North Street, transport access nodes were closely aligned with an existing campus entrance and the main internal paths. This created a continuous transport connection from external arrival through boundary access to internal circulation (Figure 8b).

The connection-imbalanced type comprised 14 samples (26.4%). Spatial interaction support, morphological difference, and transport accessibility were all below the overall average, while built-up intensity difference remained close to the mean. Peripheral roads, campus access points, and internal paths were present, but their spatial relationships were often misaligned. This resulted in a pattern of "local access but insufficient overall connection". S_G03 comprised Shenyang Conservatory of Music (Changqing Campus) and Shenyang Jianzhu University. Each campus had a clear external access sequence: Wenhui Street–East Gate–internal paths for the former, and Hunnan Middle Road–campus entrance–main internal road for the latter. However, the two connections remained spatially

separated within the cluster, with limited lateral linkage among open spaces, internal paths, and functions (Figure 8c).

The peripherally isolated type comprised 12 samples (22.6%). Spatial interaction support and transport accessibility were the lowest among the four types, whereas morphological difference and built-up intensity difference were relatively high. Internal campus organisation was generally coherent, but connections to surrounding roads, continuous built-up areas, and proximate services were limited. C_I07 corresponded to Changchun University of Technology (Beihu Campus). Internal roads and building clusters extended continuously along the campus's longitudinal axis, forming a coherent internal spatial structure. Daxuecheng Road and Zhongke Street provided relatively strong urban connections at specific locations. However, effective access along the long campus boundary remained concentrated at only a few points, while connections between peripheral roads and internal spaces were weaker in other directions. This produced a spatial relationship of "internal continuity–node-based peripheral connections" (Figure 8d).

3.4. Cross-City Comparison of Type Composition and Spatial Distribution

All four spatial types occurred in each of the three cities (Figure 9a). The Fisher–Freeman–Halton exact test showed no significant difference in type composition among the three cities ($p = 0.905$). The three cities differed mainly in the spatial distribution and configuration of the four types.

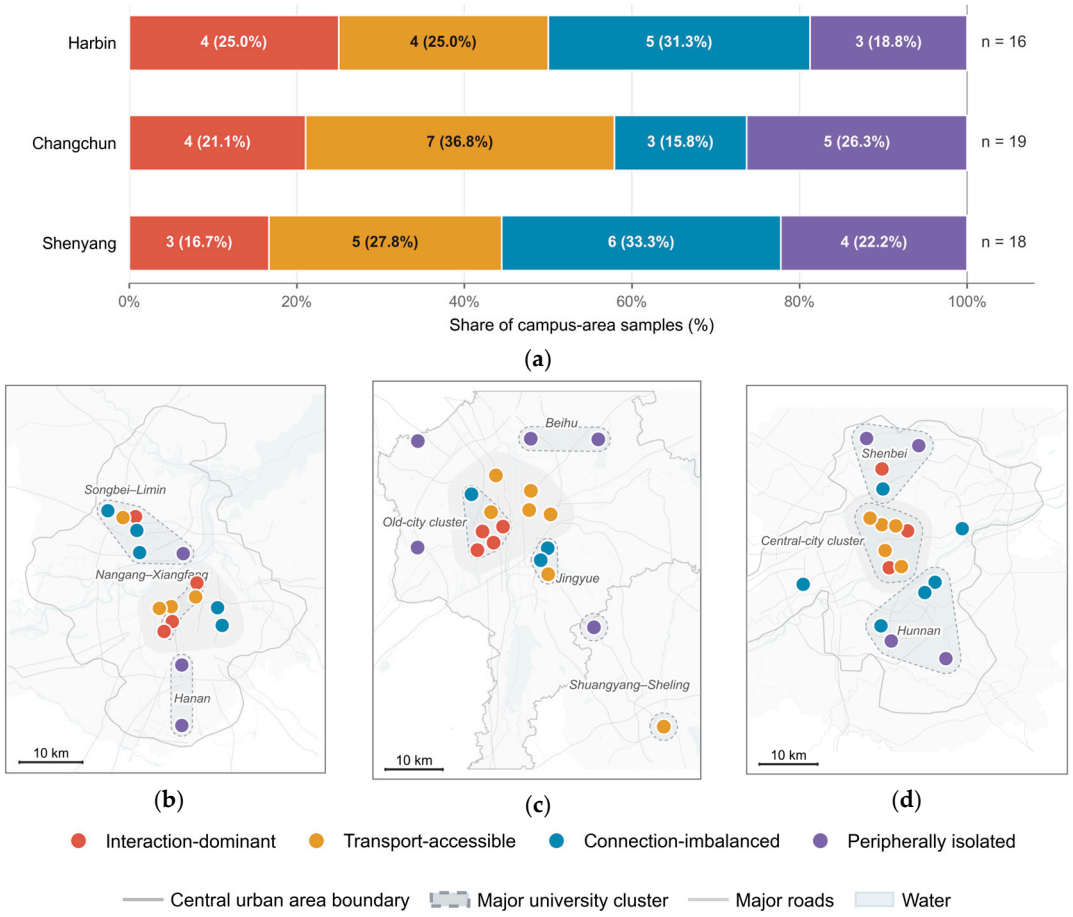


Figure 9. Type composition and spatial patterns across the three study cities. (**a**) Type composition by city; (**b**) Harbin; (**c**) Changchun; (**d**) Shenyang.

Among the 16 samples in Harbin, the four types were relatively evenly represented. In the central city, multiple types were interspersed across established university districts.

Peripheral campuses were concentrated in the Songbei–Limin and Hanan sectors, with further differentiation within these newer urban areas. Together, these distributions formed a pattern of "clustering along the central urban corridor and internal differentiation in peripheral areas" (Figure 9b).

Among the 19 samples in Changchun, the transport-accessible type was the most common (n = 7). The peripherally isolated, interaction-dominant, and connection-imbalanced types accounted for five, four, and three samples, respectively. Interaction-dominant samples were mainly located within continuous university districts in the central city. Connection-imbalanced and peripherally isolated samples were concentrated in peripheral university clusters, including Jingyue, Beihu, and Shuangyang–Sheling. Overall, the city exhibited a pattern of "continuous central embedding and differentiated peripheral clusters" (Figure 9c).

Among the 18 samples in Shenyang, the connection-imbalanced type was the most common (n = 6), followed by the transport-accessible type (n = 5). The peripherally isolated and interaction-dominant types accounted for four and three samples, respectively. Interaction-dominant and transport-accessible samples were concentrated mainly in the central city. Peripheral campuses represented multiple types and were distributed across Shenbei, Hunnan, and the eastern and western sectors of the city. Overall, this formed a pattern of "concentration of better-connected types in the centre and multinodal differentiation at the periphery" (Figure 9d).

4. Discussion

4.1. From Campus Attributes to a Campus–City Relational Typology

The findings indicate that combinations of spatial relationships can reveal differences in campus–city relationships. These differences may be overlooked by classifications based on location, scale, or spatial layout. Campus research has expanded from internal campus space to campus–community interfaces and wider urban areas [35], while campus design has gradually shifted from spatial separation towards urban integration [36]. However, attributes such as location, scale, degree of openness, and spatial layout remain insufficient to explain specific spatial connections between campuses and cities. Previous studies have shown that boundary openness and interface organisation affect campus–city accessibility and interaction [37–39]. Building on these studies, the present study examines the spatial relationships among the proximate urban area, campus boundaries, and internal campus space, as well as how these relationships combine.

The findings suggest that no single spatial characteristic can adequately represent campus–city relationships. High transport accessibility does not necessarily translate into strong spatial interaction. Even where local spatial conditions are favourable, coherent campus–city connections may not develop without continuous correspondence across spatial levels. Previous research has shown that multiple spatial relationships between campuses and their surrounding urban areas jointly shape campus–city interaction [40]. The present analysis further indicates that continuity among these relationships is equally important. The basis for type identification therefore shifts from what attributes a campus has to how it connects spatially with the surrounding city.

All four basic types were identified in each of the three cities, indicating that these relational patterns are comparable across cities. Differences in their proportions and spatial distributions may be associated with variation in urban spatial context, rather than indicating distinct city-specific types.

4.2. Winter-Relevant Spatial Conditions in Campus–City Relationships

Factor analysis showed that the four winter-relevant spatial indicators loaded on factors representing spatial interaction support, transport accessibility, and built-up intensity difference, rather than forming a separate factor. This finding reflects only their statistical associations with these dimensions. It does not provide evidence of an independent cold-climate effect. Drawing on previous research, the following discussion considers the potential implications of these spatial conditions in winter.

From a spatial perspective, the potential winter relevance of these indicators relates to three aspects: distance-related constraints, route constraints, and service support. First, WTD and OGD correspond to the transport accessibility and built-up intensity difference dimensions, respectively, reflecting walking distance to public transport and campus–city open-space separation. Previous studies have shown that low temperatures and snow- or ice-covered surfaces can reduce walking speed [41]. Longer walking distances and greater campus–city spatial separation may therefore warrant greater attention in winter. Second, BDD corresponds to the spatial interaction support dimension and is closely associated with boundary connectivity and the proximate road network. Related studies suggest that winter conditions can increase outdoor exposure and make walking more demanding, highlighting the importance of route continuity [42,43]. Finally, NISC also corresponds to the spatial interaction support dimension and is associated with the proximate road network and public transport. Indoor public spaces in cold-climate cities can support winter activities and walking [44,45]. When outdoor activities are constrained in winter, proximate indoor services may become more important, while inadequate service provision may increase outdoor travel distances and exposure time. Previous campus microclimate studies have evaluated climatic and environmental conditions through field observations or simulations [46]. In contrast, this study examines only static spatial conditions and does not directly measure climatic or microclimatic effects.

The combinations of winter-relevant spatial conditions also differ across the four spatial types. In the interaction-dominant and transport-accessible types, these conditions are mainly reflected in connections linking public transport stops, campus entrances, and internal routes. In the connection-imbalanced type, they are more evident in mismatches between external and internal routes and in boundary detours. In the peripherally isolated type, they are mainly associated with greater campus–city separation and insufficient support from proximate services.

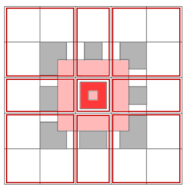
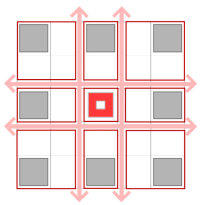
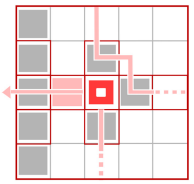
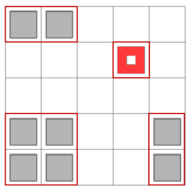
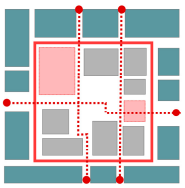
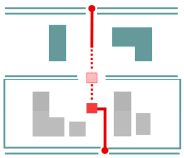
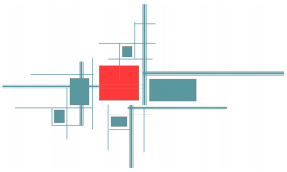
4.3. Type-Specific Implications for Campus-Area Regeneration

The four types differ in their spatial conditions and primary problems. Campus-area regeneration should therefore adopt type-specific strategies (Table 6). However, the effectiveness of these strategies still needs to be evaluated in terms of user behaviour and spatial performance [47].

The interaction-dominant type should prioritise connection strengthening. Boundary interfaces should be optimised, internal and external pedestrian routes linked, and public-space connections between adjacent campuses and surrounding urban blocks strengthened [48]. The transport-accessible type should emphasise interface activation. Public spaces and service functions should be concentrated around major entrances and public transport nodes to create a continuous activity interface along the campus edge [49]. The connection-imbalanced type should focus on linkage repair. The alignment of external streets, campus entrances, and internal routes should be improved, together with pedestrian links between adjacent campuses [50]. The peripherally isolated type should pursue structural reconfiguration. Proximate service nodes and shared facilities should

be added [51], while local streets and cross-district connections should be improved to strengthen links between the campus and surrounding urban space [52,53].

Table 6. Characteristics and regeneration strategies of the four campus-area types.

	Interaction-Dominant	Transport-Accessible	Connection-Imbalanced	Peripherally Isolated
Type characteristics	 Strong campus–city interaction; local weak links remain	 High transport accessibility; limited interface linkage	 Discontinuous internal–external connections	 Weak urban support; limited nearby services and external links
Regeneration strategy	 Connection strengthening	 Interface activation	 Linkage repair	 Structural reconfiguration

Note: Colors and shapes are used schematically to illustrate spatial relationships and intervention concepts; they do not represent quantitative categories.

5. Conclusions

This study examined 53 university campus-area samples in Harbin, Changchun, and Shenyang. The campus proper and proximate urban area were treated as a unified analytical unit to identify campus–city spatial relationships and their combinations. The findings reveal cross-level correspondences among the proximate urban structure, campus boundaries, and local campus space. Spatial differences among campus areas were summarised into four dimensions: spatial interaction support, morphological difference, transport accessibility, and built-up intensity difference. This indicates that campus areas can be classified by combinations of spatial relationships rather than by individual spatial attributes. The four winter-relevant spatial indicators loaded on three of these dimensions, reflecting spatial characteristics related to walking access to public transport, campus–city separation, route continuity, and proximate services.

Different combinations of the four spatial dimensions formed four basic types: interaction-dominant, transport-accessible, connection-imbalanced, and peripherally isolated. These types represent different states of campus–city spatial relationships rather than ordinal levels of quality. Type composition did not differ significantly among the three cities. Differences were mainly evident in the spatial distribution and configuration of the types. The main conceptual contribution of this study is to extend campus classification beyond individual spatial attributes towards a typology based on configurations of cross-level campus–city spatial relationships. Our findings further indicate that favourable individual spatial conditions do not necessarily translate into coherent campus–city connections; continuity across spatial levels also matters. This framework also incorporates winter-relevant spatial conditions into the assessment of these relationships, supporting comparative research and type-specific regeneration of campus areas in cold-climate cities.

This study has four limitations. First, the sample is limited to three cold-climate cities in Northeast China, which share similar regional and planning contexts. The applicability

of the typology to other regions and urban contexts remains to be tested. Second, the winter-relevant spatial indicators characterise only static spatial conditions that may be relevant to campus–city connections in winter. The study did not include direct observations of winter behaviour, microclimatic exposure, snow conditions, or seasonal mobility. The uniform 1000 m extent ensured spatial comparability across samples but may not fully capture differences in actual winter walking catchments. Future research could account for winter walking speeds, road-network structure, and spatial barriers. It could then assess the 1000 m extent against alternative walking catchments defined by pedestrian network distance or travel time. Third, closely spaced campuses were grouped into multi-campus sample units and analysed as a whole. This treatment may obscure differences among the constituent campuses. Accordingly, the spatial types identified in this study primarily reflect campus–city relationships at the sample-unit level. Future research could apply hierarchical or multiscale analyses to further examine internal heterogeneity within multi-campus units. Fourth, the proposed type-specific regeneration strategies are based primarily on the spatial characteristics and problems identified for each type. Their effectiveness has not yet been evaluated in terms of user behaviour and spatial performance. In addition, the study captures current campus–city spatial relationships but does not address their long-term changes. Future research could combine assessments of user behaviour and spatial performance with winter behaviour observations and comparisons over time. This would help evaluate the proposed regeneration strategies and further test the applicability and stability of the typology.

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Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Appendix A.1. Composition of Sample Units

Table A1. Composition of the 53 final campus-area sample units.

Sample ID	City	Sample-Unit Organisation	Constituent Campuses	Number of Campuses
H_G01	Harbin	Multi-campus	Heilongjiang University of Finance and Economics; Harbin Institute of Information Technology (Jiangbei Campus)	2
H_G02	Harbin	Multi-campus	Harbin Far East Institute of Technology; Heilongjiang College of Business and Technology (Songbei Campus)	2

Table A1. *Cont.*

Sample ID	City	Sample-Unit Organisation	Constituent Campuses	Number of Campuses
H_G03	Harbin	Multi-campus	Harbin Huade University; Harbin Guangsha College; Harbin Normal University (Songbei Campus)	3
H_G04	Harbin	Multi-campus	Heilongjiang Institute of Technology; Harbin Engineering University	2
H_G05	Harbin	Multi-campus	Harbin Institute of Technology (Second Campus); Harbin Sport University	2
H_G06	Harbin	Multi-campus	Harbin Institute of Technology (First Campus); HIT Civil Engineering Building	2
H_G07	Harbin	Multi-campus	Harbin University of Science and Technology (East Campus); Heilongjiang University of Chinese Medicine; Northeast Forestry University; Harbin Normal University (Jiangnan Campus)	4
H_G08	Harbin	Multi-campus	Harbin University of Science and Technology (South Campus); Harbin University of Science and Technology (West Campus); Heilongjiang University; Harbin Medical University; Harbin University	5
H_G09	Harbin	Multi-campus	Heilongjiang International University; Harbin Institute of Petroleum	2
H_G10	Harbin	Multi-campus	Harbin University of Commerce (North Campus); Harbin Conservatory of Music	2
H_G11	Harbin	Multi-campus	Harbin Vocational and Technical University; Harbin Cambridge University	2
H_I01	Harbin	Single-campus	Heilongjiang University of Science and Technology	1
H_I02	Harbin	Single-campus	Northeast Agricultural University	1
H_I03	Harbin	Single-campus	Harbin Finance University	1
H_I04	Harbin	Single-campus	Harbin University of Commerce (South Campus)	1
H_I05	Harbin	Single-campus	East University of Heilongjiang	1
C_G01	Changchun	Multi-campus	Jilin University (Qianwei South Campus); Jilin Animation Institute; Changchun University of Architecture and Engineering (High-Tech Campus)	3
C_G02	Changchun	Multi-campus	Jilin University (Nanhu Campus); Changchun Institute of Technology (Huxi Campus); Changchun University of Technology (Nanhu Campus)	3
C_G03	Changchun	Multi-campus	Changchun University of Science and Technology (West Campus); Changchun University of Science and Technology (South Campus); Changchun University of Science and Technology (East Campus); Changchun University (West Campus); Changchun University (East Campus)	5
C_G04	Changchun	Multi-campus	Jilin University (Nanling Campus); Northeast Normal University; Jilin Institute of Physical Education; Changchun Institute of Technology (Hudong Campus)	4

Table A1. *Cont.*

Sample ID	City	Sample-Unit Organisation	Constituent Campuses	Number of Campuses
C_G05	Changchun	Multi-campus	Jilin University of Arts (Comprehensive Campus); Jilin University (Chaoyang Campus); Jilin University (Xinmin Campus)	3
C_G06	Changchun	Multi-campus	Jilin International Studies University; Northeast Normal University (Jingyue Campus); Jilin University of Finance and Economics; Changchun University of Chinese Medicine; Jilin Police College; Changchun Humanities and Sciences College	6
C_G07	Changchun	Multi-campus	Jilin Agricultural University; Jilin Jianzhu University; Changchun College of Finance and Economics	3
C_G08	Changchun	Multi-campus	Jilin University of Architecture and Technology; Changchun College of Electronic Technology	2
C_G09	Changchun	Multi-campus	The Tourism College of Changchun University; Changchun University of Architecture and Engineering (Sheling Campus)	2
C_I01	Changchun	Single-campus	Changchun Normal University (Lequn Campus)	1
C_I02	Changchun	Single-campus	Changchun Normal University	1
C_I03	Changchun	Single-campus	Jilin Engineering Normal University	1
C_I04	Changchun	Single-campus	Jilin University (Heping Campus)	1
C_I05	Changchun	Single-campus	College of Science and Technology Changchun	1
C_I06	Changchun	Single-campus	Changchun Guanghua University	1
C_I07	Changchun	Single-campus	Changchun University of Technology (Beihu Campus)	1
C_I08	Changchun	Single-campus	Changchun Automobile Industry Institute	1
C_I09	Changchun	Single-campus	Jilin Business and Technology College	1
C_I10	Changchun	Single-campus	College of Humanities & Information, Changchun University of Technology	1
S_G01	Shenyang	Multi-campus	Liaoning University (Puhe Campus); Shenyang Institute of Engineering; Shenyang Normal University; Shenyang Aerospace University	4
S_G02	Shenyang	Multi-campus	Shenyang Conservatory of Music (Sanhao Campus); Northeastern University (Nanhu Campus); Luxun Academy of Fine Arts	3
S_G03	Shenyang	Multi-campus	Shenyang Conservatory of Music (Changqing Campus); Shenyang Jianzhu University	2
S_G04	Shenyang	Multi-campus	Shenyang Sport University; Shenyang Urban Construction University; Shenyang Institute of Science and Technology	3
S_G05	Shenyang	Multi-campus	Shenyang University of Chemical Technology; Shenyang University of Technology	2
S_I01	Shenyang	Single-campus	Liaoning University (Chongshan Campus)	1
S_I02	Shenyang	Single-campus	Shenyang University	1
S_I03	Shenyang	Single-campus	China Medical University	1

Table A1. *Cont.*

Sample ID	City	Sample-Unit Organisation	Constituent Campuses	Number of Campuses
S_I04	Shenyang	Single-campus	China Medical University (Shenbei Campus)	1
S_I05	Shenyang	Single-campus	Liaoning University of Traditional Chinese Medicine	1
S_I06	Shenyang	Single-campus	Northeastern University (Hunnan Campus)	1
S_I07	Shenyang	Single-campus	Criminal Investigation Police University of China (Tawan Campus)	1
S_I08	Shenyang	Single-campus	Shenyang City University	1
S_I09	Shenyang	Single-campus	Shenyang Agricultural University	1
S_I11	Shenyang	Single-campus	Shenyang Medical College	1
S_I13	Shenyang	Single-campus	Liaoning Communication University (North Campus)	1
S_I14	Shenyang	Single-campus	Shenyang Ligong University	1
S_I15	Shenyang	Single-campus	Shenyang Pharmaceutical University	1

Appendix A.2. Indicator Definitions and Measurement Rules

Table A2. Operational definitions and key measurement parameters for selected spatial indicators.

Item/Indicator	Operational Definition	Key Parameter or Decision Rule
Boundary sampling	Campus boundaries were sampled at regular intervals for indicators based on boundary points. Boundary segments were additionally generated for indicators based on boundary-length proportions.	Boundary sample interval: 50 m; boundary segment length: approximately 20 m.
Walking network	Walking distances were calculated along the filtered undirected road network. Target and destination points were connected to the nearest valid network nodes, and connector distances were included in the total walking-network distance.	Ordinary roads were treated as walkable; expressways, express roads, and ramps were excluded.
PTA	For each campus-boundary sample point, the shortest walking-network distance to the nearest public transport stop was calculated.	A sample point was considered served when the network distance was $\leq$500 m.
Potential access nodes (BC, WTD, BDD)	Potential access nodes were identified where public roads or walkable paths intersected the campus boundary. Nearby candidate nodes were merged to avoid duplicate counting.	Access-node merge distance: 20 m.
Continuous urban built-up area (BEC, OGD)	Building footprints in the proximate urban area were aggregated into continuous built-up patches using a 30 m building-link distance. Merged patches with a total building-footprint area below 10,000 m^2 were excluded. A retained patch was considered campus-adjacent when its minimum Euclidean distance to the campus boundary was no greater than 30 m.	Building-link distance: 30 m; minimum retained patch area: 10,000 m^2; campus-adjacency distance: 30 m.

Table A2. *Cont.*

Item/Indicator	Operational Definition	Key Parameter or Decision Rule
BDD	For each boundary sample point, the shortest distance along the closed campus boundary to the nearest potential access node was calculated.	BDD was represented by the 90th percentile of these along-boundary distances.
BSC	A boundary section was treated as continuously adjoining an urban street when the street remained close to and approximately parallel with the campus boundary over a continuous length, rather than intersecting it only at a point.	Street–boundary distance $\leq$ 30 m; direction difference $\leq 30^{\circ}$; minimum continuous length: 100 m.
OSA	Campus-side and city-side adjacency strips were evaluated for identifiable open space. A boundary segment qualified only when both sides met the minimum open-space proportion.	Adjacency-strip width: 30 m; minimum open-space proportion on each side: 0.5. Open space included green space, water, plazas, and playgrounds.
NISC/major indoor services	For each boundary sample point, the shortest walking-network distance to the nearest major indoor service facility was calculated.	Service threshold: 400 m. Major indoor services included catering and shopping services, daily-life services, sports and recreation facilities, healthcare services, financial services, public facilities, and selected indoor cultural venues.
POI functional categories (FM, FCD)	POIs were reclassified using one consistent functional scheme for all three cities; FM and FCD used the same categories.	Eight categories: education/research; residential/accommodation; commercial retail/catering; office/business; culture/sports/leisure; healthcare; public/daily-life services; transport services.

Note: Parameters shown here are the confirmed rules used for the spatial-indicator calculations. Only indicators requiring additional operational definitions or thresholds beyond the formulas in the main text are listed.

Appendix A.3. Factor Structure and Diagnostics

Table A3. Pattern matrix and diagnostic statistics for the four-factor solution.

Indicator	F1	F2	F3	F4	Communality (h^2)	Primary Factor
BEC	0.294	0.141	−0.059	**−0.541**	0.452	F4
OGD	−0.290	−0.141	−0.176	**0.664**	0.839	F4
R_AR	0.053	**−0.843**	0.030	0.034	0.734	F2
R_CO	−0.082	**0.845**	0.000	−0.005	0.757	F2
R_BD	0.225	0.170	−0.036	**0.729**	0.507	F4
RND	0.358	−0.248	0.146	**−0.480**	0.819	F4
PTA	0.007	−0.050	**1.009**	0.045	0.995	F3
WTD	0.047	−0.080	**−0.833**	0.080	0.702	F3
BC	**0.877**	−0.126	−0.035	−0.071	0.877	F1
BDD	**−0.856**	−0.021	−0.082	−0.013	0.794	F1
BSC	**0.365**	0.049	0.228	0.269	0.198	F1
OSA	−0.103	**−0.727**	−0.022	−0.052	0.508	F2
FM	0.072	**−0.283**	−0.137	−0.032	0.097	F2

Table A3. *Cont.*

Indicator	F1	F2	F3	F4	Communality (h^2)	Primary Factor
FCD	**−0.414**	0.072	−0.015	−0.175	0.158	F1
NISC	**0.441**	−0.083	0.305	−0.282	0.742	F1
Unrotated extracted variance (%)	36.86	12.95	5.97	5.47	—	—
Cumulative variance (%)	36.86	49.81	55.78	61.25	—	—

Note: Bold values indicate the primary loading (i.e., the loading with the largest absolute value) for each indicator and correspond to the primary factor shown in the final column.

Appendix A.4. Clustering Stability Analysis

Table A4. Overall and cluster-level resampling stability of the K = 3 and K = 4 clustering solutions.

Part A. Overall resampling stability of the K = 3 and K = 4 solutions				
K	Mean ARI	Median ARI	2.5th percentile	97.5th percentile
3	0.864	0.923	0.368	1.000
4	0.869	0.884	0.599	1.000
Part B. Cluster-level stability of the K = 4 solution				
Cluster	Spatial type	n	Mean Jaccard	Median Jaccard	2.5th–97.5th percentile
K1	Interaction-dominant	11	0.904	0.909	0.636–1.000
K2	Transport-accessible	16	0.936	1.000	0.643–1.000
K3	Connection-imbalanced	14	0.845	0.846	0.571–1.000
K4	Peripherally isolated	12	0.916	0.917	0.727–1.000

Note: ARI = adjusted Rand index. Each solution was assessed using 1000 iterations of approximately 80% subsampling (42 of 53 samples) without replacement. ARI measures overall clustering stability, while Jaccard similarity measures cluster-level stability relative to the baseline K = 4 solution.

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