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Institute of Architecture and Urban & Spatial Planning of Serbia, IAUS
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ADDRESS
Institute of Architecture and Urban & Spatial Planning of Serbia, IAUS
Spatium
Serbia, 11000 Belgrade, Bulevar kralja Aleksandra 73/II
tel: (381 11) 3207-300, fax: (381 11) 3370-203
e-mail: spatiumed@iaus.ac.rs, web address: www.iaus.ac.rs, www.spatium.rs

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EDITORIAL

Dear readers,

The overarching theme of this issue of *Spatium* (No. 55) is **continuity**. For a journal of our size, an awareness of *continuity* should be accompanied by the prudence not to boast about or become complacent with its achievements. We continually revisit selected topics, while new questions keep emerging – sometimes posed explicitly, sometimes more subtly. The result is a steadily growing body of knowledge, sustained by a childlike curiosity and enduring sense of fascination.

At the beginning of each calendar year, which also marks the start of the journal's publishing cycle, the Editors prepare for the 'worst' while hoping for the 'best' regarding the manuscripts entering the evaluation process for the forthcoming issue. Personally, what gives me particular satisfaction this year is the fact that all six scientific articles featured in the Contents of *Spatium* No. 55 were already published as Online First articles by early June 2026. This demonstrates that our expectations regarding both quality and timely publication have been fulfilled.

The international character of *Spatium* has also been maintained in this issue. The authors come from Mexico, China, the Philippines, Hungary, Turkey, the Netherlands, Ukraine, and Serbia. Their contributions explore a diverse range of topics, including the catalytic role of connectivity in territorial integration; the spatiotemporal evolution of urban sprawl in rapidly urbanising regions of East Asia; the application of space syntax analysis to villages along the Hungarian–Slovenian border; the influence of embodied cognition and environmental affordances on the formation of urban memory; the key design principles that define high-quality contemporary housing; and the concept of negative space in architecture through the relationship between solid and void.

Jasna Petrić
Editor-in-Chief

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ECONOMIC DIVERSIFICATION AND CONNECTIVITY IN THE VERACRUZ-PUEBLA REGION

Claudia Tello[1], Secretariat of Science, Humanities, Technology and Innovation, Mexico City, Mexico; Research Center in Geospatial Information Sciences, Mexico City, Mexico
Amilcar Morales, Research Center in Geospatial Information Sciences, Mexico City, Mexico
Mario Ledesma, Research Center in Geospatial Information Sciences, Mexico City, Mexico

This study analyzes the relationship between road connectivity and economic development in 273 municipalities in Veracruz and Puebla, Mexico. Using spatial statistics and correspondence analysis, it examines how road infrastructure (inter-municipal and internal-road connectivity) facilitates territorial integration, market access, and the reduction of inequalities. The findings highlight three key elements: 1) Economic diversification across the primary, secondary, and tertiary sectors, supported by micro and small firms, forms the basis of regional development; 2) Road connectivity is a crucial enabler of economic complementarity between urban and rural municipalities; 3) A unique productive ecosystem is generated, in which the spatial interaction between the road network and intermediate cities shapes a polycentric and endogenous development model. The study concludes that the region transcends the development paradigm based on large urban agglomerations. Functional complementarity, enhanced by infrastructure, transforms micro and small firms into the primary drivers of local and regional growth, highlighting the catalytic role of connectivity in territorial integration.

***Key words*: economic diversification, connectivity, complementarity, local development.**

INTRODUCTION

Road infrastructure is fundamental for regional development, as it promotes economic complementarity and diversification, facilitates access to markets and services, and reduces inequalities between urban and rural areas.

This quantitative research uses data generated by Mexican public institutions and constructs indicators to allow for comparisons between the municipalities, which serve as the base unit of the study area.

The study analyzes road connectivity (intra- and interregional) and its spatial interaction in 212 municipalities in Veracruz and 61 neighboring municipalities in Puebla, as well as its link to the main economic activities and the employed population. The study area is structured through a system of intermediate cities, which function as key nodes between rural and urban areas.

Using spatial statistics and correspondence analysis, the study examines how economic activities, labor markets, business location, and the 2024 National Highway Network generate complementarity and influence, relatively homogenizing the region. The main findings identify three key factors:

- The importance of economic diversification (primary, secondary, and tertiary sectors) and its employed population;
- The role of road connectivity as a facilitator of local and regional integration;
- The logic of complementarity creates a unique productive ecosystem, evidenced by the spatial interaction between local/interregional connectivity and intermediate cities.

These elements show that in this region, development transcends the traditional paradigm centered on large corporations. Here, micro and small firms are the fundamental pillar of endogenous economic development, both locally and regionally.

[1] Contoy 137, Col. Lomas de Padierna, Alcaldía Tlalpan, CP. 14240, Ciudad de México, México
ctello@centrogeo.edu.mx; ctellode@gmail.com

FROM AGGLOMERATION TO COMPLEMENTARITY: ROAD INFRASTRUCTURE AND DEVELOPMENT

Increased municipal road connectivity reduces socioeconomic disparities between urban and rural areas, improves access to services, integrates local markets, creates logistics corridors, and strengthens resilience to emergencies.

In contrast to the traditional view of growth based on agglomeration economies, authors such as Hausmann *et al*. (2013) and Hausmann and Hidalgo (2011) propose that economic diversification and complexity are better predictors of long-term growth and strengthen supply chains. This diversification generates multiple activity centers, which, although they may seem inefficient from the perspective of pure agglomeration, are stable and adaptable (Boschma, 2017). Good connectivity complements this strategy by facilitating value chains and resource distribution.

Within this framework, the Veracruz-Puebla region presents a polycentric and fragmented structure, without a dominant integrating economic core (Aguilar and Hernandez-Lozano, 2024; Vela Martínez, 2015; Chong, 2015). The urban system is characterized by functional pluricentrality, with interconnected medium-sized cities, forming horizontal networks without rigid spatial hierarchies. We define polycentrism using four criteria derived from our data and informed by the literature (Meijers, 2008; Burger and Meijers, 2012; Parr, 2004): (1) absence of a dominant center. Following Meijers (2008), polycentric regions are those where the largest node comprises less than 20% of the regional total; our region meets this criterion with a 7.53% share, from the Population and Housing Census 2020 (Instituto Nacional de Estadística y Geografía, 2020); (2) multiple intermediate nodes (9 intermediate cities in Veracruz and in Puebla); (3) Parr (2004) establishes that a polycentric urban region requires a minimum of three nodes of comparable size. Our region contains 9 municipalities in the range, substantially exceeding this minimum; and (4) distributed connectivity patterns: Intra- and inter-municipal road density connecting intermediate cities with large cities and rural areas, indicating that connectivity is distributed across multiple nodes rather than converging on a single metropolis.

These elements confirm that the region generates complementarity and functional completeness at the municipal level, resulting in greater economic adaptability distributed across the territory, with low concentration and balanced decentralization.

This disconnection prevents it from reaching the critical mass necessary for robust agglomeration economies. Its historical dependence on primary activities and the petrochemical industry, sectors with limited links and a tendency to operate as enclaves, led by the Mexican state-owned company Petróleos Mexicanos (Pemex), has not generated a diverse business ecosystem. Unlike other regions of Mexico – such as the Bajío, where logistics, industrial development, and economic geography are concentrated (Moreno *et al*., 2021) – the Veracruz-Puebla region lacks an equivalent integration mechanism.

Consequently, recent improvements in road infrastructure can play a fundamental role in fostering the integration of markets and economic activities. In this context, market integration is operationalized as the combination of inter-municipal connectivity (roads crossing municipal boundaries) and economic complementarity (measured via correspondence analysis, see Data and index systems). To explore this further, geographic information systems (GIS) are used to analyze road expansion in Mexico in 2024. The national road network includes paved highways, interchanges, and other types of roads. To measure connectivity in the study area, the total length of all road segments is first calculated in kilometers. Then, the local populations that benefit from road access are considered. Subsequently, specific statistical data representing the presence of economic units in each municipality across different economic sectors are incorporated, with the employed population considered an integrating element of the labor market and economic activities. Thus, the connectivity analyzed here involves the spatial interaction generated at both the intra- and inter-municipal levels. Both indicators were classified into five categories according to connectivity intensity: very low, low, medium, high, and very high.

Conceptualization of complementarity versus synergy

Intraregional and interregional connectivity find support in contemporary analyses that integrate economic theory, network analysis, and the study of synergies, highlighting the role of road networks connecting cities (Meijers, 2005).

The concept of complementarity, debated since the mid-20th century, has been measured through the relationships between the supply and demand of goods and territorial trade flows. Ullman (1956) defined it as the relationship in which the supply of one area satisfies the demand of another. Smith (1964) agreed on the need for "specific complementarity" to generate interaction and strengthen regions, warning that mere differentiation between areas does not guarantee exchanges. For his part, Stein (1964 in Meijers, 2008) linked this concept to the differentiation of urban functions, such as employment, industry, or services.

Meijers (2005; 2007) establishes a key distinction between complementarity and synergy. For this author, synergy emerges from cooperation between entities, enhancing the performance or efficiency of a network. Along the same lines, Capello and Rietveld (1998) point out that synergies derived from connectivity can have diverse outcomes: two municipalities can benefit from high connectivity and diversification, or the synergy of the road network can favor one municipality through mechanisms of cooperation, complementarity, or externality. Other studies associate complementarity with specialization processes or with quantifying relationships between nodes and networks (Capineri and Kamann, 1998; Rodrigue and Ducruet, 2024).

Research on networked cities suggests that infrastructure is a necessary condition for efficient connectivity systems. Studies focused on spatial patterns of complementarity within transport and communication networks – which move people, cargo, information, and capital – reveal significant differences in the degree and spatial configuration of this complementarity between cities (Sohn, 2015; Burger, 2011; Batten, 1995; Camagni *et al*., 1994).

Meijers (2005) proposes that complementarity can generate synergy between municipalities, referring to the specific nature of a relationship between complementary activities (economic sectors, urban facilities) or places (commercial or residential environments, or, at a macro level, cities).

This is a spatial phenomenon where proximity and interaction are relevant, and economic activities overlap. Authors such as Ullman (1956), Lambooy (1969), and Camagni and Salone (1993) conceptualize complementarity as a key interurban relationship for understanding connectivity and spatial interaction. However, the concept has been little analyzed, and several authors argue that territorial complementarity alone is not enough for full spatial interaction, which can only occur when intervening opportunities do not block interaction (McMillan *et al*., 2017; Lee and Hewings, 2015; Thompson, 1974; Stouffer, 1940). These authors offer valuable perspectives on how economies can function without depending on large agglomerations, which aligns with the idea of a homogeneous economic structure rather than a strict concentration of economic activities.

Connectivity relationships

Analyzing how road connectivity affects the location of economic activities, and the developing productive sectors allows us to examine the geographic distribution of resources based on infrastructure and its accessibility. Some authors have identified connectivity as a central element for economic competitiveness, finding differences between territorial scales according to coverage and physical accessibility (Suárez and Zúñiga, 2022; Gómez Mora *et al*., 2009).

To understand the relationship arising from intra- and inter-municipal connectivity, we begin by defining the former as a municipality's capacity to have an efficient internal road network that connects its urban and rural areas, facilitating access to services, resources, and employment, which is crucial for local development. Inter-connectivity, on the other hand, refers to the connection between municipalities through roads of different types, integrating geographic units into a broader network.

Both types of connectivity can facilitate trade, increase regional competitiveness, integrate communities, optimize distributing goods and services, and reduce socioeconomic inequalities. Together with spatial analysis, they allow us to understand the distribution and accessibility of infrastructure, identifying dynamics and tensions within the territory.

The spatial structure of the study area reveals how municipalities are connected, patterns of continuity, topography, and spatial cohesion, contributing to a hierarchical and complex analysis of the network. In contrast, Rodrigue (2007), and Camagni and Capello (2004) agree that the discontinuity of economic activities depends on spatial organization, where employment zones become poles of attraction.

Using spatial information facilitates the planning of investments in road infrastructure, ensuring that new connections increase regional competitiveness and improve the link between rural and urban areas. Geographic Information Systems (GIS) have enabled the development of empirical work by mapping connectivity and evaluating coverage across the territory. This allows us to identify how routes connect productive zones with urban centers or rural areas.

Combining geospatial information with statistical and socioeconomic tabular data to develop expressed indicators contributes to the analysis of territorial inequalities and access to road infrastructure.

The articulating role of intermediate cities

Intermediate cities play a crucial role in territorial development by serving as connection points between rural areas and large urban centers. By concentrating on services, infrastructure, and population, they can drive local economic diversification through the promotion of micro and small firms. Local diversification depends on the capacity of these businesses to adapt to the market and generate employment. Public policies aimed at fostering them, along with strengthening cooperation networks, are key to creating a more resilient economic base in these cities.

Small businesses do not compete in isolation. Complementarity analysis reveals that they form clusters or networks that, together, achieve the critical mass necessary for development. This establishes a horizontal complementarity: a municipality with many agricultural micro and small firms are complemented by another with food processing establishments, and both benefit from a third with logistics companies. Road connectivity enables this synergy.

Intermediate cities have been characterized as strategic connectivity hubs. The analysis identifies intermediate cities (such as Xalapa, Veracruz-Boca del Río, and Orizaba) as territorial articulation nodes where the flows of goods, services, and people materialize. These cities execute crucial interconnectivity relationships: a product from a rural area is consolidated in an intermediate city before being distributed regionally or nationally, demonstrating their strategic role in the polycentric development network.

DATA AND METHODOLOGY

Study area

The study area comprises 212 municipalities in the state of Veracruz and 61 adjacent municipalities in the state of Puebla (Figure 1), forming not an arbitrary administrative grouping but a single functional unit. This is because the eight logistics corridors that pass through the Veracruz-Monterrey, Altiplano, Acapulco-Tuxpan, Acapulco-Veracruz, México-Progreso, Trans-Isthmian Circuit, Puebla-Salina Cruz and Manzanillo-Tampico do not operate independently; rather, they intersect and exchange flows within these two states, making Veracruz and Puebla the central hub of a national logistics network. As a result, the 273 municipalities are economically and operationally interdependent. In 2024, these municipalities accounted for 68,612,588.78 kilometers of travel on the National Road Network, representing 7.18% of the national total of 954,849,007.54 kilometers. The region is connected to at least eight of the country's fifteen strategic trunk and radial corridors (Secretaría de Infraestructura, Comunicaciones y Transportes, 2023), which link major cities longitudinally and transversally and provide access to transportation hubs

serving industrial zones and businesses of all sizes micro, small, medium, and large. Consequently, the region can be characterized as polycentric, with its centers defined by the intermediate cities typical of Veracruz and encompassing both significant urban and rural areas.

Four interrelated dimensions support defining this area as a functional unit:

- Physical Connectivity (a): A network of state highways directly connects the municipalities within the study area, linking rural communities to urban hubs. Municipalities such as Teziutlán, Cuetzalan, Xicotepec, Jalpan, Ciudad Serdán, and Tehuacán function as nodes of economic activity (agribusiness, livestock, tourism, and industry). Because these highways connect municipalities within the study area rather than bypassing them, they create a dense internal web of movement that distinguishes this region from adjacent areas;
- Strategic Framework (b): Public infrastructure policies between 2018 and 2024 (Diario Oficial de la Federación, 2019) and the National Highway Infrastructure Program 2024-2030 (Comité de Planeación para el Desarrollo del Estado de Puebla, 2024) explicitly target the inter-mountain highway and other linkages between Veracruz and Puebla. These policies treat the two states as a single planning unit, reinforcing their functional integration through coordinated rehabilitation, reconstruction, and maintenance;
- Regional Integration (c): The road network within the study area connects seamlessly to major national highways, forming a strategic corridor in central and northern Mexico. This integration enhances transportation safety and efficiency specifically for routes that cross between Veracruz and Puebla, which would not be possible if the municipalities were treated as separate regions;
- Logistical and Socioeconomic Symbiosis (d): The most direct evidence of a functional unit is the logistical and economic symbiosis between the port of Veracruz and the industrial center of Puebla. The eight corridors channel freight, commuters, and goods directly between these two poles. This relationship extends beyond transportation into daily life, culture, commerce, and agricultural production, intertwining the identities and economies of both states. For example, agricultural products from Puebla municipalities are processed and exported through Veracruz, while manufactured goods from Veracruz move inland via Puebla's distribution networks.

Together, these dimensions demonstrate that the study area is an integrated unit spanning state boundaries, not two separate regions. Physical connectivity (a) and logistical symbiosis (d) in particular produce what is known as functional pluricentrality: multiple medium sized cities (e.g., Tehuacán, Teziutlán) act as interdependent nodes rather than depending on a single metropolis. This pattern is empirically observable in freight flows, commuting data, and shared supply chains across the 273 municipalities. Therefore, the original definition of the study area as a functional unit is validated not by assumption, but by the convergence of infrastructure, policy, and socioeconomic exchange.

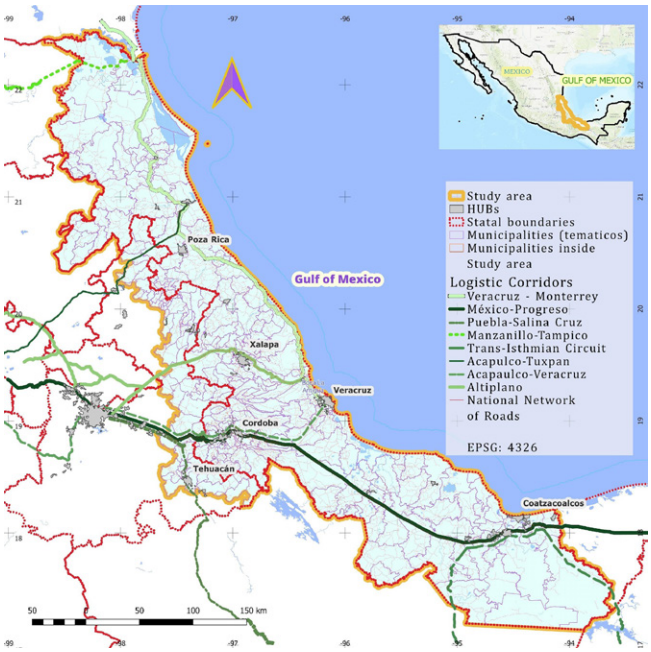


Figure 1. Study area
(Source: Author's own elaboration with data from Sistema Nacional de Información Municipal (2023) and from the Consejo Nacional de Población (2020))

Data and index systems

This study uses available geospatial information and layers, such as the 2024 National Road Network (RNC), produced by the National Institute of Statistics and Geography (INEGI) in collaboration with the Ministry of Infrastructure, Communications and Transportation (SICT) and the Mexican Transportation Institute (Instituto Mexicano del Transporte, 2024), as well as data from the National Statistical Directory of Economic Units or DENUE (Instituto Nacional de Estadística y Geografía, 2025), the Population and Housing Census 2020 (Instituto Nacional de Estadística y Geografía, 2020), and the Agricultural Census (Instituto Nacional de Estadística y Geografía, 2022).

To analyze intra- and inter-connectivity, the constituent segments of each road were integrated to determine whether the roads connect only within a single municipality or facilitate connections between several municipalities. An integration process was carried out to join road segments divided by intersections or crossroads from the road network to reduce the number of roads to be analyzed and simplify the geospatial analysis of the network.

Other connectivity measures require the construction of indices that consider the number of road links divided by the number of nodes or intersections, as well as links that include road segments. Some of these indices establish the degree of connectivity based on the number of intersections, relationships between the network and Euclidean distances, or a combination of composite indices that include accessibility, walkability, and transitability, where connectivity considers local communication routes (Soltani

and Allan, 2005; Giacomin and Levison, 2015). It should be added that these indices are influenced by how areas and spatial geometry are defined in each territory.

Intra- and inter-municipal connectivity indices. For intra-municipal connectivity values in the study area, the connectivity indicator was calculated by summing the length of road segments of the National Road Network (Instituto Mexicano del Transporte, 2024) within each municipality. These segments were then classified into quantiles with five ranges, from very low to very high connectivity. Like intra-municipal connectivity, inter-municipal connectivity values were calculated counting the number of roads that cross the municipality, but only those crossing more than one municipality. This data was then used to create a classification based on quantiles with five intervals showing the number of inter-municipal roads within each municipality.

Seven variables were used to consider the sectors of economic activity, using the databases of the National Statistical Directory of Economic Units (DENUE). These variables correspond to the manufacturing, agricultural, electricity, gas and water, mining, and service sectors, including tourism and wholesale and retail trade. An additional variable for agricultural activity was taken from the Agricultural Census. To account for the importance of economic activities in the territory, the number of people employed in each economic unit was considered. A count of economic activities was carried out by municipality, grouping them according to firm size based on the number of employees, using the Instituto Nacional de Estadística y Geografía (INEGI) classification:

- micro-enterprises (1-10 people),
- small enterprises (11-50 people),
- medium-sized enterprises (51-100 people), and
- large enterprises (101 people and more).

These variables were grouped by activity into two categories: smaller and larger. The lowest value was obtained by combining the values of the micro and small classifications, while the highest value was the sum of the medium and large classifications. For the agricultural sector, it should be noted that information from the National Statistical Directory of Economic Units was considered, which includes aquaculture, fishing, and forestry related services. Agricultural production data were obtained from the 2022 Agricultural Census. Although connectivity is regulated by the Ministry of Communications and Transportation (SICT), functional relationships exist between the municipalities in the region, particularly where connectivity links potential areas for network development. Other connectivity possibilities illustrate how new road segments connect remote areas.

Complementarity and Proximity. A multivariate correspondence analysis (MCA) was conducted using connectivity indicators (see Greenacre, 1993; Clausen, 1998) to identify underlying relationships between categories of intra- and inter-road connectivity and economic activity sectors. The method performs a dimensional decomposition of the contingency matrix. To construct the contingency matrix, the 273 municipalities (rows) were cross-tabulated against 15 sector-size categories (columns: 7 economic sectors × 2 firm-size groupings, plus agricultural census as a separate category). Each cell contained the employed population count. The MCA was applied to the Burt matrix (the symmetric matrix of all two-way cross-tabulations). Because the total inertia of this matrix is inflated by the diagonal submatrices (which represent autocorrelations), the eigenvalues were corrected using the Benzécri method (Greenacre and Vrba, 1984) to obtain an unbiased factor solution.

The complementarity index was constructed using eq. 1 and 2 below. The interpretation is as follows: a low complementarity value (e.g., <10%) indicates that municipalities have similar economic profiles (high diversification), while a high value indicates specialization (few municipalities dominate a sector). The maximum possible inertia equals the number of municipalities, minus one (272 in our case). Thus, a complementarity index of 3.56% (micro/small manufacturing) means that municipalities are highly homogeneous in their manufacturing profiles.

$$\textit{Total inertia} = \Sigma_i \; p_i * d_i^2 \qquad \text{(eq. 1)}$$

where:

p_i = weight of the category (municipality or sector)

d_i = chi-square distance from the point to the centroid (average profile)

$$\textit{Complementarity index} = \textit{Total inertia}/(\textit{maximum possible inertia}) * 100 \qquad \text{(eq. 2)}$$

where:

Maximum possible inertia = number of municipalities -1 =272

The third spatial indicator (eq. 3) is a composite index that reflects the inter- and intra-municipal connectivity interaction in the region for each economic activity. Fifteen indicators were obtained, grouped by sectors of activity (agriculture; electricity; gas and water; manufacturing; mining; retail and wholesale trade; and tourism services) and by the size of the economic units (smaller and larger). This indicator is a two-digit combination. The first digit represents the municipal indicator inter-municipal connectivity (classified into 5 levels: 1 = very low to 5 = very high). The second digit corresponds to the economic activities in relation to the population they employ (also classified into 5 levels). Values range from 11 (lowest connectivity, lowest sectoral presence) to 55 (highest connectivity, highest sectoral presence).

To refine the analysis of spatial proximity, weighted centroids were calculated for each sector-activity (k) and size category within each municipality (i). These centroids represent the geographic core of each activity, weighted by employment or number of establishments. The distance between centroids of the same sector and size category across neighboring municipalities was then computed. The proximity threshold θ is set to 0.5, meaning that two municipalities are considered spatially integrated if the

distance between their activity centroids is less than or equal to half the average centroid distance for that sector ($\bar{D}_{i,k}$). The complete indicator system is formalized as:

$$I_{i,k} = 1\,[(m(C_i) + m(E_{i,k}) \geq \tau) \wedge (\exists i' \in \mathcal{N}_i : ||c(i,k) - c(i',k)|| \leq \theta \cdot \bar{D}_{i,k})] \quad \text{(eq. 3)}$$

where:

C_i is the standardized inter-municipal connectivity

$E_{i,k}$ is the standardized sectoral presence relative to employed population

$m(\cdot)$ discretizes values into 5 levels (1 to 5)

τ is a predefined threshold score

$c_{(i,k)}$ is the weighted centroid of activity k in municipality i

$\mathcal{N}_i$ are municipalities neighboring i

$||c_{(i,k)} - c_{(i',k)}||$ is the distance between centroids

$\bar{D}_{i,k}$ is the average centroid distance between neighboring pairs for activity k

θ is a threshold parameter

$1[\cdot]$ is the indicator function (1 if condition true, 0 otherwise)

Thus, $I_{i,k}$ indicates whether municipality *i* is effectively integrated for sector–size combination *k*. The third indicator not only classifies municipalities by connectivity and sectoral intensity but also incorporates the spatial proximity of activity cores to identify new patterns of territorial continuity based on the roads that connect multiple municipalities in the study area.

Tools and software

QGIS 3.22 was used for visualization and construction of spatial layers. PostgreSQL 17 with PostGIS 3.5.2 was used for data management and processing, and the algorithms for constructing indicators were written in Python 3.12.

RESULTS

Complementarity and connectivity

For the analysis of complementarity at the regional level, it is important to recognize that a large share of activities, facilities, and services are dispersed across cities or municipalities. Each locality hosts some of these elements, but not all, meaning that cities or municipalities complement one another. This dynamic is closely linked to levels of intra- and inter-connectivity, which play different yet mutually beneficial roles in urban, rural, or peripheral areas, each characterized by distinct road infrastructure.

The results reflect a high degree of widespread territorial diversification and, conversely, an absence of regional specialization defined by clusters or agglomeration economies in the region. To assess diversification, we use the following criterion: a complementarity index below 10% indicates high diversification (municipalities have similar economic profiles), while an index above 20% indicates specialization. As shown in Table 1, micro and small enterprises across all sectors have complementarity indices between 3.46% and 7.05% – well below the 10% threshold, confirming that these firms are distributed homogeneously across the territory. Only large enterprises (11.55%–33.66%) and mining (16.0%) exceed the 10% threshold, indicating sectoral concentration. By applying these established criteria, we can confidently state that

Table 1. Municipal connectivity complementarity index, by type of economic activity sector, according to the employed population (Source: Author's own elaboration, 2025)
Note: Connectivity levels are very low (VL), low (L), medium (Medium), high (H), and very high (VH).

Sector	Firm size	Total inertia	Complementarity	Contribution of connectivity to complementarity
Agriculture	Micro and small	9.80	7.05	L /VL
	Large and very large	6.55	21.85	VH / Medium
	Census*	9.78	3.59	VL / VH
Manufacturing	Micro and small	9.69	3.56	VH / Medium
	Large and very large	8.55	11.55	VH / VL
Mining	Micro and small	8.16	16.00	VH / VL
Electricity, Gas and water	Micro and small	9.05	3.52	VH / Medium
Retail	Micro and small	9.71	3.57	VH/ VL / Medium
	Large and very large	7.12	11.87	VL / H
Wholesale trade	Micro and small	9.36	3.61	VH / VL
	Large and very large	7.67	14.20	L
Tourism	Micro and small	9.38	3.46	VH / Medium
	Large and very large	3.37	33.66	VH /L

Note: Connectivity levels are very low (VL), low (L), medium (Medium), high (H), and very high (VH).

our results operationalize and validate the concepts of diversification (low complementarity of small firms) and functional polycentricity (spatially concentrated large firms linked by high connectivity). This aligns with Jacobs's externalities, which argue that regional growth often stems from variety and cross-sector pollination rather than pure specialization. Structural homogeneity across territory implies a uniform distribution of characteristics. The state of Veracruz presents a unique development pattern characterized by a homogeneous distribution of economic activities throughout its territory. Contrary to traditional models that favor specialized concentration, Veracruz has developed a productive ecosystem where diversification – not agglomeration – constitutes the main competitive advantage.

In this sense, we may ask how diversification manifests empirically and where to find patterns, given that diversification itself is a pattern. It can therefore be inferred that economic activity in the territory functions as an integrated system, breaking with theoretical scenarios of regional specialization. The temporality of diversification is not a recent phenomenon in the study area. Four key findings emerge: (1) there are no dominant specialized clusters in the study area; (2) sectoral presence is ubiquitous; (3) each municipality contains a representative sample of the diversity of the sectors analyzed; and (4) production configurations are evenly distributed.

The urban system is characterized by functional pluricentrality, with interconnected medium-sized cities forming horizontal networks without rigid spatial hierarchies. Three indicators are used to support this characterization: (1) The Herfindahl-Hirschman Index (HHI) of employment concentration across the 273 municipalities is 0.014 (where 1 would indicate a single municipality concentrating all employment and near 0 indicates perfect dispersion); (2) The top 5 municipalities by employment account for only 23.4% of regional employment; (3) At least 12 municipalities have employed populations that function as interdependent nodes without a single dominant center. These indicators confirm that the region generates complementarity and functional completeness at the municipal level, resulting in greater economic adaptability distributed across the territory, with low concentration and balanced decentralization. This regional model strengthens local endogenous development with productive flexibility that does not depend on port activity. A key challenge will be to enhance intersectoral synergies and maintain investment in interconnection infrastructure and distributed logistics

Patterns of intra- and inter-connectivity

The analysis of connectivity and employment patterns for micro and small firms reveals six distinct territorial configurations (see Table 2). First, *specialized and integrated* municipalities combine very high interconnectivity with high employment, particularly in agriculture, wholesale trade, and manufacturing. Second, *specialized but isolated* municipalities exhibit high employment despite low connectivity, as observed in forestry and fishing (Jopala, Jonotla, Zoquiapan) and in peripheral manufacturing areas. Third, *connectivity without activity* municipalities (Apazapan, Nanchital) have high connectivity but low sectoral presence, functioning as transit corridors. Fourth, *isolated labor attractors* (Ayotoxco de Guerrero, Chilchotla, Tehuacán, Boca del Río) draw workers despite low connectivity. Fifth, *rural isolated areas* show both low connectivity and low employment, reflecting little productive integration. Sixth, transitional municipalities display *mixed patterns* with variable connectivity and employment levels.

Some examples are the electricity, gas, and water sector, which exhibit a strong positive association between infrastructure quality and sectoral presence (Poza Rica, Cuetzalan, Huatusco, Xalapa, Nanchital, Fortín), while deficient infrastructure correlates with little activity. Mining presents a fragmented and limited structure, concentrated in the Sierra Norte region. Manufacturing displays dual patterns: integrated industrial municipalities with high connectivity coexist with peripheral industrial areas where high employment persists despite low connectivity, alongside rural areas with little integration and well-connected municipalities with low manufacturing employment. Retail trade depends primarily on connectivity levels, with medium/high connectivity corresponding to medium/high employment where commerce is the main activity, although some well-connected municipalities show low retail employment, indicating commerce is not their principal sector. Tourism requires consolidated infrastructure; well-connected transit corridors do not guarantee tourism development, as evidenced by municipalities with high connectivity but low tourism employment.

Table 2. Territorial patterns by sector and connectivity level (micro and small firms)
(Source: Author's own elaboration, 2025)

Sector	Connectivity pattern	Employment pattern	Municipalities (examples)	Finding
Agriculture	Very high interconnectivity	High employment	(Multiple)	Specialized, well-integrated
	Low intra-connectivity	Low employment	(Multiple)	Isolated, low activity
	High/Medium/Very low (heterogeneous)	Variable	(Multiple)	Mixed patterns
Forestry and Fishing	Low connectivity	High employment	Jopala, Jonotla, Zoquiapan	Specialized but isolated
	High connectivity	Low activity	Apazapan, Nanchital	Connectivity without activity
	Low connectivity	Attracts labor	Ayotoxco de Guerrero, Chilchotla, Tehuacán, Boca del Río	Isolated labor attractors

Sector	Connectivity pattern	Employment pattern	Municipalities (examples)	Finding
Electricity, Gas and Water	Excellent infrastructure	Strong presence	Poza Rica, Cuetzalan, Huatusco, Xalapa, Nanchital, Fortín	Positive association
	Deficient infrastructure	Little activity	(Multiple)	Negative association
	Mixed	Mixed	(Multiple)	Transitional
Mining	Fragmented, limited	Variable	Sierra Norte region	Structurally complex
Manufacturing (micro and small)	High interconnectivity	High employment	(Multiple)	Industrialized, integrated
	Low connectivity	High employment	(Multiple)	Peripheral industrial
	Low connectivity	Low employment	Rural areas	Little integration
	High connectivity	Low employment	(Multiple)	Connectivity without industry
Wholesale Trade	High interconnectivity	High employment	(Multiple)	Logistically integrated
Retail Trade	Medium/High	Medium/High	(Multiple)	Commerce as main activity
	Medium/High	Low employment	(Multiple)	Commerce not principal
Tourism	High connectivity (consolidated)	High employment	(Multiple)	Well-developed tourism
	High connectivity (transit)	Low employment	(Multiple)	Tourism not developed

Economic diversification and road connectivity in the region

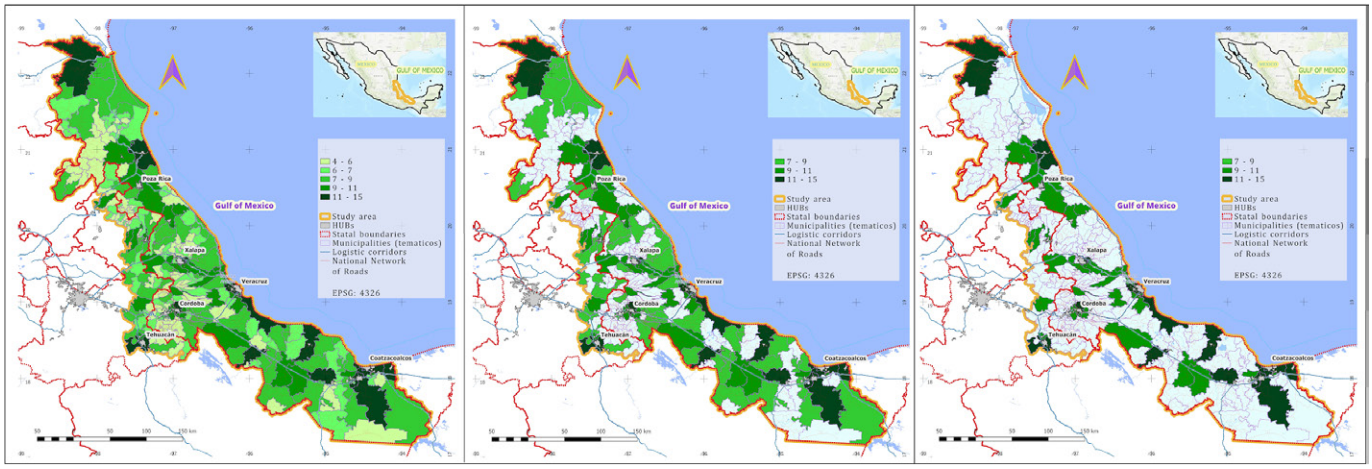
Based on the intra- and inter-connectivity indicators mentioned above, a two-digit composite index was constructed. The first digit represents connectivity between the municipality and other municipalities in the region, while the second digit considers diversifying economic activities according to the employed population. The indicator values range from 1 to 15, where 15 represents the highest level of economic activity in the municipalities. Figure 2a shows the behavior of the indicator in the study region. There is a clear pattern in the road connectivity network, with municipalities exhibiting widespread economic diversification (values 1 to 15). To simplify the visualization, two other cases were examined. For example, if only the categories with medium and high economic diversification values (presence of 7 to 15 sectors) are considered, connected subregions can be observed (Figure 2b) that derive from the spatial patterns of the municipalities. A finer filter, as shown in Figure 2c, with values ranging from 10 to 15, corroborates diversification, but in a fragmented structure in a region where the road connectivity is strong and dominant. This suggests that in those areas: high economic diversification is spatially clustered, not random, good road infrastructure exists between those high-diversification municipalities, and the connectivity of the road network is the defining characteristic of those subregions.

Intermunicipal and internal connectivity of roads in the region: patterns by sector of activity

The sectoral composition of the municipalities and the region is diversified. The findings on the functionality in the region derived from intra- and inter-connectivity are reinforced by the complementarity mechanism between urban and rural municipalities that interact with compact, highly connected

Figure 2. Diversification of Economic Activity and Connectivity
(Source: Author's own elaboration, 2025)

2a **2b** **2c**



hubs, where there is a strong and diversified clustering of production functions. Road connectivity has been linked to hierarchical structures among the different urban and peri-urban areas, generating alternative forms of spatial organization that strengthen the region. Specifically, unlike the monocentric, cluster-based organization seen in other regions, the continuous spatial pattern of micro and small firms shown in Figures 3a and 4a represents an alternative: a polycentric network without dominant hubs, where municipalities complement each other horizontally rather than competing for agglomeration rents. This conclusion is supported by (a) the low complementarity indices (<7%) for micro/small firms across all sectors, indicating ubiquity rather than concentration; (b) the spatial continuity observed in Figures 3a and 4a, where neighboring municipalities share similar sectoral profiles; and (c) the centroid proximity analysis (eq. 3), which confirms that activity cores are geographically close across municipal borders.

Figures 3 and 4 show examples of the composite indicator (eq. 3) for the two economic activity sectors that were relevant in this study (manufacturing and retail trade) for both micro and small firms and for medium and large firms, considering the interconnectivity and proximity of municipalities closest to the intra-connectivity attractor in each sector. In these figures, the road network is overlaid as line layers to visually demonstrate the relationship between connectivity and sectoral presence. The five categories (very low, low, medium, high, and very high) reflect economic units in each sector within the municipalities and their relationship to inter and intra-connectivity. Two relevant examples are the contrasts in enterprise size. Figures 3a–4a demonstrate the powerful presence of micro and small firms in the manufacturing and retail trade sectors. The population employed in these firms confirms a relevant factor of complementarity in the region, related to labor markets and other sectors of economic activity. Continuous sectoral organization is observed in the region, unlike the patterns seen for medium-sized and large firms, which have a fragmented structure throughout the region without clear specialization. However, there is significant evidence of complementarity provided by the road network, and consolidating road infrastructure also improves complementarity (Figures 3b–4b).

DISCUSSION AND CONCLUSIONS

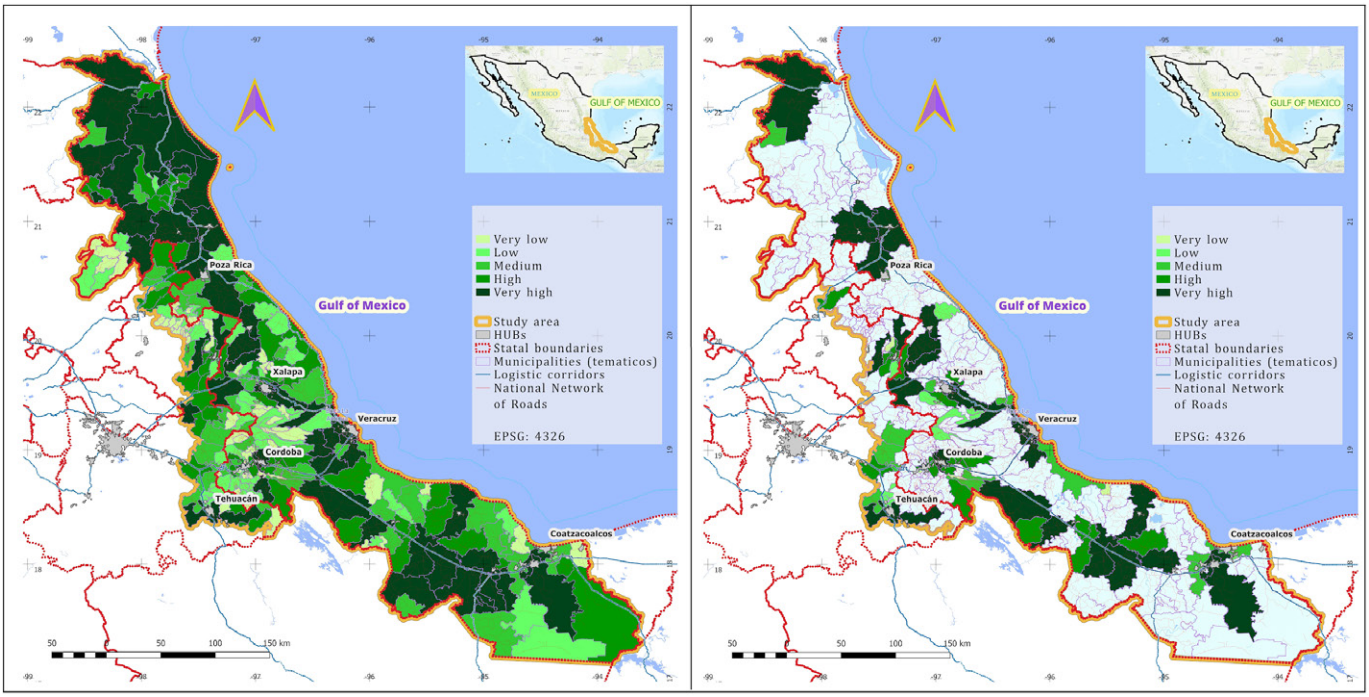
This study highlights that intra- and inter-connectivity of highways are fundamental to the territorial development of the Veracruz-Puebla region, as they imply not only the existence of infrastructure, but also processes of complementarity and continuity that functionally integrate municipalities and regions.

The four dimensions of functional unity can now be linked to the results of this study. As established on Sec. Study area, the study area functions as an integrated unit across these dimensions. Empirical results provide direct evidence for each:

- Dimension (a) Physical connectivity: Table 2 demonstrates that municipalities with "very high interconnectivity" (e.g., in agriculture, manufacturing, wholesale trade) exhibit correspondingly high employment levels, confirming that the road network physically integrates rural and urban areas;
- Dimension (b) Strategic framework: The spatial patterns in Figures 3a and 4a show that municipalities targeted by the National Highway Infrastructure Program 2024–2030 (e.g., those along the inter-mountain highway between Veracruz and Puebla) have the highest composite indicator scores (values 10–15 in Figure 2c);

Figure 3. Intra- and interconnectivity of the manufacturing sector
(Source: Author's own elaboration, 2025)

3a Micro and small sized industries **3b Medium and large-sized industries**



4a Micro and small sized industries **4b Medium and large-sized industries**

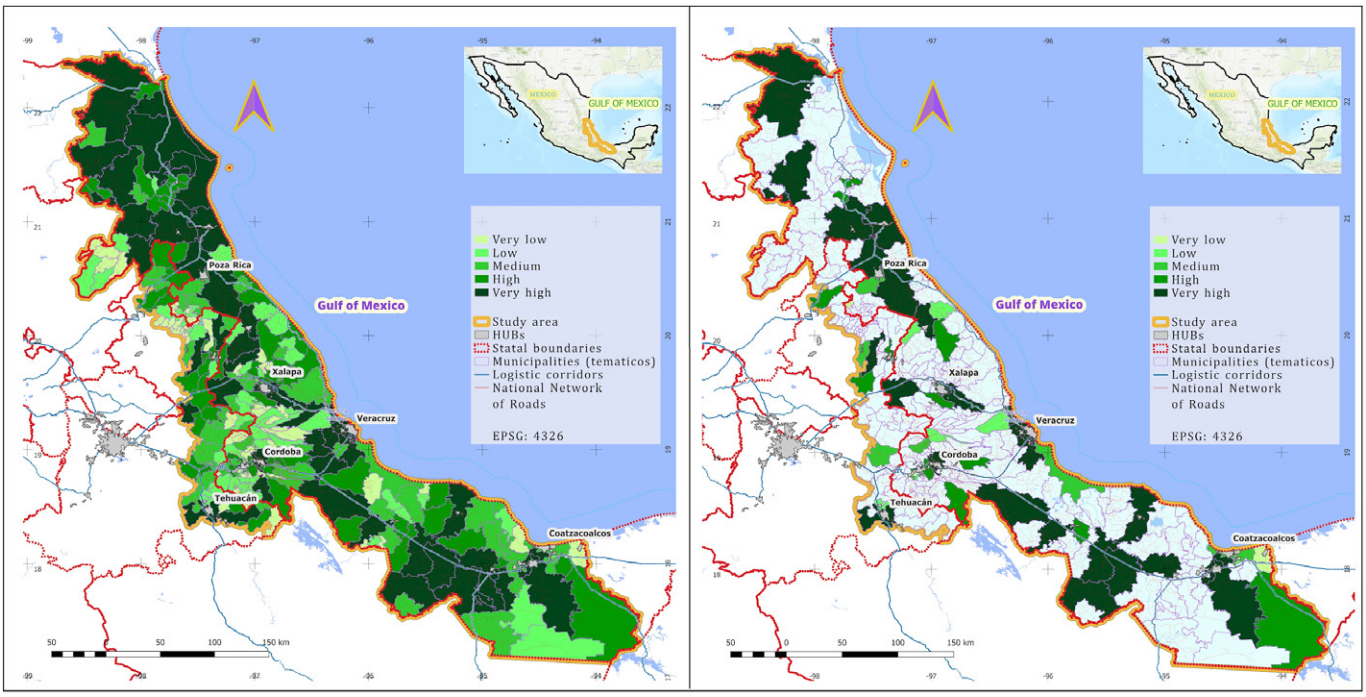


Figure 4. Intra- and interconnectivity of Retail trade
(Source: Author's own elaboration, 2025)

- Dimension (c) Regional integration: The seamless connectivity of the road network within the study area to major national highways is evidenced by the fact that the 273 municipalities account for 7.18% of national road travel (68.6 million km), with inter-municipal roads crossing state boundaries without interruption;
- Dimension (d) Logistical and socioeconomic symbiosis: The high complementarity index for wholesale trade (14.20% for large firms, Table 1) and the spatial continuity of retail and manufacturing micro/small firms (Figures 3a, 4a) directly reflect the logistical symbiosis between the port of Veracruz and the industrial center of Puebla.

Main findings. The central findings consist of functional complementarity, since highways not only connect but also organize networks that allow for economic and social integration. This is observed in the connection between urban and rural areas, facilitating access to markets, services, and employment. The expansion and maintenance of the highway network are identified as crucial elements for efficient connectivity that promote the development of more remote areas of the region and their relationship with intermediate cities, changing the spatial arrangement between local and regional infrastructure.

Alternative spatial organization. The Veracruz-Puebla region exhibits a polycentric network where micro and small firms are distributed ubiquitously, while large firms concentrate on specific nodes connected by high-quality roads. This represents an alternative form of spatial organization – one that relies on horizontal complementarity rather than vertical agglomeration. Spatial patterns beyond the center-periphery model are identified, with diversification in the region linked to dynamic zones, extractive enclaves, and the possibility of strengthening local development.

Policy implications. The federal highway expansion policy has transformed the territory, but significant challenges remain in local and regional planning. An organized integration of the road network is required to avoid a centripetal approach from centers to peripheries, territorial fragmentation, and environmental and landscape tensions.

Limitations and future research. This study is limited to 2024 data and does not analyze temporal changes in connectivity. Future research should employ panel data to assess causal relationships between road investment and economic diversification.

In short, road connectivity in the Veracruz-Puebla region acts as a potential catalyst for integration and local development. Territorial complementarity and the continuity of the road network are essential to reducing inequalities and promoting integrated planning that considers both infrastructure and the dynamics of the local economy.

ORCID

Claudia Tello https://orcid.org/0000-0002-0664-6713
Amilcar Morales https://orcid.org/0000-0001-5560-4125
Mario Ledesma https://orcid.org/0000-0001-6927-6185

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URBAN SPRAWL EVOLUTION AND ITS IMPACTS ON THE HUMAN SETTLEMENT ENVIRONMENT IN HANGZHOU, CHINA

Mengmeng Lin[1], Saint Louis University, School of Engineering and Architecture, Environment and Habitat Planning, Baguio City, Philippines; Hangzhou City University, Hangzhou City, China
Lord Byron F. Gonzales, Saint Louis University, School of Engineering and Architecture, Environment and Habitat Planning, Baguio City, Philippines

Urban sprawl has become one of the most prominent spatial phenomena in rapidly urbanizing cities, generating profound effects on the ecological environment, economic efficiency, and social sustainability. However, the comprehensive influence of urban sprawl on human settlements remains insufficiently studied in rapidly urbanizing regions of East Asia, particularly in Chinese cities. This paper investigates the spatiotemporal evolution of urban sprawl in Hangzhou, China, from 2014 to 2023, and evaluates its impacts on human settlements using Wu Liangyong's five-system framework. Land use data derived from remote sensing imagery and statistical sources were analyzed with Geographic Information Systems (GIS), the Shannon entropy model, and the Sprawl Index to measure the intensity, direction, and equilibrium of the sprawl. A weighted index system based on the entropy weight method and Stepwise Regression analysis was employed to assess human settlement responses across five subsystems: Natural, Human, Social, Living, and Supportive Networks. Results reveal that Hangzhou experienced a significant expansion of its built-up areas, primarily through the conversion of cultivated land and woodland. The urban structure shifted from a monocentric to a polycentric pattern, with the main urban core approaching saturation and new growth concentrated in suburban centers and along transportation corridors. The Comprehensive Settlement Index improved markedly, with the Supportive Network and Living Systems most sensitive to sprawl, while the Natural System lagged behind due to ecological degradation. These findings highlight the dual role of sprawl – enhancing social and infrastructural systems while weakening ecological resilience – and underscore the necessity of integrated planning strategies to balance urban development with environmental sustainability.

Keywords: **urban sprawl, spatiotemporal evolution, GIS, Hangzhou, China.**

INTRODUCTION

Over the past century, global urbanization has accelerated markedly. The share of the world's urban population rose from 30% in 1950 to 55% in 2018 and is projected to reach 68% by 2050 (Li *et al*., 2022). According to United Nations forecasts, the global urban population will grow by 2.5 billion by 2050, with nearly 90% of this increase occurring in Asia and Africa. India, China, and Nigeria alone are expected to account for about 37% of global urban population growth between 2014 and 2050 (Kohli and Agarwala, 2017). While urbanization has driven significant economic growth and social development, it has also created challenges such as uncontrolled expansion, environmental pollution, ecological degradation, and urban sprawl. Among these, urban sprawl, defined as low-density, dispersed, and peripheral urban development lacking compactness and effective land-use planning, has emerged as a major global concern (Frumkin, 2002).

Empirical studies show that in many regions, urban land expansion has outpaced population growth. For example,

[1] Receiving Office, Zhejiang University of City College, No. 51 Huzhou Street, Gongshu District, Hangzhou City, Zhejiang Province, P. R. China
linmm@hzcu.edu.cn

European cities expanded their built-up areas by 78% between the mid-1950s and 2000, while the population grew by only 33% (Martins, 2012). Similarly, in the United States, 281 metropolitan areas expanded by 47% between 1982 and 1997, compared with a 17% rise in population (Fulton *et al*., 2001). In China, rapid urbanization since the 1978 reform and opening-up policy has led to an eightfold increase in built-up areas, with land urbanization significantly exceeding population growth. This trend is evident not only in megacities, but also in smaller inland cities (Kuang *et al*., 2016; Wang *et al*., 2020; Tavares *et al*., 2019).

Quantifying urban sprawl requires diverse methodological approaches. Indicator-based methods assess population and employment density, land-use growth rates, spatial accessibility, fragmentation, and landscape metrics (Fulton *et al*., 2001). Geospatial approaches utilize GIS and remote sensing to map impervious surfaces, calculate Shannon entropy, and evaluate landscape indices (Gonzales, 2016). Modeling approaches, such as cellular automata, simulate spatial growth under various assumptions and driving forces (Torrens and O'Sullivan, 2001). Increasingly, studies integrate multiple methods, combining indicator analysis with GIS-based techniques to capture the spatiotemporal dynamics and drivers of urban sprawl (Shifaw *et al*., 2020).

The drivers of urban sprawl vary across regions and include both natural and anthropogenic factors. In China, economic growth, industrial restructuring, demographic dynamics, government policies, and local interactions are dominant drivers, while the influence of natural geographic factors has diminished over time (Liu *et al*., 2005). Quantitative approaches, such as regression models, are commonly employed to evaluate the contributions of socioeconomic and policy variables to urban expansion (Harris, 1968).

Classical geographic theories provide valuable insights into the mechanisms linking urban sprawl and human settlements. Central Place Theory (Christaller, 1966) explains the hierarchical organization of urban systems, where peripheral expansion often converts farmland, wetlands, and forests into urban land, resulting in ecological degradation, social inequality, and uneven resource distribution. Agglomeration Theory (Marshall, 1890; Krugman, 1991) describes the spatial clustering of industries, populations, and services, illustrating how peripheral industrial parks and economic zones foster decentralization, exacerbate environmental pressures, and reinforce the spatial segregation of low-income groups in polluted areas. Together, these frameworks illuminate the multiple pathways through which urban sprawl impacts the natural, social, human, residential, and supportive network subsystems.

The concept of the human settlement environment offers a comprehensive framework for analyzing the impacts of urban sprawl. First formalized in the 1976 Vancouver Declaration by the United Nations, human settlements are defined as integrated systems encompassing social, material, organizational, spiritual, and cultural dimensions across urban and rural contexts. In China, Wu (1993) further advanced this concept through human settlement environment science, conceptualizing human settlements as dynamic systems centered on habitation, composed of five interrelated subsystems: natural, human, residential, social, and supportive networks. Building on this foundation, recent studies have developed multidimensional human settlement evaluation frameworks to assess urban development quality and livability across different regions and scales. These studies typically integrate natural, social, and infrastructure subsystems to generate comprehensive assessments of human settlements and reveal their spatial differentiation patterns (Zhang *et al*., 2023; Liu *et al*., 2023; Fang *et al*., 2022). Concurrently, international research on livability, sustainability, and human well-being has produced multidimensional analytical frameworks emphasizing the interactions and coupling among ecological, social, and economic subsystems within urban systems (Stern *et al*., 2025; Ameen and Mourshed, 2019; Michalina *et al*., 2021). Although research priorities and theoretical emphases differ, these studies collectively highlight a multisystem integration approach as central to understanding urban complexity.

However, from a theoretical development perspective, existing studies remain largely outcome-oriented, focusing on the assessment of human settlement status or development level, while paying comparatively less attention to the dynamic embedding of urban expansion processes and their driving mechanisms. This limits the capacity to systematically explain the intrinsic mechanisms of urban development. Similarly, urban sprawl research has tended to focus on spatial patterns and driving factors, often treating urban expansion as an independent spatial process, with limited attention to its interactions with human settlement systems. Although some studies have attempted to integrate urban expansion with ecological or social indicators, systematic analyses linking urban sprawl processes, drivers, and multisystem responses in human settlements remain limited.

Zhejiang Province exemplifies the rapid pace of China's urbanization, with Hangzhou, its capital, serving as a representative case. The city's built-up area grew from 433 km^2 in 2010 to 801.63 km^2 in 2022, expanding by approximately 135 km^2 annually, reflecting an intensified sprawl trend. This rapid growth has contributed to rising carbon emissions, encroachment on rural land, farmer unemployment, and intensified urban heat island effects, posing serious challenges to both human well-being and ecological sustainability (Hangzhou Municipal Bureau of Statistics, 2023; Heurlin, 2019).

Examining Hangzhou's urban sprawl provides critical insights into the interactions between spatial expansion and human settlement systems. It enables the identification of key drivers, spatiotemporal dynamics, and impacts across natural, social, human, residential, and infrastructural subsystems. Such understanding is vital for formulating sustainable planning strategies that balance economic development with environmental protection and social equity.

In the context of Hangzhou, a number of studies have examined urban expansion from different perspectives, including land-use change, spatial growth patterns, and

socioeconomic drivers. These studies have provided important insights into the rapid urbanization process of the city, particularly in relation to construction land expansion and economic transformation.

However, most existing studies remain fragmented, typically focusing on single dimensions such as land-use dynamics or economic factors, with limited attention to the integrated analysis of spatiotemporal processes, driving mechanisms, and their impacts on the human settlement environment.

Therefore, this study aims to provide a more comprehensive framework by linking urban sprawl processes with multidimensional human settlement systems, thereby offering a more systematic understanding of urban development in Hangzhou.

By integrating theoretical frameworks, quantitative techniques, and empirical evidence, this study aims to provide a comprehensive understanding of how urban expansion interacts with natural, social, human, residential, and infrastructural subsystems. The findings may offer useful insights for other rapidly urbanizing cities in China and beyond, potentially informing more balanced and sustainable approaches to urban development.

STUDY AREA

Hangzhou, the capital of Zhejiang Province on the eastern coast of China, is situated on the southern wing of the Yangtze River Delta Urban Agglomeration. As a sub-provincial city and a core growth pole within one of the world's most dynamic urban agglomerations, Hangzhou plays a pivotal role in China's national urban system. It is also a renowned historical and cultural city and a pilot zone for the innovative development of the digital economy (Figure 1).

Hangzhou lies at the southern edge of the Yangtze River Delta, bordering the Qiantang River and embracing the West Lake, with hilly terrain surrounding its western and southern periphery. These natural conditions historically constrained compact urban development. However, in recent decades, rapid urbanization and infrastructure expansion have driven the city to extend toward suburban plains and peripheral districts and counties. The municipality covers a total administrative area of 16,847 km^2, with a permanent resident population of approximately 12.5 million and an urbanization rate of 84.8% by the end of 2023.

As a major economic, cultural, and technological hub, Hangzhou has developed a diversified industrial structure dominated by the digital economy, high-tech manufacturing, finance, and tourism. Its gross domestic product (GDP) increased significantly from 834.6 billion RMB in 2014 to 2,005.4 billion RMB in 2023. Meanwhile, large-scale investments in transportation infrastructure, including metro systems, expressways, and high-speed railways, have facilitated suburban expansion and the emergence of multiple growth poles. This process, however, has also introduced challenges such as cultivated land loss, ecological pressure, and changes in the human settlement environment.

Administratively, Hangzhou governs 10 municipal districts, 2 counties, and 1 county-level city. Within China's administrative system, municipal districts constitute the core urban areas of prefecture-level cities and are highly integrated into unified urban planning and governance. Counties function as basic administrative units responsible for coordinating urban-rural development, while county-level cities, although administratively equivalent to counties, exhibit higher levels of urbanization and more developed urban service functions. This three-tier structure of "municipality-district-county (county-level city)" forms the fundamental governance framework of Hangzhou's human settlement system.

From a spatial perspective, Hangzhou has developed a polycentric and networked urban structure. The main urban area – comprising Shangcheng, Gongshu, Xihu, and Binjiang Districts – serves as the primary urban core, concentrating high-level administrative, commercial, and cultural functions. Six sub-central districts (Xiaoshan, Yuhang, Linping, Qiantang, Fuyang, and Lin'an) function as secondary urban centers, accommodating industrial development, population redistribution, and regional service provision. In addition, county-level areas in the western ecological zone serve as tertiary centers, focusing on ecological conservation, tourism, and local service functions.

Overall, Hangzhou forms a hierarchical urban system consisting of a primary core, multiple secondary sub-centers, and peripheral county-level centers. The municipality encompasses a diverse range of urban and rural settlements,

Figure 1. Location of Hangzhou city and its administrative divisions (Source: Authors' own elaboration based on administrative boundary data from the National Catalogue Service for Geographic Information, 2023, http://www.webmap.cn/)

including central city districts, suburban towns, and rural townships. Population distribution across this system is highly uneven, exhibiting a clear pattern of "high density in the east and low density in the west". The eastern plains and core urban areas show population densities exceeding 10,000 persons per km^2, while western regions such as Chun'an County, Jiande City, and parts of Lin'an District remain relatively sparsely populated. This spatial differentiation reflects the city's development strategy of "advancing along the river and optimizing the east while developing the west", and provides a representative case for examining the impacts of urban sprawl on the human settlement environment.

METHODS AND PROCEDURES

This study employs a mixed-methods framework to analyze the spatiotemporal dynamics of urban sprawl in Hangzhou from 2014 to 2023 and its effects on human settlement quality. Land-use data were derived from remote sensing images provided by the Zhejiang Geographic Information Public Service Platform, processed through ENVI 5.3 and ArcGIS 10.8 using supervised classification, maximum likelihood estimation, spatial correction, and accuracy verification. Land-use categories followed the LUCC framework of the Chinese Academy of Sciences (Liu, 1996). Socioeconomic and environmental data, including population, GDP, infrastructure, housing, and ecological indicators were collected from the Hangzhou Statistical Yearbook, annual construction reports, and ecological bulletins, and were standardized to ensure temporal and spatial consistency.

Urban sprawl was measured using two complementary approaches. First, the Shannon Entropy Index quantified land-use dispersion across urban zones:

$$H = -\sum_{i=1}^{n} P_i \ln P_i$$

where P_i is the proportion of land-use type *i*. Values approaching 0 indicate compact development, while values approaching ln(n) indicate dispersed sprawl. Second, the Sprawl Index (SI) measured the relative pace of land expansion to population growth (Jiang *et al*., 2007):

$$SI = \frac{U}{P}$$

where *U* and *P* denote the growth rates of built-up land and population, respectively; SI>1 reflects sprawl, whereas SI<1 suggests compact growth.

This study assesses the impact of urban sprawl on the human settlement environment by adopting an evaluation system rooted in Wu Liangyong's Five-System Framework. Wu Liangyong's Five-System Framework conceptualizes the human settlement environment into five interdependent subsystems: Nature, Human, Society, Live, and Supportive Network (Wu, 2001). This holistic and multi-dimensional approach provides a structured tool for evaluating urban development and human settlement environments. In this regard, it aligns with some general principles of European human geography, such as cultural ecology (Sauer, 1967) and spatial systems analysis (Haggett, 2001), which emphasize the dynamic interaction between human societies and their physical environments. However, compared with the long-established critical and interpretive traditions in European human geography, the Five-System Framework is largely functionalist, focusing on subsystem equilibrium and resource allocation, while giving less attention to power relations, social inequalities, and the socially constructed nature of space (Harvey, 1992). Moreover, European geography emphasizes relationality and multi-scalar flows (Massey, 2013), whereas Wu's framework treats subsystems as relatively bounded and stable, paying limited attention to the impacts of globalization, policy interventions, and inter-regional connectivity.

Despite these differences, given China's rapid urbanization and policy-driven development, the Five-System Framework effectively integrates natural, social, population, and infrastructural factors, providing a practical and comprehensive tool for assessing urban sprawl and human settlements. Therefore, it remains highly applicable in the Chinese context.

Building on existing scholarly research on human settlement environment evaluation, this study further subdivides each of the five core systems into ten indicator layers. Through systematic optimization and screening, the final evaluation framework is structured into five major systems, ten subsystems, and 25 specific evaluation indicators. To avoid the subjectivity inherent in manual weight determination and address the issue of information overlap among multiple indicator variables, the entropy weight method was employed to assign weights. This objective weighting approach is widely accepted in socio-economic and other research domains and is well-suited for comprehensive evaluations involving multiple indicators (Wehrl, 1978; Zhu *et al*., 2020). For each indicator j, normalized proportions were computed as:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$$

Entropy values were then calculated as:

$$e_j = -k \sum_{i=1}^{m} p_{ij} \ln(p_{ij}), \quad k = \frac{1}{\ln m}$$

and final weights obtained as:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)}$$

ensuring that indicators with greater variability contribute more to the composite index. The weighted scores were aggregated to produce annual subsystem and overall settlement quality indices for 2014–2023.

Finally, stepwise regression analysis was applied to examine the relationship between urban sprawl (SI) and Human settlement environment quality (composite score). Diagnostic tests confirmed the absence of severe collinearity and heteroscedasticity, ensuring the robustness of the regression results.

RESULTS AND DISCUSSION

The evolutionary pattern of urban sprawl phenomenon in Hangzhou, China

Temporal evolution of urban sprawl

The spatiotemporal trajectory of urban sprawl in Hangzhou (2014–2023) shows a structural shift from a demographically constrained compact model to a land-driven expansionist regime. This evolution, marked by inflection points in the Sprawl Index (SI) and divergent growth gaps, unfolded in five phases shaped by state-led policies and exogenous shocks.

- Phase I (2014–2015): The regime of demographic compactness

Hangzhou initially exhibited compact development, with built-up land expansion lagging behind population growth; SI values remained sub-unity (0.40–0.94). In 2014, the population growth rate (3.38%) was over twice the land expansion rate (1.37%), aligned with China's New-type urbanization strategy that prioritized demographic optimization and land intensification. Urban growth was functionally clustered, with spatial supply matching the demographic absorption capacity.

- Phase II (2016–2019): Transition to infrastructure-led supply

A 2016 inflection shifted growth to supply-side expansion: average annual built-up land expansion (5.36%) far outpaced population growth (2.84%), pushing SI to 1.36-3.08 (above unity). This structural change stemmed from national regional integration and infrastructure-led development mandates. The 2017 "Along the River" Development Strategy drove eastward expansion along the Qiantang River, reorienting growth from accommodating residents to preemptively building frameworks for economic agglomeration.

- Phase III (2020–2021): Volatility from exogenous shocks and mega-events

This period revealed high sensitivity to external factors. The 2020 COVID-19 pandemic reduced land development to 2.62%, lowering SI to 0.86 despite 3.03% population growth. In 2021, 19th Asian Games preparations triggered a land supply surge: built-up area expansion hit 19.02% while population growth slowed to 2.00%, pushing SI to a decadal peak of 9.52. Mega-events thus temporarily decoupled spatial production from demographic trends.

- Phase IV (2022–2023): Stabilization in a land-dominant equilibrium

Post-peak, sprawl intensity eased but did not return to compactness. SI fell from 9.52 to 2.39-2.86, yet average land development (3.37%) remained over double the population growth (1.3%). This indicates a persistent structural shift: Hangzhou entered a "new normal" of moderate land-led expansion, with spatial overcapacity from the infrastructure boom dictating growth even after pandemic and games triggers faded.

Collectively, Hangzhou's urban form evolution reflects a profound land-population decoupling, with SI rising from less than 1.0 (Phase I) to more than 2.0 (Phase V). This outcome, driven by state-led planning (New-type urbanization, Regional Integration) and event mobilization, prioritized spatial capacity building exemplified by 2021's 19.02% land spike over immediate demographic absorption.

Peripheral expansion guided by transport corridors

Land use change analysis reveals a distinct spatial shift in Hangzhou's urban expansion between 2014 and 2023, with development momentum transitioning markedly from the spatially saturated Main Urban Core to secondary urban centers. The Main Urban Core – encompassing Shangcheng, Gongshu, Binjiang, and Xihu districts – contributed merely 9.4% of the total newly added built-up area, reflecting constrained development potential due to spatial saturation and limited available land resources. In stark contrast, secondary urban centers (Xiaoshan, Fuyang, Yuhang, Lin'an, Qiantang, and Linping districts) absorbed 72.6% of the newly

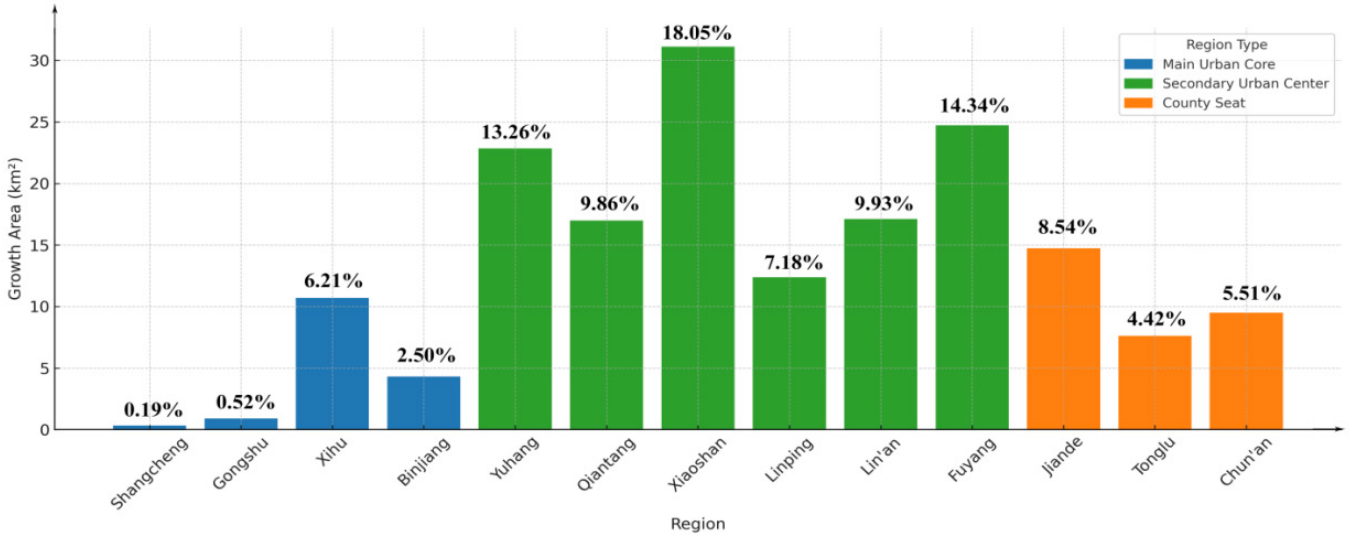

Figure 2. Built-up area expansion and its proportion across Hangzhou's districts from 2014 to 2023 (Source: Hangzhou Municipal Bureau of Statistics, 2023, https://ceidata.cei.cn/)

developed built-up land, exhibiting rapid and multidirectional growth that was predominantly concentrated along major transport corridors (Figures 2 and 3).

Newly developed built-up land was spatially agglomerated around key transportation hubs, including intercity expressways, ring roads, and critical corridors linking Hangzhou to surrounding economic agglomerations. This spatial alignment with major urban transport arteries has fostered a corridor-oriented, linear development pattern. Notably, Hangzhou's urban sprawl was no longer characterized by continuous outward expansion from the core; instead, it exhibited a dispersed and multi-directional trend, wherein emerging urbanized areas were interconnected through an extensive transportation infrastructure network (Figure 3). This pattern reflects a transition from monocentric expansion to polycentric development, driven by the saturation of core areas and the strategic development of secondary centers supported by transport infrastructure.

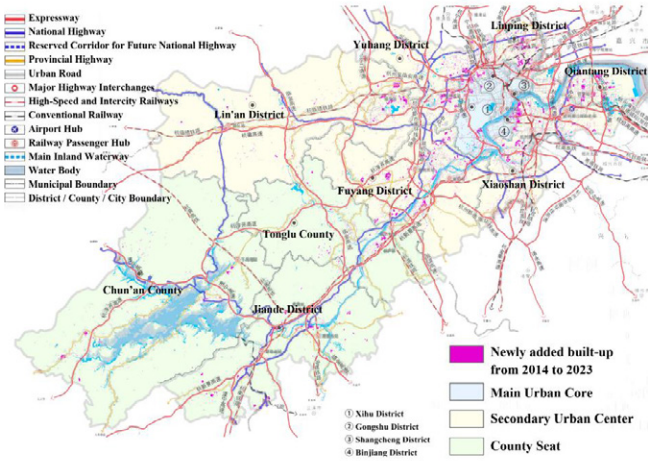

Figure 3. Municipal Comprehensive Transportation Plan Map (2021–2035) with Newly Added Built-up Areas in Hangzhou
(Source: Authors)

From monocentric core to polycentric system

Hangzhou's National Territorial Spatial Plan (2021–2035) defined the spatial framework for urban development and ecological protection through designated urban development boundaries. Xihu, Shangcheng, Gongshu, and Binjiang were heavily constrained by these development boundaries, with minimal room for horizontal expansion. These four core areas exhibited significantly higher population densities and GDP output per unit area than peripheral districts. They served as high-density, high-efficiency urban nodes, concentrating key functions such as financial institutions, technology parks, and commercial service centers.

Meanwhile, districts such as Yuhang, Linping, Qiantang, Xiaoshan, Fuyang, and Lin'an have experienced substantial built-up area expansion, functioning as overflow zones for population, industry, and infrastructure. These districts gradually evolved into relatively independent urban sub-centers. The functional areas in these zones were densely distributed and diverse, including high-density residential communities, high-tech industrial parks, and public service facilities – demonstrating a clear trend of "industry-city integration". Each emerging sub-center formed its own functional identity: Yuhang and Linping focus on digital innovation and artificial intelligence; Qiantang emphasized advanced manufacturing and logistics; Xiaoshan featured a balanced mix of industrial, commercial, and residential uses, acting as a southern transportation hub; while Fuyang and Lin'an played key roles in eco-tourism, cultural heritage, and ecological support for the region (Figure 4).

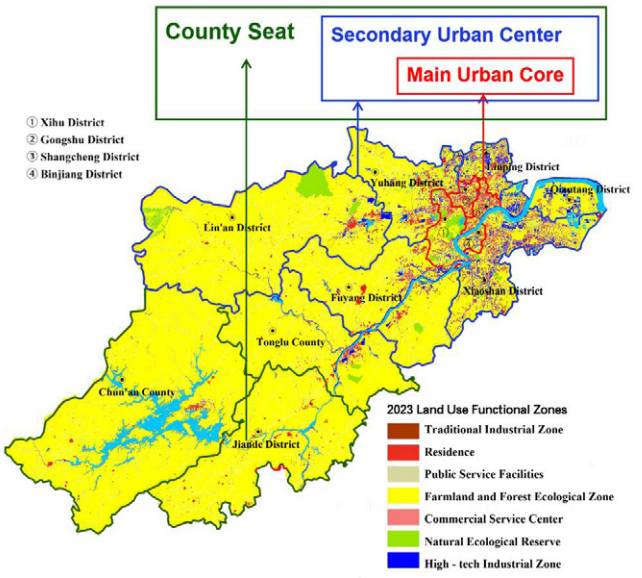

Figure 4. 2023 Land use functional zones
(Source: Authors)

Land use transformation driven by functional reconfiguration

Urban sprawl was inevitably accompanied by a restructuring of land use patterns. Between 2014 and 2023, Hangzhou's built-up area increased by 173.22 km^2, while the area of cultivated land decreased by 129.49 km^2 (Table 2). Ecological land, such as forested areas and water bodies, remained relatively stable during this period, indicating that urban expansion was primarily achieved through the orderly conversion of agricultural land. This spatial trade-off was evident in the land use maps, where large contiguous tracts of farmland – previously located on the urban periphery – have gradually been transformed into urban construction land, particularly within the expansion zones delineated by the urban development boundaries (Figure 4).

An overlay analysis of functional zoning (Figure 4) and land use change (Figure 3) revealed that the most significant land transformations occurred in Yuhang, Linping, Qiantang, Xiaoshan, Fuyang, and Lin'an districts. These areas, initially dominated by agricultural or ecological functions and located on the urban fringe, have been restructured through functional upgrades and the implementation of new town development plans. They are now evolving into emerging zones of residential, industrial, research, and integrated service functions.

Analysis of land use structure equitability

The analysis of Shannon entropy (H) reveals marked spatial differentiation in land use diversity across Hangzhou. The Main urban core (H ≤ 1) exhibited the lowest diversity and poorest balance, primarily reflecting its advanced stage of urbanization, in which construction land dominated by residential and commercial functions has encroached upon farmland and woodland, resulting in a highly simplified land use structure (Table 1). In contrast, the secondary urban centers and county seats (H > 1) demonstrated higher diversity and greater balance. This pattern is attributable to their transitional development stage, whereby these areas simultaneously accommodate the expansion of construction land while retaining significant shares of agricultural and ecological land, thereby preventing dominance by a single land use type.

At the citywide level, Hangzhou's Shannon entropy (H), Equitability index (EH), and Equivalent number of types (Nq) showed a modest upward trend between 2014 and 2023 (Table 2). Nq is a land use diversity metric derived from Shannon entropy and calculated as $Nq=e^{H}$, which represents the effective number of equally proportioned land use types in a study area. This indicates a slight overall improvement in land use diversity and balance during the study period. As reflected in the land use changes of Table 2 (173.22 km^2 expansion of built-up areas), the spatial expansion of constructed land was accompanied by a gradual population shift from the saturated main urban core to peripheral sub-centers and semi-urban areas: this redistribution alleviated excessive settlement density in the core districts and moderately raised density in the expanding peripheral zones, aligning with the polycentric urban development trend.

Table 1. Analysis of land diversity in three types of regions (Main urban area, secondary urban center, and county seat) in Hangzhou in 2023 (Source: Authors)

Urban classification	Shannon entropy (H)	Equitability index (EH)	Equivalent number of types (Nq)
Main urban area			
- Shangcheng district	0.84	0.469	2.27
- Gongshu district	0.82	0.458	2.27
- Xihu district	1.00	0.586	2.86
- Binjiang district	0.91	0.508	2.48
Secondary urban center			
- Yuhang district	1.35	0.754	3.86
- Qiantang district	1.15	0.642	3.16
- Xiaoshan district	1.28	0.715	3.60
- Linping district	1.21	0.675	3.35
County seat			
- Jiande city	1.02	0.570	2.77
- Lin'an district	1.32	0.737	3.74
- Fuyang district	1.42	0.793	4.13
- Tonglu county	1.38	0.771	3.97
- Chun'an county	1.25	0.698	3.49

Table 2. Analysis of land diversity in Hangzhou in 2014 to 2023 (Source: Authors)

Code	Classification	2014 area (km^2)	2023 area (km^2)	Land change (km^2)
1	Cultivated land	3,027.18	2,897.69	-129.50
2	Woodland	11,460.05	11,413.62	-46.43
3	Grassland	395.29	398.24	2.95
4	Waters	890.39	890.67	0.28
5	Built-up areas	1,085.30	1,258.52	173.22
6	Unused land	5.99	6.04	0.05
	TOTAL	16,847	16,847	
	Shannon's entropy (H)			1.463 → 1.492
	LN(N)			2.944 → 2.944
	Shannon's equitability (EH)			0.497 → 0.507
	Numbers equivalent (Nq)			4.312 → 4.447

Spatially, higher levels of urbanization were associated with greater homogeneity in land use, while peripheral and semi-urban areas with stronger ecological preservation capacity maintained richer diversity. Temporally, expansion of built-up land remained the dominant process, largely at the expense of farmland and woodland. Nonetheless, minor internal adjustments within land categories contributed to a gradual improvement in structural balance.

In conclusion, Hangzhou's urban expansion (2014–2023) shifted from population-driven to land-led growth, with core districts saturated and sprawl moving to peripheral sub-centers via transport guidance, transforming the structure from monocentric to polycentric. Built-up areas expanded mainly by converting cultivated land and woodland, while ecology and water remained stable, aligning with planning. Spatially, higher urbanization brought more homogeneous land use, with secondary centers and ecologically preserved counties showing greater diversity; temporally, despite farmland/woodland reduction, land use diversity improved slightly due to internal adjustments.

The driving factors behind urban sprawl

Hangzhou's rapid urban sprawl from 2014 to 2023 was primarily driven by the combined forces of economic growth, industrial upgrading, and demographic expansion. The city's GDP more than doubled (950.2 to 2005.9 billion yuan), accompanied by a 170% increase in cumulative real estate investment and a 54% surge in fixed-asset investment in infrastructure, directly fueling large-scale land conversion for residential and commercial purposes. Meanwhile, the share of Hangzhou's primary, secondary and tertiary industries in GDP shifted from 3.0:41.9:55.1 to 1.7:28.3:70.0, a structural transformation that attests to the rise of the digital economy and high-tech sectors – the core drivers fueling the substantial increase in the tertiary industry's GDP share from 55.1% to 70.0%. Over the same period, the added value of Hangzhou's core digital industries nearly tripled from the initial year to reach 567.5 billion yuan, accounting for 28.3% of the city's gross regional product (GRP). The clustering of technology parks, higher-education zones, and emerging industries such as e-commerce and internet finance reshaped the urban form by driving suburban expansion. In parallel, the permanent population increased from 7.07 to 12.38 million and the urbanization rate rose to 84.2%, while per capita disposable income almost doubled. This demographic and income growth reinforced demand for suburban housing, with residential sales expanding by 34.6%, intensifying outward urban sprawl.

At the same time, infrastructure development, administrative restructuring, and major events acted as structural enablers of spatial expansion. Transport breakthroughs, with metro mileage reaching 516 km, expressways exceeding 500 km, and airport passenger throughput rising from 29.3 to 41.2 million, greatly enhanced connectivity, reinforcing suburbanization and cross-regional integration. Administrative adjustments, such as the incorporation of Fuyang and Lin'an as districts, expanded the urban area from 4,876 to 8,003 km^2 and population by 1.38 million, while the 2023 territorial plan institutionalized a *one main city, six sub-cities, three towns* framework, consolidating a polycentric pattern. Major events provided catalytic momentum: the 2016 G20 Summit spurred upgrades in transport and real estate markets, while the 2023 Asian Games accelerated infrastructure, energy, and cultural construction. Collectively, these forces not only expanded Hangzhou's built-up areas but also transformed its spatial structure from a compact monocentric model toward a decentralized, polycentric metropolitan system.

Urban sprawl impact on Hangzhou's human settlement environment

The evaluation index system for Hangzhou's human settlement environment constructed in this study (Table 3) is based on the Pressure-State-Response (PSR) model proposed by the OECD and UNEP, a classic framework in human settlement and regional development evaluation. Based on the model's core logic, this study accurately maps the indicators to the three "Pressure-State-Response" dimensions, depicting the evolution mechanism of the human settlement environment under urban sprawl: development disturbances from urban sprawl as the pressure dimension, the actual characteristics of the human settlement environment as the state dimension, and targeted urban governance measures as the response dimension.

The index system was screened based on three scientific principles: conformity with Hangzhou's urban sprawl and human settlement characteristics, the availability and consistent statistical caliber of 2014–2023 panel data, and indicator independence and non-redundancy. It includes 5 first-level indicators (natural, human, social, living, and supportive network systems), each decomposed into three PSR-corresponding second-level indicators (pressure, state, response), with 25 third-level sub-indicators. All indicators and weight analysis cover Hangzhou's entire administrative jurisdiction, with original data from authoritative sources to ensure scientificity and objectivity.

Specifically, pressure-type second-level indicators (environmental, population, economic, housing pressure) characterize urban sprawl's negative impacts; state-type indicators (environmental quality, population benefit, industrial, housing momentum) reflect the human settlement's actual state; response-type indicators (urban consumption, infrastructure) embody Hangzhou's governance measures. These interrelated indicators integrate the PSR model with the index system, reflecting its complete logical chain. All the indicators in Table 3 correspond to the entire urban area of Hangzhou, reflecting the overall evolution of the human settlement environment. In specific analyses, subregional data can be used to examine local evolutionary characteristics, but this evaluation system is primarily intended for the macro level, providing a reference for the overall human settlement development in Hangzhou.

The entropy method was used to determine indicator weights, objectively weighting based on the temporal variability of municipal-level indicators during 2014–2023: the larger an indicator's time-series coefficient of variation, the smaller its information entropy and the higher its weight, avoiding subjective biases. The core purpose of weighting is to quantitatively identify key drivers of

Table 3. Data on the weights of indicators at all levels for Hangzhou's human settlement environment (Source: Authors)

First-level indicator	Weight of first-level indicator WS	Second-level indicator	Sub-indicator of second level	Calculation	Weight of sub-indicator of second Level Wj
Nature system	0.180	Environmental stress (E1)	Fine particulate matter concentration (PM2.5)	Annual average PM2.5 concentration measured by urban monitoring stations	0.028
			Per capita industrial wastewater discharge	Total industrial wastewater discharge ÷ urban population	0.033
		Environmental quality (E2)	Air quality index	Official AQI value; higher values indicate worse air quality	0.040
			Green coverage rate in built-up areas	(Green area in built-up areas ÷ total built-up area) × 100	0.055
			Per capita green space and park area	Total green and park area ÷ urban population	0.024
Human system	0.201	Population pressure (P1)	Unemployment rate	Number of unemployed ÷ labor force × 100	0.025
			Population density	Urban population ÷ built-up area	0.038
		Population benefit (P2)	Urbanization rate of population	Urban population ÷ total population × 100	0.034
			Per capita deposit balance	Total deposits in financial institutions ÷ urban population	0.061
			Average wage of employees	Total wages ÷ number of employed persons	0.043
Society system	0.174	Economic pressure (S1)	Theil index	Measures regional income inequality using the formula: $T = \frac{1}{N}\sum_{i=1}^{N}\frac{y_i}{\bar{y}}\ln\frac{y_i}{\bar{y}}$ where *N* is total population or unit count, yi is per capita income of unit i, $\bar{y}$ is overall average income.	0.037
			Consumer price index	CPI published by the statistical bureau, base period = 100	0.019
		Industrial momentum (S2)	Per capita regional gross domestic product	Regional GDP ÷ total population	0.033
			Economic density	Regional GDP ÷ built-up area	0.040
			Level of industrial agglomeration	Industrial output in clustered areas ÷ total regional industrial output × 100	0.045

First-level indicator	Weight of first-level indicator WS	Second-level indicator	Sub-indicator of second level	Calculation	Weight of sub-indicator of second Level Wj
Live system	0.200	Housing pressure (L1)	Per capita completed real estate investment amount	Total completed real estate investment ÷ urban population	0.043
			Transaction price of commercial housing	Average market price of commercial housing per m^2	0.046
		Housing momentum (L2)	Proportion of urban construction land	Urban construction land ÷ total urban land × 100	0.047
			Per Capita Sold Residential Area	Total residential area sold ÷ urban population	0.065
Supportive network	0.244	Urban consumption (R1)	Per capita water consumption	Total urban water consumption ÷ urban population	0.028
			Electricity consumption per unit of GDP	Total electricity consumption ÷ GDP × 10,000	0.025
		Urban infrastructure (R2)	Proportion of investment in municipal public facilities	Municipal public facility investment ÷ total fixed asset investment × 100	0.041
			Per capita urban road area	Total urban road area ÷ urban population	0.070
			Proportion of education expenditure	Education expenditure ÷ total fiscal expenditure × 100	0.057
			Per capita number of medical beds	Total hospital beds ÷ urban population	0.024

Hangzhou's municipal human settlement quality evolution under urban sprawl, clarify the relative importance of each dimension and indicator, and lay a scientific foundation for comprehensive evaluation and evolution analysis.

The results (Table 3) show that the Supportive network system (0.244) had the highest weight, indicating that infrastructure and public services exerted the most substantial influence on settlement quality in Hangzhou. In contrast, the Nature system (0.180) carried the lowest weight, reflecting its relatively limited variation during 2014–2023. At the sub-indicator level, per capita urban road area (0.070) and education expenditure ratio (0.057) obtained the largest weights, underscoring the pivotal role of transport and education investments in shaping livability. Conversely, indicators such as per capita green space (0.024) exhibited lower weights, suggesting more stable conditions with weaker explanatory power. These patterns are consistent with Hangzhou's governance trajectory, whereby infrastructure and social services were prioritized in recent development agendas, while ecological improvements advanced at a steadier pace.

However, subsystem dynamics reveal that the benefits of sprawl were unevenly distributed. While the supportive network and living systems recorded the largest gains, the natural system exhibited both the lowest baseline and the weakest growth. Its score rose from 0.0236 in 2014 to

Table 4. Hangzhou's urban sprawl index and human settlement environment quality scores (Source: Authors)

Year	Natural system	Human system	Social system	Living system	Supportive network	Comprehensive evaluation score	Sprawl index
2014	0.0236	0.0369	0.0167	0.0000	0.0630	0.1402	0.4047
2015	0.0387	0.0432	0.0347	0.0326	0.0411	0.1903	0.9390
2016	0.0553	0.0628	0.0402	0.0845	0.0430	0.2857	3.0753
2017	0.0691	0.0591	0.0602	0.0709	0.0679	0.3273	1.7273
2018	0.0898	0.0840	0.0761	0.0746	0.0940	0.4185	1.3566
2019	0.1157	0.0871	0.1157	0.0848	0.1265	0.5298	1.7091
2020	0.1039	0.0946	0.1037	0.0876	0.1120	0.5018	0.8630
2021	0.1021	0.1987	0.1556	0.1884	0.1981	0.8429	9.5205
2022	0.1567	0.1190	0.1501	0.1203	0.1460	0.6921	2.3914
2023	0.1789	0.1577	0.1550	0.1349	0.2060	0.8326	2.8580

0.1789 in 2023 (Table 4), but during the peak expansion year of 2021, when the sprawl index reached 9.5205, the natural system lagged behind all other subsystems at only 0.1021. This suggests that ecological dimensions are more sensitive to rapid land conversion and large-scale construction than socio-economic dimensions, which improved more consistently.

The stepwise regression analysis demonstrates a statistically significant positive association between the sprawl index and the comprehensive livability score ($\beta = 0.644$, $p = 0.044$). This indicates that during 2014–2023, urban expansion in Hangzhou contributed positively to human settlement quality by improving infrastructure provision, housing availability, and accessibility to public services. These results are consistent with previous studies showing that moderate urban sprawl can alleviate congestion in the saturated urban core while extending modern amenities to peripheral areas (Zhang *et al*., 2022; Wu *et al*., 2017).

The relatively low Durbin–Watson value (0.519) indicates residual autocorrelation, reflecting the temporal nature of the dataset. While this does not undermine the robustness of the identified positive association, it suggests that results should be interpreted with caution. Applying panel or dynamic regression models in future research could better capture the long-term causal mechanisms between sprawl and settlement systems.

Overall, these findings confirm that Hangzhou's sprawl, under a governance framework emphasizing infrastructure and service investment, has functioned as a driver of livability improvement. Yet, the disproportionate vulnerability of the natural system highlights the need for integrating green infrastructure, ecological safeguards, and growth boundary controls into future expansion strategies. Without such measures, socio-economic gains in livability may outpace ecological resilience, creating sustainability risks in the long run.

CONCLUSIONS

This study systematically examines the spatiotemporal evolution, driving mechanisms, and multidimensional impacts of urban sprawl on the human settlement environment in Hangzhou between 2014 and 2023. The aim is to elucidate the causal pathways of urban expansion under rapid urbanization and provide evidence-based insights for decision-makers, urban planners, and environmental managers. By integrating Geographic Information Systems (GIS), the Sprawl Index, and the entropy weight method within the framework of Wu Liangyong's five-system theory for human settlements, this research not only characterizes the spatial patterns of sprawl but also reveals the underlying mechanisms and system-level responses.

The results indicate that Hangzhou's urban sprawl exhibits distinct phased features, transitioning from population-constrained compact development to land-driven peripheral expansion. The core urban areas have reached developmental saturation, with 72.6% of newly added built-up areas concentrated in peripheral sub-centers, and forming axial agglomeration along major transportation corridors. Land-use conversion primarily involved the transformation of cultivated land and woodland into urban construction areas. Although ecological land remained relatively stable overall, it experienced intermittent disturbances due to rapid development.

Mechanism analysis reveals that the sprawl process is driven by the interaction of three major forces:

- Planning-led factors: strategies such as the "Development along the river" initiative and broader territorial spatial planning provided institutional guidance, serving as the core drivers of expansion;
- Market-driven spontaneous factors: digital economy agglomeration, real estate demand, and population mobility generated spillover effects that facilitated peripheral growth; and
- Short-term catalytic events: mega-events such as the G20 Summit and the Asian Games acted as temporary accelerators of construction activities.

This mechanism elucidates a clear causal chain: institutional planning provides direction and governance, market forces drive the actual spatial manifestation, and short-term events accelerate localized expansion, together forming a "planning-led, market-spontaneous, event-catalyzed" compound growth pattern.

Urban sprawl exerted dual effects on Hangzhou's human settlement environment. On the positive side, the supportive network and living systems were substantially upgraded, with improved infrastructure and expanded public services driving a rise in the comprehensive human settlement index, highlighting the potential benefits of moderate sprawl in alleviating core-area congestion and optimizing spatial efficiency. On the negative side, the natural system was highly sensitive to rapid land conversion and consistently lagged behind socio-economic dimensions, emerging as a critical bottleneck for high-quality human settlement improvement and emphasizing the necessity of ecological protection.

In terms of practical implications, this study provides actionable insights for multiple stakeholders:

- Urban policymakers can utilize the identified polycentric and corridor-oriented sprawl pattern to delineate growth boundaries and optimize urban structures;
- Urban planners can design differentiated regulatory strategies based on the observed synergy between planning and market drivers; and
- Environmental managers gain quantitative evidence on ecological sensitivity, supporting cultivated land protection, green infrastructure development, and strict enforcement of ecological red lines.

Theoretically, this research advances the comprehensive evaluation of sprawl effects by integrating previously fragmented analyses within Wu Liangyong's five-system framework, quantifying the coupling and coordination among subsystems. The findings reveal cascading effects and compensatory mechanisms among human settlement subsystems under rapid urbanization, providing new empirical evidence for understanding complex urban systems.

This study has certain limitations. The relatively short time series, although capturing key transitional phases, may not fully reflect long-term evolutionary dynamics. Micro-scale variations in human settlement responses were also not addressed. Future research could extend the temporal series, employ dynamic or panel regression models to explore causal mechanisms in depth, and incorporate survey-based data to better capture residents' perceptions and micro-level system responses.

Compared with previous studies on urban expansion in Hangzhou and other rapidly urbanizing Chinese cities, the findings of this study are broadly consistent in identifying the outward expansion of built-up areas and the increasing role of economic transformation as key drivers.

However, this study extends existing research in several important ways. First, it reveals the phased and process-oriented characteristics of urban sprawl, rather than treating it as a static outcome. Second, it explicitly links spatial expansion with a composite mechanism involving planning-led, market-driven, and event-catalyzed forces, thereby clarifying the causal pathways underlying urban growth. Third, by incorporating the human settlement framework, this study provides a more comprehensive assessment of the multidimensional impacts of urban sprawl, highlighting both its positive and negative effects across different subsystems.

In summary, this study clarifies the mechanisms of urban sprawl in Hangzhou by distinguishing between planning-led and spontaneous processes, and reveals their differentiated impacts on human settlement systems. It contributes to a more integrated understanding of urban sprawl by linking spatial processes, driving mechanisms, and multidimensional system responses, while offering practical insights for achieving a balance between spatial expansion, ecological protection, and infrastructure development.

ORCID

Mengmeng Lin https://orcid.org/0009-0000-4970-5579

Lord Byron F. Gonzales https://orcid.org/0009-0000-1020-9594

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SPACE SYNTAX ANALYSIS OF SETTLEMENT NETWORKS IN THE HUNGARIAN-SLOVENIAN BORDER REGION

Ágnes Bertyák[1], Department of Urban Planning and Design, Faculty of Architecture, Budapest University of Technology and Economics, Budapest, Hungary
Kornélia Kissfazekas, Department of Urban Planning and Design, Faculty of Architecture, Budapest University of Technology and Economics, Budapest, Hungary

In the field of morphological research, the relationship systems between small settlements, especially the situation of villages along borders, remain a grey area to this day. This is despite the location and nature of borders between countries having a profound impact on the fate of the settlements along them. This research seeks to answer the question of how the physical network connections and population indicators of a given, typically small settlement area have changed, with particular regard to the border situation. The sample area for the research is the Őrség region, located on the western border of Hungary and the eastern border of Slovenia. The research uses space syntax analysis to explore the network interrelationships of the settlements concerned. The study proposes a new classification-based method for interpreting the space syntax model at the regional level. With this tool, the spatial roles of settlements in the examined region were analyzed across three time periods, and the main hubs were identified, as well as the strength of their roles, and their temporal and spatial development. The results were compared with the population characteristics of the region, thereby identifying the most disadvantaged settlements. With its rural theme and regional approach, the research represents an innovation in space syntax analysis at an international level.

***Key words*: settlement network, border situation, space syntax analysis, spatial interactions, Őrség.**

INTRODUCTION

In the field of morphological studies, space syntax analysis has gained significant traction, since it seeks to understand the various relationships between the physical environment and human behavior by examining a specific spatial situation. Its subject matter is most often urban or city-scale, but recently, analyses of rural villages have also become increasingly common (Sun *et al*., 2024; Zhang *et al*., 2023). At the same time, these studies often treat settlements – and their physical spaces – as independent entities, ignoring their topological and geopolitical situation, as well as their complex relationships with their environment and neighboring settlements. Although the dense spatial structures of cities can be easily understood by examining their internal systems, the functioning of smaller villages, in contrast, is often incomprehensible in itself, because this type of settlement is dependent on its neighboring settlements in terms of its economy, public administration, institutional and service provision. Consequently, a regional approach is necessary for the analysis of villages.

Since space syntax was developed primarily with a focus on the local context, today there is very little space syntax research at the regional level (Mohamed and van der Laang Yamu, 2024). Research is mostly related to the functioning and networked elements of metropolises (Serra and Pinho, 2013), accessibility and availability (Önder and Gigi, 2010), or the operating and examination principles of polycentric urban regions (Krenz, 2017). However, the space syntax analysis of villages on a regional scale is almost completely absent from the repertoire of research methods. This is particularly true for the system of villages located along national borders.

The very few space syntax studies that analyze border regions also focus mainly on cities, mostly on the

[1] Műegyetem rakpart 3, 1111 Budapest, Hungary
bertyak.agnes@epk.bme.hu

development of their mobility corridors (Zaleckis *et al.*, 2015), however, there are also some comparative studies of villages located along borders (Edgu *et al*., 2018). Although these comparative studies may be useful in exploring the formal and local usage patterns of settlements typical of the border region, they do not address the larger-scale operation of the settlement network formed by the villages, or their changes.

The aim of the research is to examine the physical connections between small settlements in a selected region separated by a national border, which historically belonging together. The study area in this research is the Őrség region, divided by the Hungarian-Slovenian border. The hypothesis of the research is that as a given network – located in a border region – expands and densifies, the network role of settlements located directly on the border and those with a larger population increases. And this process will also promote better 'system integration' of neighboring settlements.

BACKGROUND AND INTERNATIONAL CONTEXT

Functional role of borders in the life of the settlements

Numerous publications deal with the nature and development opportunities of border regions between individual countries (Brunet-Jailly, 2022), their permeability and transport potential (Medeiros, 2019), the system of cross-border tourism relations (Kádár and Gede, 2021), or even such topical issues as migration and mobility trends (Tapia Ladino, 2021), and cross-border regional cooperation (Böhm, 2023). Although various border regions have been researched worldwide, existing studies have not explored the situation for small settlement units, and it is still the case that most of the border regions in many countries, such as Hungary and Slovenia, consist mainly of peripheral small villages.

The geographical location, role, extent and strength of state borders can change in space and time depending on the current political power, which significantly shapes the physical, economic and social functioning and relations of border settlements (Anderson and O'Dowd, 1999; Scott, 2019). Their cultural and ethnic diversity, as well as the maintenance or establishment of cross-border connections, are daily challenges. Thus, an essential element of the analysis of border areas is the exploration of the connectivity of the local system, to which the nature of the given border also contributes.

State borders have two types of understanding in terms of permeability: a) as a barrier, acting as a separator, an obstacle to cooperation; and b) as a connector, allowing links between neighboring areas and encouraging cooperation. These can change, merge, strengthen or weaken through certain historical periods and events, substantially influencing the direction and quantity of the settlement network connections of their surrounding settlements (Bertyák and Kissfazekas, 2023; Dokoupil and Havlíček, 2002).

The permeability development of Central Europe's borders over the past three decades has changed the volume and intensity of cross-border interactions. In Hungary, for historical reasons, the concept of borders is still often associated with the barrier role, since the post-World War I designation of borders in several cases separated historically or culturally contiguous areas. And later, the hermetic demarcation of borders during the state socialist period (1949-1989) overshadowed their connecting role. The border settlements were consciously not developed, and slowly became the periphery of their country. The first change in this process was brought about by the regime change in the (former) socialist countries, which placed the independent states in a new economic and political situation. In recent decades, with the establishment of the European Union and the Schengen border area, the importance of national borders – as political and economic barriers – has diminished. Their connecting role has come to the fore, creating opportunities for the revival and development of (old) new cross-border relationships, which can have a positive impact on the fate of border settlements and their inhabitants (Fehérvölgyi, 2010).

Networks and settlement networks

General theory

Network research is an emerging and dynamically developing field of science, the roots of which date back to the early 18th century, although it only started to become an independent scientific discipline in the late 1990s. Networks are suitable for describing systems and relational phenomena in many scientific fields, so we can often encounter a wide range of terms and research characteristics related to them, the usage, interpretation, and meaning of which may vary from field to field, as may their analysis methods (Lewis, 2009; Molontay and Nagy, 2021). The present research deals with the specificities of inter-settlement networks.

In network science, the concept of a network is of mathematical origin, based on the theoretical framework of graphs generated by the abstraction of elements and processes occurring in the real world. A graph is built up from nodes (vertexes) and edges (links) and the relationships between them. Settlements usually form complex networks, in which the nodes of the network are the settlements themselves, while the edges are determined by the nature of the connections between them (transport routes, public services, social and cultural dynamics, etc.). The role (value) of the nodes (settlements) and the edges that connect them are diverse, since the spatial and functional role of each settlement is different. This variation creates more dominant and weaker linkages, and so settlement networks do not form a homogeneous system, but rather there are vertical (hierarchy) and horizontal (division of labor) relationships between them (Faragó, 2007).

The concept of a settlement hierarchy refers to the emerging – mainly functional – relationships of subordination and superordination, which can be used to describe the role of a country, region or settlement group in a network. The ranking of settlements is also based on the evolution of settlement size and population, as the nature and number of settlement functions increases with settlement size and a higher population (Pirisi *et al*., 2011). As a result, the larger settlements tend to have a more important role in the hierarchy, and when a network expands, these settlements are more likely to establish new links.

In addition to their hierarchical system, settlements also have horizontal relations, characterized by the division of labor between them at the same level of the hierarchy. This network of connections can be divided into two groups: a) a competitive relationship and b) a complementary relationship. In the former case, competition between settlements can be identified over access to scarce resources (development resources, population, tourist assets, etc.), while in the latter case, the aim is to take advantage of the benefits of cooperation between settlements with common foundations (geographical location, traditions, uniqueness etc.) (Pirisi *et al*., 2011). In today's globalized social and economic situation, the survival and development of small villages is only possible in the latter case. According to several studies, the wider and better functioning the connectivity within a system (in our case settlement system), the more resilient, stable, flexible and sustainable it is, and therefore the more competitive it is as well (Ventura *et al*., 2008).

Settlement network characteristics in Hungary and Slovenia

In both Hungary and Slovenia, the capital city is at the top of the settlement hierarchy, with 17.6% of the population in the former (Budapest) and 13.6% in the latter (Ljubljana). At the other end of the hierarchy are small villages which do not exceed 500 inhabitants and, due to their size, have inadequate functional services, thus, their lives often depend on their relations with neighboring settlements. The location of small village areas in both Hungary and Slovenia depends on the topography and natural conditions, since the diverse hilly and mountainous character of the area is not suitable for the development of larger settlements capable of fulfilling a central function. In Hungary, which has larger plains, the proportion of small villages is approximately 37% – representing 3.1% of the total population – while in Slovenia, which is mostly divided by hills and mountains – involving 31.9% of the total population – it is approximately 90% (Table 1). The development characteristics and opportunities of these small settlements can vary greatly within and between countries (KSH, 2025; GisStat, 2025).

In the case of the Hungarian small settlements – mainly due to historical traditions and the economic and urban development concepts of the former state socialist ideologies – deficiencies in the transport network, economic structure and territorial supply, as well as loss of function, and negative demographic processes are typical. There is significant out-migration, mainly affecting young people of working age, leading to the ageing of small villages (Bajmócy and Balogh, 2002). In Slovenia, the situation of the settlement type is more favorable, as, thanks to the country's polycentric development, they do not show the characteristics of typical rural settlements. Many small villages operate as mainly residential agglomerations of settlements with rural-central functions, with a commuting but stable population. The exceptions are the peripheral mountainous and border areas of the country, where less developed small villages are characteristic, due to the absence of a major economic center in their surroundings. These depopulated areas – that are often more difficult to access – account for 42% of Slovenia's territory (Kušar, 2013; Lampič and Potočnik-Slavič, 2007).

Table 1. Number and population of Hungarian and Slovenian settlements by population size categories (Source: own editing based on KSH, 2025 and GisStat, 2025)

SETTLEMENT POPULATION SIZE CATEGORIES (PEOPLE)	**-199**	**200-499**	**500-999**	**1000-4999**	**5000-9999**	**10.000-49.999**	**50.000-99.999**	**100.00-**	**SUM**
IN HUNGARY (January 2024)									
Number of settlements (piece)	**426**	**736**	673	1052	128	127	24	11	**3177***
Percentage of settlements (%)	**13.4**	**23.2**	21.2	33.1	4.0	4.0	0.8	0.3	**100**
Population (people)	**50,376**	**247,568**	428,253	2,251,424	887,253	2,472,235	1,681,447	1,512,071	**9,530,627**
Population distribution (%)	**0.5**	**2.6**	4.5	23.6	9.3	25.9	17.7	15.9	**100**
IN SLOVENIA (January 2023)									
Number of settlements (piece)	**4331**	**1113**	354	196	24	15	1	1	**6035**
Percentage of settlements (%)	**71.8**	**18.4**	5.9	3.2	0.4	0.2	0.05	0.05	**100**
Population (people)	**336,450**	**339,397**	242,282	375,266	159,420	280,872	96,209	287,076	**2,116,972**
Population distribution (%)	**15.9**	**16.0**	11.5	17.7	7.5	13.3	4.5	13.6	**100**

* In the table, Budapest is included by district (total population of the Capital: 1,686,222 people - 17.6% of the population.)

Over the past three decades, the political and economic restructuring of Central Europe and the opening of borders have led to the revaluation of small border villages – especially in the western border regions – which were marginalized in the past, and opened up the possibility of cross-border connections and cooperation. The rural population hoped for positive changes, but this did not always happen (Ilcsikné Makra *et al*., 2018). The Őrség region on the Hungarian-Slovenian border, which forms the sample area for the research can be classified as a small village region, showing the characteristics, shortcomings, economic and social trends of that settlement type. Despite this, the area is continuously strengthening, mainly by building on its natural and built values, which is helped by the expansion of its physical network connections and the improvement of the border's permeability.

INTRODUCTION TO THE RESEARCH AREA - ŐRSÉG

The delimitation of the territory of Őrség has been studied by many researchers since the 19th century, but its exact scope is still a matter of debate. Today it is located in the western border region of Hungary and the eastern border region of Slovenia. According to the earliest known historical written source (1280) the area included 18 settlements (Balogh, 1898), which are the villages of the Historical Őrség. As a result of the amalgamation of some former villages, the Historical Őrség region currently comprises 14 settlements, of which 11 are in present-day Hungary and 3 in present-day Slovenia (Figure 1). According to the local public consciousness, 4 additional villages are also closely associated with the region (Beluszky, 2005), these form the territory known as Inner Őrség. This research refers to these settlements collectively as the Őrség region, which covers a total area of 200.39 km^2 (182.64 km^2 in Hungary and 37.75 km^2 in Slovenia). The rural nature of Őrség is reflected in its average population density, which is only 17.9 people/km^2 (KSH, 2025; GisStat, 2025).

Until the end of World War I, the small villages of the region lived mainly from agriculture, animal husbandry and livestock trade, taking advantage of the significant demand for livestock from neighboring countries (Beluszky, 2005). The flourishing and close economic ties were cut off by the state border arrangement after World War I. Some of the villages (present-day Hodoš, Krplivnik, Domanjševci, Čikečka vas and Središče) were attached to the territory of the former Yugoslavia (present-day Slovenia). Őrség was thus split into two. The previously existing connection between the separated settlements was maintained to a

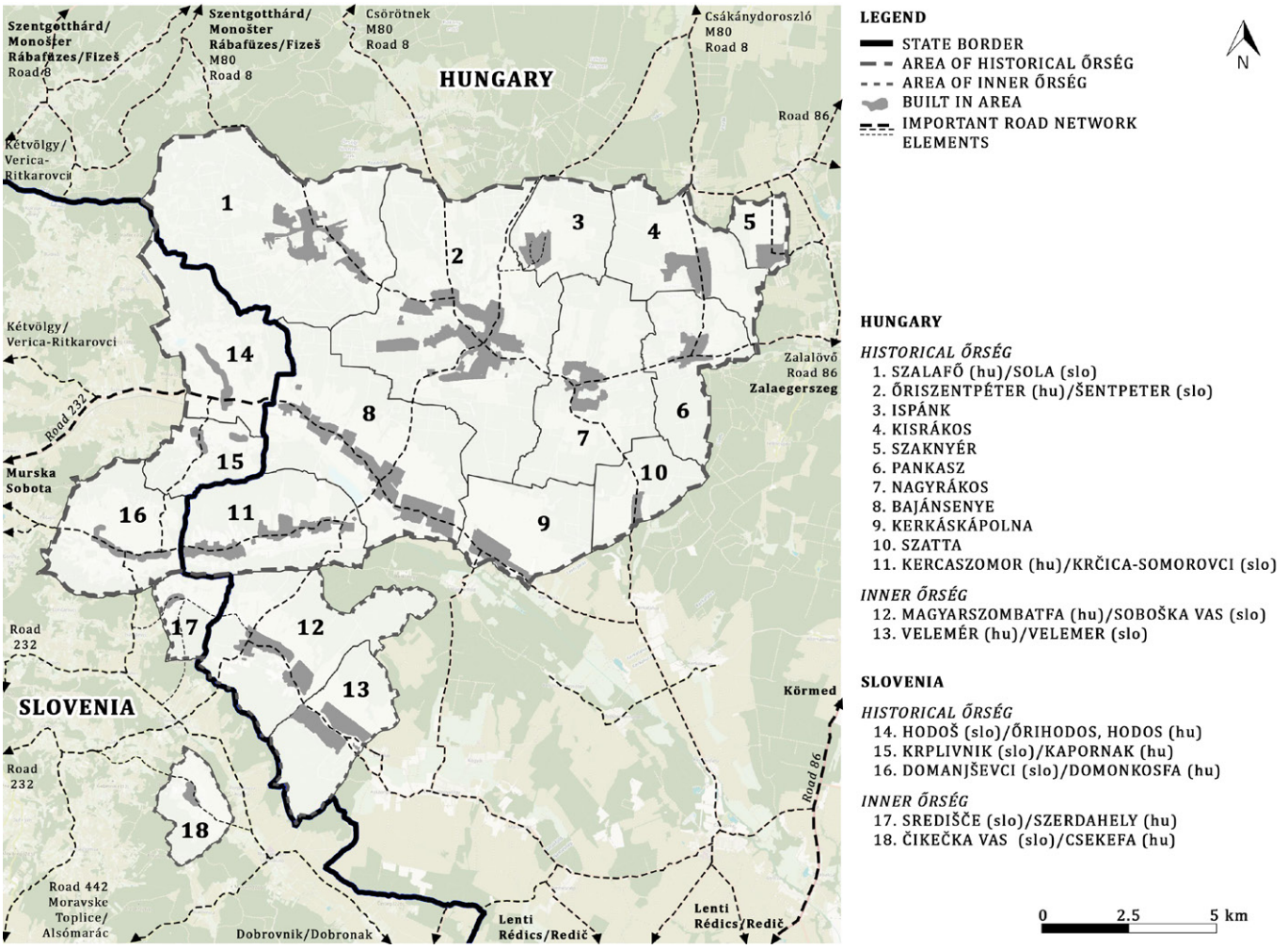

Figure 1. The delimitation of the Őrség area (Source: Authors, 2026)

greater or lesser extent until 1947, thanks to the loose, poorly controlled border strip, but, the hermetic border closure introduced in 1949 continuously destroyed the historical inter-settlement network systems for several decades, which significantly affected the life of the settlements of Őrség both in Yugoslavia and in Hungary.

In the Hungarian territory of Őrség, the border was mined, and in a 15-kilometre strip even Hungarian citizens could only enter with a permit. This also left its mark on the land use and state improvement system of the area, which, combined with the ideological, urban development and economic policy ideas of the state socialist system, slowly led to the area's disadvantaged status. The National Settlement Network Development Concept adopted in 1971 discriminated against small villages. At the state level, settlements with a population of less than 3,000 were officially declared 'unsustainable', thus did not receive any state development support (Kőszegfalvi, 2009).

Since the settlements of the Őrség region in the territory of the former Yugoslavia were closely cooperating with the Hungarian settlements and were economically and administratively interconnected, the drawing of the new border was a shock for them as well. Although Slovenia was one of the most developed member states of the former Yugoslavia, and rural areas and smaller villages were in a more favorable position than in other socialist countries thanks to the polycentric settlement development characteristic of the member state (Uršič, 2012; Allcock, 2002), border regions, including Őrség, were among the more problematic areas, experiencing a steady decline in population (Perpar, 2002). This is clearly illustrated by the fact that the average population of the settlements in the Őrség region, even in its peak period (1949), was 532 people, whereas today it is 219 people. On average, population loss in Hungarian territory amounts to 59.0%, and in Slovenian territory 57.6% since 1949 (GisStat, 2025; Hungaricana, 2025; Sebők, 2024).

As the regime of state socialism was relaxed, the closure of borders began to loosen, but border regions continued to be treated as peripheral. However, the permeability of the Hungarian-Yugoslav-Austrian border improved when the Bajánsenye–Hodoš international border crossing was opened in 1975, in addition to the existing two border crossings near the area: Rábafüzes/Fizeš (HU-AU) and Rédics/Redič (HU-SLO).

The change of regime in Hungary, as well as Slovenia's independence, however, brought a huge change in the life of the settlements in the Őrség area, as the previously marginalized border region became accessible again, opening up boundaries and allowing free movement to neighboring countries. Relations in the region were further strengthened by the joint accession of Hungary and Slovenia to the European Union in 2004. From the end of 2007, the two countries became part of the Schengen zone, which meant that after almost 90 years, it was once again possible to move freely between the settlements of Őrség, which had been divided by history and politics, without any border controls (Gyuricza and Ginzer, 2009).

RESEARCH METHODOLOGY

The research examines the inter-settlement relations made possible by the permeability of the national border affecting the region in terms of two periods: a) during state socialism, when the closed, dividing borders defined the life of the area; and b) after the change of regime in Hungary (1989–1990) and the independence of Slovenia (1991), when open, connecting borders became a dominant feature. The first period can be divided into further time slots depending on the number of existing border crossing points: aa) 1949–1975, when the region was not directly affected by a border crossing; ab) 1975–1990, after the opening of the Bajánsenye–Hodoš border crossing.

With the help of network-based research, it is possible to determine the hierarchical roles of the individual sample settlements in addition to the changes in cross-border and intra-border relationship systems, which also anticipates their future development opportunities. The research analyzes the physical connectivity between settlements by examining the road network. The main resources – vectoral data – were provided by the national map database downloadable from the Geofabric system. This was applied to create the base map containing the current status. The closest cartographic source material to the beginning of state socialism was provided by a Military Map from 1941, which made it possible to trace back the road network through time. The main routes are largely the same as they are today, as infrastructure development has been slow in the area. Significant differences in the road network can be identified in the changes in agricultural and forestry roads, the opening of new public spaces due to the growth of certain settlements, and the motorways that appeared in the vicinity of the study area in the 2000s.

The research uses space syntax analysis as a tool to investigate physical links, which, by converting the vector elements of individual road network components into segments, enables quantitative research to be performed. The space syntax method, introduced by Hillier and Hanson (1984), uses spatial attributes to explore and interpret patterns of interaction between the physical space and the society. The mathematical basis of the methodology is the depth calculation of graphs; the connection probabilities of each element are typically determined by using the tools of integration (reachability), choice (flow through), and depth (distance). The present research focuses on the *choice* and *integration* segments to carry out spatial studies, as they can be used to explore the local and global connectivity of a given network. With the *choice* segment, it is possible to analyze the potential for through movement, which reveals the hierarchy of the system under study, in this case the route network, while *integration* expresses the degree of accessibility of a given road section in relation to the value of the whole system. The space syntax method allows us not only to easily identify a homogeneous network structure, but also its important nodes, centers and sub-centers, and density points by building on the basic elements of graphs (Hillier, 2007).

Since settlements form a more complex system, their diversity is a complicating factor (Krenz, 2017; Pafka *et al*., 2020). Several studies draw attention to the interpretative problems arising from the larger scale and multi-centered regional settlement structure. To resolve this issue, Serra and Pinho (2013) discuss the ideal scale for selecting the metric radius used in space syntax analyses. They found that a metric radius between 1200-8200 meters should be used for city-scale analysis, while a radius above 8200 meters should be used for regional-scale analysis. The greater the value of the metric radius, the more the systemic (global), major pathways and links are highlighted. Based on this, in the present research, the prepared base maps were examined using three different metric radii: 5 km – local system, settlement scale; 25 km – inter-settlement importance, regional scale; n – full system, global scale.

During the space syntax analyses, a buffer zone of approximately 15 km was included around the study area, which was induced by the road network dynamics between the studied settlements and the nearby bigger cities, and the ability to reach the nearest major border crossing. The use of a buffer zone ensured that the important settlements located in the vicinity of the sample area were included in the system under investigation, thereby helping to identify any shifts in the network's centers of gravity. The research was performed using DepthMapX 0.8.0 software. The data obtained from the analysis were quantified for each sample settlement as follows: for the entire transport network system under study, the values of the *choice* and *integration* segments for the different metric radii were calculated for the settlements in the region. The settlement from Őrség with the largest overall network role was identified for each segment. These were treated as 1.00 units and then the strength of the network role of all other settlements was proportionally measured against them. This gave us numbers between 0 and 1, which were added together to create a 'scoring system'. Each settlement could score 3–3 points in the *choice* and *integration* segments (settlement, regional, global values), for a total of up to 6 points. This system allowed comparisons to be made between study periods and systemic trends in the development of different settlements to be easily tracked.

The space syntax analyses were supplemented by statistical data concerning the demographical aspects, which helped to answer the question of how the region's steadily declining population correlates with the network role of individual settlements observed during the periods under review.

RESEARCH RESULTS

During the research, space syntax analyses were performed at 3 scales in both the *choice* and *integration* segments for 3 time periods (Bertyák, 2026), the evaluation of which is described in the following sections, broken down into individual investigation time periods.

Spatial interactions - Closed border (before 1990)

The nature of borders is best illustrated by their permeability, which is determined not only by the political and legal situation, but also by their physical accessibility, which depends significantly on the number and location of border crossings. Under the state socialist era, there were only two strictly controlled international border crossing points in the surroundings of Őrség, Rédics/Redič (Yugoslavia, now Slovenia) and Rábafüzes/Fizeš (Austria), which were located about 55 kilometers apart. This rigid system was eased by the reopening of the Bajánsenye–Hodoš border crossing in 1975. The space syntax analysis was also carried out for this situation, to explore how much just one (old) new connection can transform the settlement network hierarchy of an isolated area.

Characterization of the situation between 1949 and 1975 based on space syntax analysis

The political alienation of Hungary and Yugoslavia were reflected in the physical network of Őrség. During this period, there was a significant exodus of the rural population, which also led to the transformation of cultivated lands. The number of farm roads, which were necessary for cultivation but at the same time provided connections between settlements in several places, began to steadily decrease, and links were lost or transformed. These processes were accompanied by the impossibility of developing border areas and the cutting off of international physical connections.

Using the scoring system described in the research methodology, the strength of the network role of each settlement was assessed, revealing that in the period 1949-1975, the settlements of Őriszentpéter (5.61), Szalafő (4.22), Domanjševci (3.94) and Nagyrákos (3.87) had outstanding *choice* and *integration* scores (Table 2). This shows, that even then, the main center of the region was Őriszentpéter, formerly with a population of about 1500, which today is called the 'capital of Őrség'.

Based on the research, the overall network role of Hungarian settlements in the studied region proved to be more significant than that of the former Yugoslav settlements, which was contributed to by the prominent location and catchment area of Őriszentpéter, as well as the lack of border crossings and thus international road connections. The revealed state also clearly illustrates the difficult situation of Yugoslav settlements, which lost their historical focus, and thus started their own micro-level centralization.

If we examine the values obtained in the research more closely, we can see that at the settlement level and at the regional level (5 km and 25 km), Yugoslav settlements in general had a higher *choice* value (SLO: 0.38; HU: 0.30) than Hungarians. This means that movements covering shorter distances within the examined transport system were mathematically concentrated in these areas, and thus their direct physical network connection was more decisive. This was due to the density of road networks, reflecting the area's fragmented topography, and thus the development of a more compact settlement structure, in contrast to the more dispersed Hungarian settlement network. At the same time, at the global level (full system), Hungarian settlements occupied on average a position about 15% higher in the hierarchical structure of the routes studied than those beyond the borders, mainly due to the proximity and easy accessibility of Szentgotthárd, which is a city, and the border crossing at Rábafüzes. At a global level, the catchment area of the city of Murska Sobota/Muraszombat, only partially determined the network role of the settlements of Őrség at that time.

Table 2. 'Scoreboard' of network role strength by synthesizing the results of the closed boundary space syntax analysis (Source: Authors, 2025)

Ch = choice In = integration		Ch - 5 km	Ch - 25 km	Ch - full system	Sum Ch		In – 5 km	In - 25 km	In - full system	Sum In		SUM Ch+In
Hungary	**Bajánsenye**	0.17	0.33	0.45	***0.96***		0.69	0.88	0.91	***2.48***		**3.44**
	Ispánk	0.28	0.34	0.40	***1.02***		0.73	**1.00**	0.97	***2.70***		**3.72**
	Kercaszomor	0.19	0.26	0.29	*0.73*		0.47	0.75	0.87	*2.09*		2.83
	Kerkáskápolna	0.06	0.21	0.41	*0.68*		0.50	0.87	0.90	***2.28***		2.95
	Kisrákos	0.13	0.47	0.22	*0.83*		0.54	0.95	0.94	***2.43***		**3.25**
	Magyarszombatfa	0.19	0.13	0.15	*0.47*		0.47	0.61	0.79	*1.87*		2.34
	Nagyrákos	0.44	0.50	0.26	***1.20***		0.77	0.96	0.94	***2.67***		**3.87**
	Őriszentpéter	**1.00**	0.63	**1.00**	***2.63***		0.98	**1.00**	**1.00**	***2.98***		**5.61**
	Pankasz	0.33	0.49	0.24	***1.06***		0.54	0.94	0.92	***2.40***		**3.46**
	Szaknyér	0.11	0.03	0.02	*0.16*		0.37	0.86	0.93	*2.17*		2.32
	Szalafő	0.72	0.38	0.34	***1.44***		**1.00**	0.82	0.96	***2.78***		**4.22**
	Szatta	0.09	0.11	0.08	*0.27*		0.39	0.80	0.85	*2.05*		2.32
	Velemér	0.13	0.05	0.03	*0.21*		0.48	0.49	0.71	*1.69*		1.90
Yugoslavia	**Čikečka vas**	0.23	0.07	0.03	*0.32*		0.44	0.60	0.58	*1.62*		1.94
	Domanjševci	0.55	**1.00**	0.39	***1.94***		0.60	0.73	0.67	*2.00*		**3.94**
	Hodoš	0.42	0.35	0.14	***0.91***		0.59	0.58	0.56	*1.73*		2.64
	Krplivnik	0.44	0.39	0.16	***0.99***		0.53	0.61	0.58	*1.72*		2.71
	Središče	0.27	0.06	0.02	*0.35*		0.43	0.66	0.61	*1.70*		2.05
Average					***0.90***		**Average**			***2.19***		**3.08**

Highlighted values refer to the above average results

Regarding the analysis of the *integration* segment, the average integration score of Hungarian settlements exceeded the integration scores of the former Yugoslavian settlements of Őrség at all levels, due to the central role of Őriszentpéter, the better accessibility of the road to the border crossing at Rábafüzes and the isolating effect of the borderline. In fact, the closest possible crossing of the closed border between Yugoslavia and Hungary was near Rédics, which significantly reduced the accessibility and possibilities of the villages in Őrség beyond the border.

Based on the research values obtained for the period 1949-1975, the lowest aggregated scores were found in one Hungarian and one present-day Slovenian settlement (Velemér: 1.90; Čikečka vas: 1.94), thus, these settlements can be described as peripheral settlements of the hierarchical network resulting from the road system.

Characterization of the situation between 1975 and 1990 based on space syntax analysis

The reopening of the international border crossing between Bajánsenye and Hodoš in 1975 was a very important event in the life of the Őrség area. In the 1970s, political relations between Yugoslavia and Hungary became more balanced, leading to closer trade and tourism ties between the two countries.

With the opening of the Bajánsenye–Hodoš crossing, the network connections between the settlements in the area of Őrség have also been given different centroids based on the data generated by the values of the space syntax analysis. In the *choice* segment, Bajánsenye (2.40) and Hodoš (2.57) even outmatched the 'capital' of the region, Őriszentpéter (2.11), because while locally the role of Őriszentpéter remained significant, in the medium term, globally the role of the border crossing settlements had become important (Figure 2). It is interesting to note that for most of the settlements, however, a decreasing role value was observed in the hierarchical network, the reason for which was to restrict the main movements in the area to a certain point (border crossing) and thus privilege it.

The significantly strengthened position of Hodoš in the network also promoted the growth of the hierarchical status of its surrounding settlements, so that in the period under study the average *choice* score of Hungarian settlements in Őrség in all areas of the *choice* segment was lower than that of Yugoslav settlements. This was also due to the revaluation of the road link between Murska Sobota and Hodoš, which brought new urban influences to the study area.

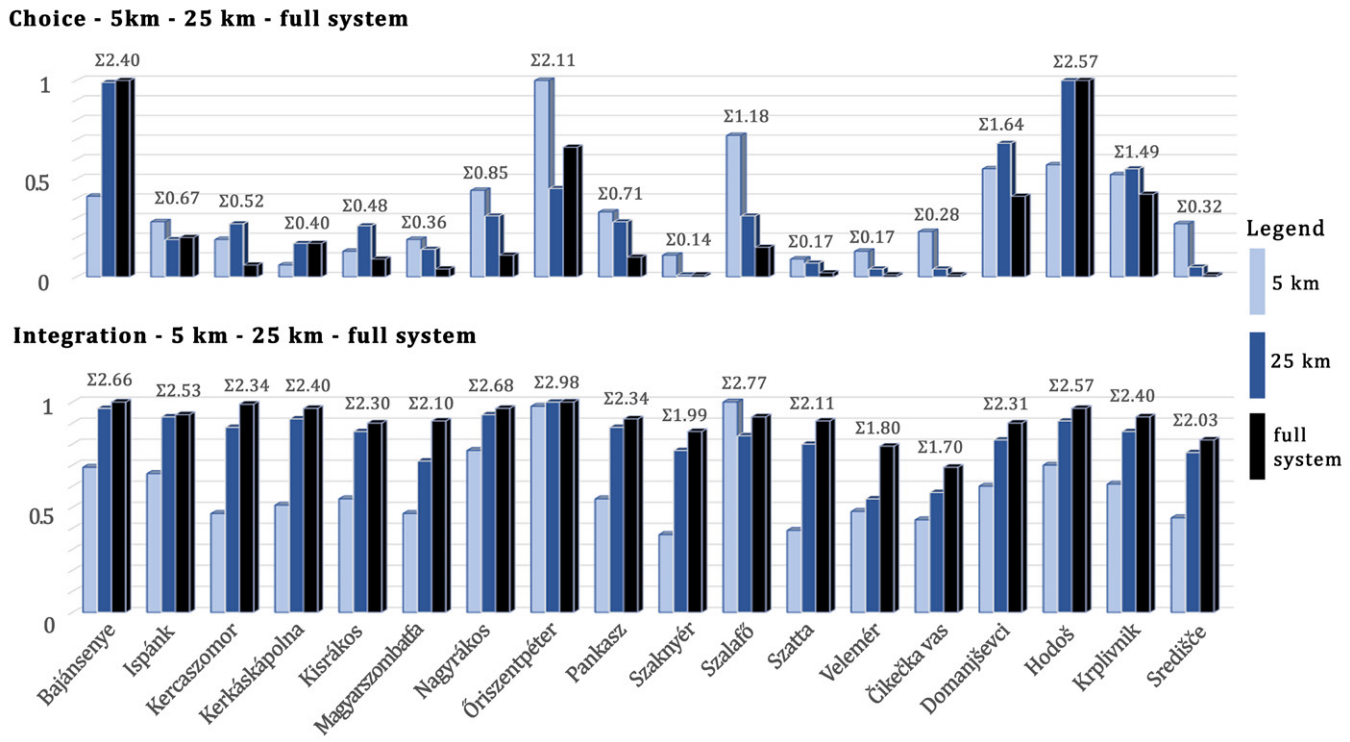

Figure 2. 'Scoreboard' of the network role strength after the opening of the border crossing at Bajánsenye-Hodoš by synthesizing the results of the space syntax analysis
(Source: Authors, 2025)

The *integration* segment shows an increase in the point value – namely the degree of integration – of most settlements, due to the new access opportunities opened up by the border crossing and thus the improvement in local and global accessibility. A particularly large increase in the integration value can be observed in the case of the Yugoslavian settlements of Őrség (Čikečka vas: +0.08; Domanjševci: +0.32; Hodoš: +0.85; Krplivnik: +0.68; Središče: +0.33), which were thus reconnected with their historical neighbors.

The opening of the international border crossing made the overall connectivity of the examined road network system stronger by approximately 17%. Based on the data obtained, during the examined period a network of three poles was established along a central line, which included Hodoš (5.15), Bajánsenye (5.06) and Őriszentpéter (5.09). Velemér (1.98) and Čikečka vas (1.97) were still considered peripheral settlements, but the decline of Szaknyér had also begun.

Spatial interactions – open borders (after 1990)

The independence of Slovenia and the change of regime in Hungary took place at almost the same time, facilitating a significant transformation of cross-border relations. In addition to the existing border crossings at Rábafüzes, Bajánsenye and Rédics, 7 more international border crossing points were added near the Őrség region. With the expansion of border crossing points and thus actually the facilitation of border crossing, the restoration and development of the settlement network systems began. Later, after joining the Schengen Agreement (2007), the abolition of border controls allowed free movement between countries, thus creating an open border zone with a connecting role, promoting the European integration of both Slovenia and Hungary.

During this period, Őrség was a region with significant arrears (infrastructure, settlement functions) and problems (emigration, ageing). Recognizing this, in 2005, Őriszentpéter – back then with around only 1200 inhabitants – was given city status, and Domanjševci and Hodoš were designated micro-local centers in Slovenia. The main function of these settlements was to supply their surroundings, making their network position and accessibility even more important. However, according to the space syntax analysis, these settlements were already historically important network nodes.

Based on the scoring system described in the research methodology, the emphasis of network roles in the study area shifted towards the border settlements and around Őriszentpéter, which further strengthened its central function (Figure 3). This is also due to the fact that the area between Magyarszombatfa–Prosenjakovci/Pártosfalva and Kercaszomor–Domanjševci became passable again. The *choice* segment at the local (5 km) level tracks these new links well, valorizing them. However, in the medium term and at a global level, the status of most settlements in the road network hierarchy improved over the period. The only exceptions are Bajánsenye and most of the Slovenian villages, because the system, which used to focus on a single point of connection (border crossing), had suddenly dissolved. The number of edges between nodes in the network (in this case, road connections) was expanded, thereby increasing the number of options for major movements through the area.

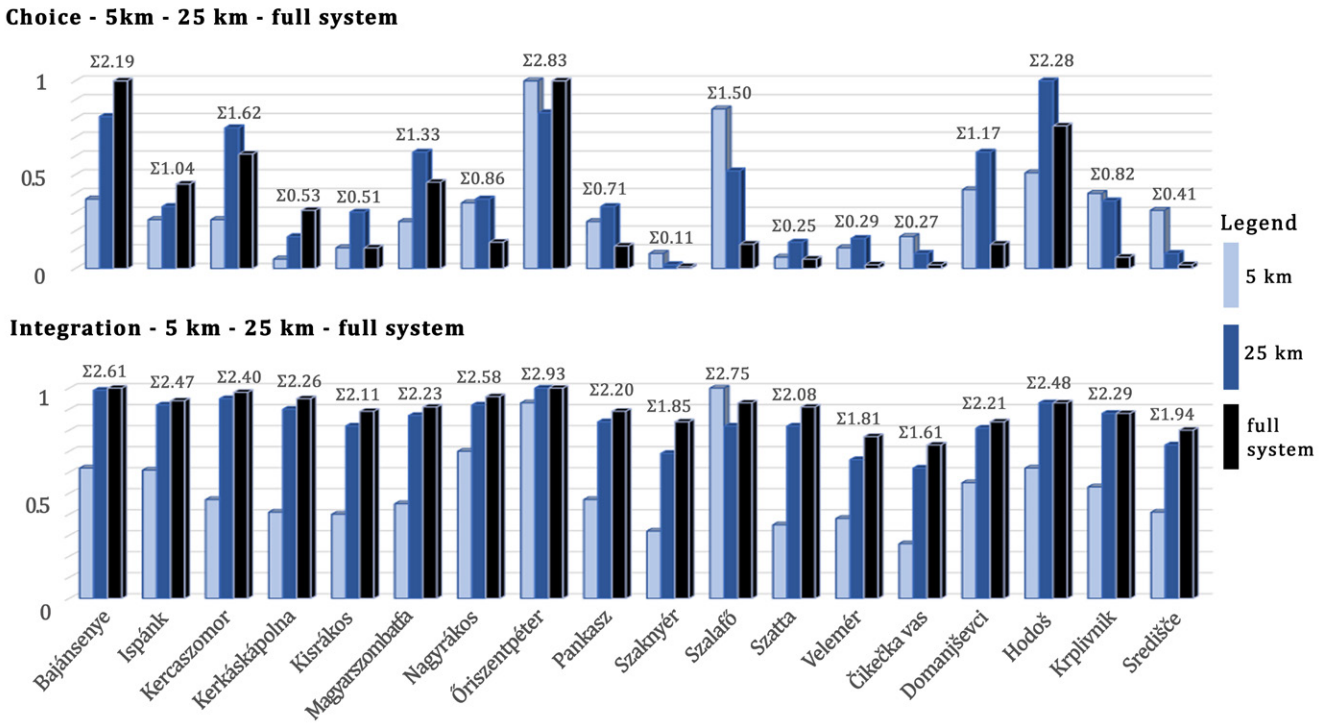

Figure 3. 'Scoreboard' of network role strength by synthesizing the results of the open boundary space syntax analysis (Source: Authors, 2025)

The analysis of the *integration* segment shows that the average integration value of Hungarian settlements continued to exceed the integration scores of Slovenian villages at all levels, while at the same time these values were continuously converging, which shows an increase in approachability and accessibility. It is interesting to note that the new connections were less important for the networking of Slovenian settlements, as they had already been significantly upgraded earlier by the positional growth of neighboring Hodoš.

Based on the analysis of the current situation, the peripheral settlements of the identified network system are Szaknyér (1.96) and Čikečka vas (1.88), since Velemér, which was previously in a more disadvantaged situation, is now in a slightly better position thanks to the increased role of the neighboring Magyarszombatfa which is a small hub.

Population trends

Regular censuses, conducted every ten years since the end of the 19th century, have made it possible to statistically analyze the population trends in the area, which show a drastic downward trend (Table 3). While before 1990, the average population decline was 19.4% at county level, after 1990 this rose to 22.8%, which is exceeded by the trends experienced in Őrség. Based on statistical data, the population of the settlements examined is currently only 41.2% of what it was in 1949, when it reached its peak (9,580 people). The decline began largely as a result of mass migration caused by historical, settlement, economic, and political events following World War II, but it continued to increase in the 1990s.

In each of the examined settlements, we can see varying degrees of population decline during the three different periods of the study. Between 1949 and 1975, the population decline in Hungarian settlements was on average more significant than that of their Slovenian neighbors. After the re-opening of the Bajánsenye–Hodoš border crossing (1975), the population of Szatta declined the most (-44.7%), but several Hungarian settlements lost another 40% of their population. At that time, Őriszentpéter, the center of the region, was in the most favorable position (-1.9%), since a shoe factory had been operating there since the early 1970s, providing nearly a hundred new jobs for the locals. The average population decline in the Hungarian and Slovenian settlements examined was almost identical during this period. However, after the political transition of Hungary, and Slovenia's independence (1990-2025), the average population decline in the Slovenian settlements became more significant and exceeded that of its Hungarian neighbors. Središče lost 57.5% of its population during this period alone. Currently, while Őriszentpéter and Hodoš are in a relatively better situation, Kercaszomor, Kerkáskápolna, Szaknyér, Velemér, and Središče have lost nearly 75-80% of their population compared to the situation in 1949 (Hungaricana, 2025; KSH, 2025; GisStat, 2025).

EVALUATION AND DISCUSSION

The new transport connections resulting from the opening of the border area have shifted the center of gravity of the system under study westwards. The formerly more dominant Rábafüzes–Őriszentpéter axis has been replaced by a Szentgotthárd–Őriszentpéter-Prosenjakovci and a Murska Sobota-Hodoš–Bajánsenye axis. Based on the above studies and the established point system, the average

Table 3. Population trends in Őrség by settlement
(Source: Authors' editing of GisStat, 2025; Hungaricana, 2025; Sebők, 2024)

SETTLEMENT	POPULATION (PEOPLE)						CHANGE (%)			
	1949-1975		*1975-1990*		*1990-2025*					
	1949	1970	1980	1990	2010	2025	1949-1970	1970-1990	1990-2025	1949-2025
In present day Hungary										
Bajánsenye*	1140	833	726	653	487	487	-26.9	-21.6	-25.4	-57.3
Ispánk	249	148	106	91	102	91	-40.6	-38.5	0.0	-63.5
Kercaszomor*	723	463	343	274	202	181	-36.0	-40.8	-33.9	-75.0
Kerkáskápolna	357	195	145	123	98	85	-45.4	-36.9	-30.9	-76.2
Kisrákos	487	390	333	279	204	159	-19.9	-28.5	-43.0	-67.4
Magyarszombatfa*	706	576	438	356	278	241	-18.4	-38.2	-32.3	-65.9
Nagyrákos	657	501	415	349	276	254	-23.7	-30.3	-27.2	-61.3
Őriszentpéter	1507	1231	1192	1208	1187	1007	-18.3	-1.9	-16.6	-33.2
Pankasz	723	683	626	562	433	370	-5.5	-17.7	-34.2	-48.8
Szaknyér	186	134	102	80	58	43	-28.0	-40.3	-46.3	-76.9
Szalafő	682	474	387	281	214	211	-30.5	-40.7	-24.9	-69.1
Szatta	210	159	102	88	67	62	-24.3	-44.7	-29.5	-70.5
Velemér	337	232	149	135	84	71	-31.2	-41.8	-47.4	-78.9
Hungarian SUM	**7964**	**6019**	**5064**	**4479**	**3690**	**3262**	**-24.4**	**-25.6**	**-26.6**	**-59.0**
In present day Slovenia										
Čikečka vas	208	165	131	112	83	67	-20.7	-32.1	-40.2	-67.8
Domanjševci*	587	474	440	350	286	246	-19.3	-26.2	-29.7	-58.1
Hodoš*	429	418	339	326	226	267	-2.6	-22.0	-18.1	-37.8
Krplivnik	240	183	156	133	89	68	-23.8	-27.3	-48.9	-71.7
Središče	152	124	118	87	53	37	-18.4	-29.8	-57.5	-75.7
Slovenian SUM	**1616**	**1364**	**1184**	**1008**	**737**	**685**	**-15,6**	**-26.1**	**-32.0**	**-57.6**
Summary										
SUM	**9580**	**7383**	**6248**	**5487**	**4427**	**3947**	**-22.9**	**-25.7**	**-28.1**	**-58.8**
County data (Hungarian)										
Vas County	**282,958**	**280,188**	**285,498**	**275,944**	**259,364**	**245,598**	**-1.0**	**-1.5**	**-11.0**	**-13.2**
Villages in Vas County	**n.d.**	**153,878**	**136,230**	**124,021**	**103,006**	**95,775**	**n.d.**	**-19.4**	**-22.8**	**n.d.**

Highlighted values: above-average population loss
(Average population loss between 1949-1970: -24,1%; 1970-1990: -31,1%; 1990-2025: -32,6%; 1949-2025: -64,2%.)

network values of the settlements in Őrség have increased over the years. The most powerful positive change is observed in Hodoš (+2.12) and Bajánsenye (+1.36), as well as in Kercaszomor (+1.20) and Magyarszombatfa (+1.22), which are all border settlements.

The extension of the network to Őrség and the new priority given to certain villages has also had an impact on the situation for neighboring settlements. Due to the strong attractive effect of the new focus nodes, some settlements have been more integrated into the system, while others have been pushed to the background (Table 4). Thus, while between 1949 and 2025, Velemér, Krplivnik and Središče experienced a more significant positive change, several settlements gradually lost their importance in the internal network. This may be less of a burden for villages with

Table 4. Change in point values in the Őrség area between 1949 and 2025 (Source: Authors, 2025)

Change in point values for individual settlements	CHOICE						INTEGRATION						Cumulative change (choice+integration)
	1949-1975	1975-1990	1990-2025	Change 1949-1990	Change 1990-2025	SUM Change 1949-2025	1949-1975	1975-1990	1990-2025	Change 1949-1990	Change 1990-2025	SUM Change 1949-2025	
In present day Hungary													
Bajánsenye*	0.96	2.40	2.19	**1.44**	-0.21	**1.23**	2.48	2.66	2.61	**0.18**	-0.05	**0.13**	**1.36**
Ispánk	1.02	0.67	1.04	-0.35	**0.37**	**0.02**	2.70	2.53	2.47	-0.17	-0.06	-0.23	-0.21
Kercaszomor*	0.73	0.52	1.62	-0.21	**1.10**	**0.89**	2.09	2.34	2.40	**0.25**	**0.06**	**0.31**	**1.20**
Kerkáskápolna	0.68	0.40	0.53	-0.28	**0.13**	-0.15	2.28	2.40	2.26	**0.12**	-0.14	-0.02	-0.17
Kisrákos	0.83	0.48	0.51	-0.35	**0.03**	-0.32	2.43	2.30	2.11	-0.13	-0.19	-0.32	-0.64
Magyarszombatfa*	0.47	0.36	1.33	-0.11	**0.97**	**0.86**	1.87	2.10	2.23	**0.23**	**0.13**	**0.36**	**1.22**
Nagyrákos	1.20	0.85	0.86	-0.35	**0.01**	-0.34	2.67	2.68	2.58	**0.01**	-0.10	-0.09	-0.43
Őriszentpéter	2.63	2.11	2.83	-0.52	**0.72**	**0.20**	2.98	2.98	2.93	0.00	-0.05	-0.05	**0.15**
Pankasz	1.06	0.71	0.71	-0.35	0.00	-0.35	2.40	2.34	2.20	-0.06	-0.14	-0.20	-0.55
Szaknyér	0.16	0.14	0.11	-0.02	-0.03	-0.05	2.17	1.99	1.85	-0.18	-0.14	-0.32	-0.37
Szalafő	1.44	1.18	1.50	-0.26	**0.32**	**0.06**	2.78	2.77	2.75	-0.01	-0.02	-0.03	**0.03**
Szatta	0.27	0.17	0.25	-0.10	**0.08**	-0.02	2.05	2.11	2.08	**0.06**	-0.03	**0.03**	**0.01**
Velemér	0.21	0.17	0.29	-0.04	**0.12**	**0.08**	1.69	1.80	1.81	**0.11**	**0.01**	**0.12**	**0.20**
In present day Slovenia													
Čikečka vas	0.32	0.28	0.27	-0.04	-0.01	-0.05	1.62	1.70	1.61	**0.08**	-0.09	-0.01	-0.06
Domanjševci*	1.94	1.64	1.17	-0.30	-0.47	-0.77	2.00	2.31	2.21	**0.31**	-0.10	**0.21**	-0.56
Hodoš*	0.91	2.57	2.28	**1.66**	-0.29	**1.37**	1.73	2.57	2.48	**0.84**	-0.09	**0.75**	**2.12**
Krplivnik	0.99	1.49	0.82	**0.50**	-0.67	-0.17	1.72	2.40	2.29	**0.68**	-0.11	**0.57**	**0.40**
Središče	0.35	0.32	0.41	-0.03	**0.09**	**0.06**	1.70	2.03	1.94	**0.33**	-0.09	**0.24**	**0.30**
Average													
Average	**0.90**	**0.91**	**1.04**	**0.02**	**0.13**	**0.14**	**2.19**	**2.33**	**2.27**	**0.15**	**-0.06**	**0.08**	**0.23**

* Settlements with border crossing opportunities
Highlighted values: the settlements affected by positive change

larger populations that were previously in a higher position (e.g., Domanjševci, Nagyrákos), but at the same time, it may negatively affect settlements that were already on or close to the periphery, especially those with a smaller population and thus poor functionality (e.g., Szaknyér, Čikečka vas), because their network dependence is inherently more significant in terms of maintaining their stability and resilience.

At the same time, we must also take into account that the wider network under examination, to which the Hungarian and Slovenian settlements of Őrség are also connected, does not show a stable, permanent system, but an expanding tendency. In other words, there has been a densification of the overall network system, with an average increase of 34% in the *choice* segment and 26% in the *integration* segment since 1949. In addition to the growth of individual villages and cities, the emergence of motorways and new road, bicycle and pedestrian routes has also contributed significantly to this. Thus, in fact, the quantifiable value of those settlements in the overall network of the Őrség area that showed a decreasing trend within the examined internal network has also increased.

At the same time, although the overall network role of settlements has increased, their population has declined steadily, albeit to varying degrees. The border situation and the permeability of the border only slightly influenced this, as is clearly shown by the fact that the population decline in settlements that currently have border crossing points and facilities was 7.4% lower than that of their neighboring settlements without border crossing points, projected over the period 1949–2025. Currently, the most disadvantaged situations are found in those settlements that have a weak or declining network role and significant population loss (Figure 4). Based on this, special attention needs to be paid to the development of the lagging, peripheral areas of the network,

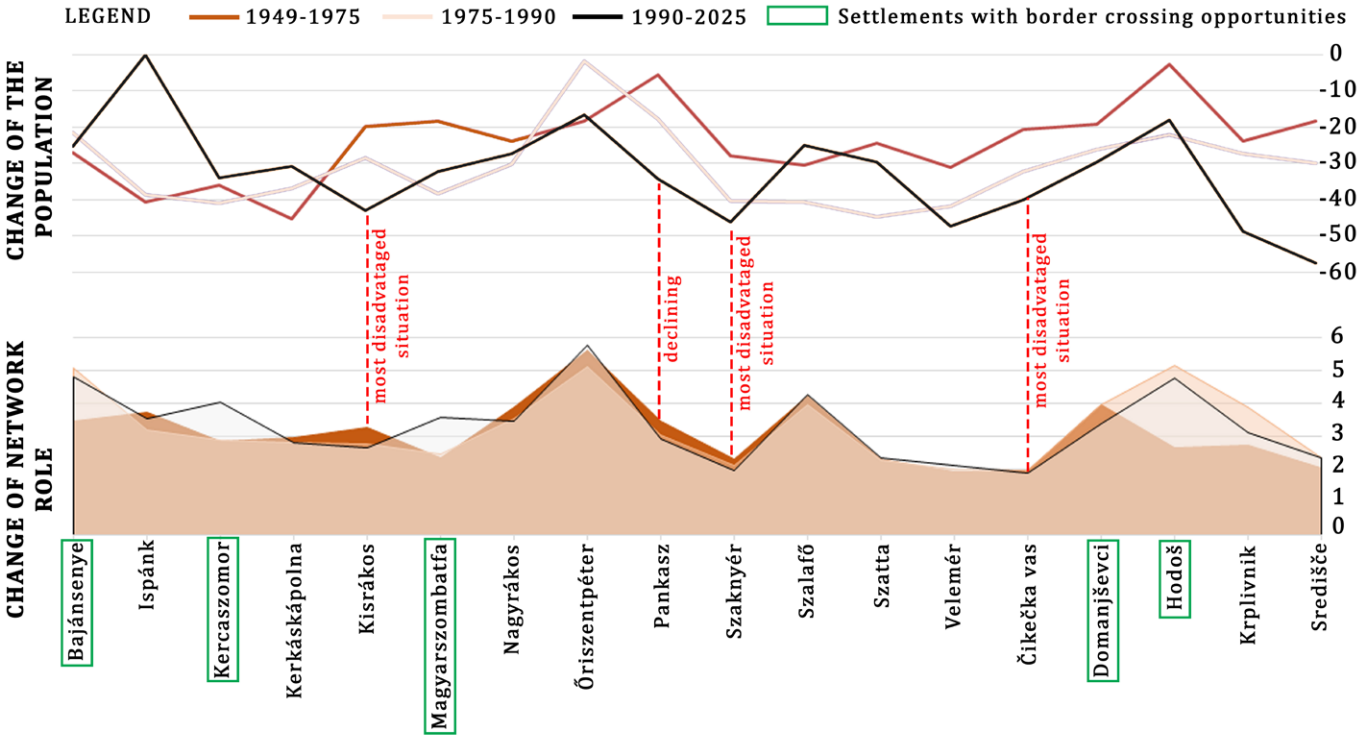

Figure 4. Changes in network role and population in individual settlements (Source: Authors, 2026)

to ensure their future stability. Cross-border mutual economic, tourism and functional cooperation also could significantly contribute to achieving this. It is no coincidence that some programs financed by the European Union (e.g., cohesion funds, Leader program) and national budgetary resources (e.g., Hungarian Village Program) also focus strongly on the targeted development of areas similar to those mentioned above.

The research proves that space syntax analysis can also be applied on a regional scale. The network role of settlements with border crossing options grew steadily after 1975 (Bajánsenye–Hodoš) and then after the change of regime in Hungary, and Slovenia's independence (Kercaszomor, Magyarszombatfa), shifting the center of gravity of the system towards the border. This process of network role changes also led to the systematic 'strengthening' of neighboring settlements mainly located near the border as well (Szalafő, Velemér, Krplivnik, Središče). However, the part of the hypothesis that assumes interactions between the population of the settlement and its network role can only be partially proven. For example, Őriszentpéter, functioning as the 'capital' of the study area, can be described as the hub with the most connections as it has the largest population in the studied region and the largest network role. Pankasz, however, which ranks third among the settlements in terms of population, shows a steadily declining pattern in its network role. On the one hand, this can be attributed to only a slight expansion of the settlement's physical network, and on the other hand, it may indicate that closeness to the (western) border has recently become an important factor in the system under review.

CONCLUSION

The research contributes to establishing a regional approach to space syntax analysis, thereby enabling data-based investigation of the physical networks of connected regions. The results of the study are easily applicable internationally in terms of approach and methodology. In the present case, examination of the sample area has shown that network development in the region follows a pattern that shifts towards the borderline crossing the area. The reason for this is that the organic growth of the network of settlements was hindered for several years for economic and political ideological reasons. However, the opening of border crossings and the emergence of new transport routes at the end of the twentieth century brought the settlements on both sides of the border closer together in terms of their physical network. At the same time, in addition to road network and population indicators, it is necessary to examine economic parameters, institutional provision, tourism-generated services, and the (holiday) population – which is not necessarily reflected in statistical data – in order to reveal a more nuanced, complex role of villages in the hierarchical system of settlements. These will need to be investigated in the future. Quantitative space syntax analysis can be compared extremely well with qualitative research areas (actual use, sense of belonging), thus providing an opportunity to continue and expand the research too. At the same time, the current methodology can already be applied in the future to other settlement groups, by helping to identify settlements in a more disadvantaged systemic situation, thereby providing novel, measurable data for strategic and development plans representing medium- and long-term thinking.

ORCID

Ágnes Bertyák https://orcid.org/0009-0003-8886-3088

Kornélia Kissfazekas https://orcid.org/0000-0002-7371-9644

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THE DYNAMISM OF URBAN MEMORY: INVESTIGATING THE AFFORDED MEANINGS AND HABITS OF A HISTORIC KHAN

Serap Durmuş Öztürk [1], Karadeniz Technical University, Department of Architecture, Trabzon, Türkiye
Abdullah Yasin Dündar, Delft University of Technology, Department of Architecture, Delft, The Netherlands

This paper uses affordance theory and the 4EA approach – extended, embodied, embedded, enacted, and affective cognition – to show how embodied cognition and environmental affordances shape urban memory. The activation of urban senses through affordances highlights how technological apparatuses can express what already exists in experiences, but is yet to be examined. The narrative flow of the city, beginning with operative behaviours and roles, is enhanced and complemented by student sketches of the urban fabric, driven by structural elements, which together evoke a similar sense of memory but in different ways. Drawing on students' narratives and sketches of Alacahan, a historic khan in Trabzon, Türkiye, the paper explores how architecture can affectively shape and be shaped by urban actors. Consequently, this paper suggests a theoretical and pedagogical framework based on sketches and narratives as technological apparatuses to investigate how vital memories and habits of urban fabrics enable new meanings and values to produce urban appropriation and sustainability. The sensory landscape of Alacahan, with its rhythm of copper work, cool air, sharp metallic scents, and the reverberations of timber and stone, collectively forms a living, multisensory urban memory. This framework shows that architectural experience and its dynamic habits persist in sketches, stories, and activities, embedding architecture in embodied cognition.

Key words: **urban memory, narratives, sketches, khan.**

INTRODUCTION

From Henri Lefebvre's seminal work, *The Critique of Everyday Life*, to Richard Sennett's *Flesh and Stone*, the experience of urban life and its memories is explored through how urban actors actively shape their environment, by politicising and appropriating it (Lefebvre, 1991; Sennett, 1996). As Sennett emphasises, experience of the urban fabric is not operated in an objectified, linear sense from conception to execution and to living. Nevertheless, what is urban depends on how each era has collectively understood and regarded the body, in other words, the urban actor. Considering the increasing influence of the Anthropocene, which defines the current era in which human interventions are the leading cause of planetary change, reevaluating how urban action is perceived beyond ready-made schemas is needed. To do that, an approach beyond prioritising human control must be argued. The main aim of this paper is to understand architectural attunement to the world, leading to an embodied cognition that binds perception and action. To reevaluate how urban memory operates in everyday life, this paper uses Alacahan (an example of a khan; khans were mostly built in urban centres for lodging and commerce) as the case study and employs three methods to challenge the established linearity from perception to action. To better situate how we can understand the dynamism of urban memory, the main arguments, questions, and approaches of three conceptual developments will be explicated first.

One of this paper's theoretical frameworks is based on psychologist J. J. Gibson's (2015) affordance theory, an alternative to a top-down approach to perception. For Gibson, perception is not about following a linear progression from passive recognition of things to identifying their "qualities" (Gibson, 2015, p. 126) based

[1] Üniversite, Milli Egemenlik Cd., 61080, Ortahisar, Trabzon, Türkiye
serapdurmus@ktu.edu.tr

on ready-made schemas and then conforming to them to a suitable category of reality. Gibson criticises prioritising an abstract understanding of perception that starts with the mind. Andrej Radman (2022), an architectural theorist with numerous studies on Gibson, highlights the architectural influence of the linear perception-to-action approach. This approach results in the absurdity of positioning images in the mind and movements in space, distinctly separating the relationship between perception and action. Gibson strongly emphasises "movement as the basis of perception", an aspect one should always recall in architectural thinking (Radman, 2022, p. 21). The meaning itself is actively produced through the coupling of perception and action, offering meaningful insights into the urban fabric. One of Gibson's (2015) examples of this coupling is the ability to sit. To perceive a chair, one needs to perceive what the environment affords: the ability to sit on it. This means we can directly receive the meanings and values that the environment affords. There are no conscious calculations or recall of representative forms of sitting beforehand to be able to sit. Sitting is directly enacted in the environment; this means that what is at the centre is *sit-on-ability*. To understand perception, one should focus on the conditions that enable actors to form habits. Habits give meaning to the acts that arise from lived experience. While bookshelves are sit-on-able for cats, but not for humans, the floor is walk-on-able for both (Gibson, 2015). To understand affordances, one must consider how we inhabit the world before applying categories and labels to qualities. This presents a crucial step for the analysis of this paper. Put briefly, affordances are the properties of objects that can be embedded within an actor's capabilities. Affordances are the actor's skills plus the potential activities the environment provides.

One may ask at this point: if humans already directly sense what is affordable in the milieu, what is the role of technological tools? The response to this question comes from a complementary line of thought in recent cognitive science studies, namely the 4EA approach. 4EA is an umbrella term for *extended, embodied, enacted, embedded,* and *affected* understandings of cognition, as in the works of cognitive scientists Alva Noë, Andy Clark, Tim Ingold, and affect philosopher Brian Massumi (Protevi, 2010). These scholars continue the project of affordances by investigating how the brain co-evolves with the body. Noë (2006) understands perceiving as a way of acting out meanings, by underlining their inseparability. He defines it as *enactive* perception. This approach is not about overfocusing on how the fundamental elements of reality are represented in a vacuum. Thus, it is meaningless to start with spatial categories and typologies without considering how urban actors perceive, live, and appropriate architecture. Investigating how the environment is available to the senses and how one can express desires is crucial for analysing dynamic environmental aspects (Noë, 2006). Enactive perception is about knowing how to act. Using the example of a visually challenged person with a walking cane who senses by tapping the floor, Noë (2006) argues that every perceived object is directly related to our actions and is shaped by our capabilities. This is where the importance of technological apparatuses comes into play. As a technical object, the cane acts as an extension of the body, interlocked with the other bodily organs. This step is vital to understanding pedagogical methods of sketching and storytelling as architectural expressions of memories and values made with tools.

The last thread is on the technological means of experiences, which can guide an analysis of expanding our realm of sensibility. The important question is how one can think of this increase of sensibility without increasing human dominance over the world (Radman, 2022). What defines the urban meaning-making process is 1) the offerings of the environment, 2) how urban actors interact with them through their habits, and 3) how those habits can be enactively sensed through apparatuses that make the world more intelligible. Underscoring how the acts exceed the intended ways of living in the environment, computer scientist Paul Dourish (2001) argues that life's dynamic flow arises from embodied activities and interactions *embedded* within it. The way we sense, perceive, and understand the world does not operate on one-size-fits-all generalisations, but rather on associative and reciprocal processes that both define how we *affect* and are affected by the environment (Goldhagen, 2017). Another supportive argument for technological tools was advanced by Ingold. He argues that a form of technology may initially be nothing more than an obstacle until it is embedded within the value system of actors. Considering this, what lies behind urban habits of experiencing needs to have light shed upon it. This is the paper's main point of investigation: analysing sketching and narrating as technological apparatuses (Ingold, 2001). Put succinctly, the main hypothesis is that meaning is produced by the capacities and capabilities of the action an actor can afford in the environment with the help of technological apparatuses.

These three theories help investigate the case study of Alacahan, in Türkiye, and its significance for urban actors. First, a broad investigation of Alacahan is made in the next section to situate this building's character within the city (Figure 1). Second, how architectural students created their meanings for this building is analysed through narratives and sketches. The extent to which those tools demonstrate the city's dynamism and its memories is investigated. After analysing students' active coupling of perception and action in Alacahan, the study addresses the vital roles of afforded meanings and habits in a situated pedagogical approach. This paper's analysis highlights how material, sensory, and behavioural traces intertwine to sustain the dynamics of lived space and social meaning. Within the framework of the United Nations Sustainable Development Goals – particularly SDG 4 (Quality Education), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production) (UN, 2017) – this paper's findings suggest that historical architectural contexts can operate as living pedagogical environments where learning, making, and remembering coexist. Drawing on Gibson, this paper's aim is to analyse the various "offerings" (Gibson, 2015, p. 121) and habits of Alacahan. The paper also aims to propose a pedagogical potential for situated urban memories through sketching and storytelling as apparatuses of environmental imagination.

DYNAMIC HABITS IN A KHAN

Alacahan is an Anatolian inn located in the city of Trabzon, in the Northeast part of Türkiye. The city's coastal location has long supported commercial exchange and craft production, as Trabzon has historically served as a central hub for trade routes that come from the East and West (Üstün Demirkaya and Kırcı, 2020). As shown in Figure 1, Semerciler Street, which connects Alacahan to the urban fabric, extends the main historical and commercial bazaar axes of Trabzon, namely Kunduracılar, Kahramanmaraş, and Uzun Street. Kunduracılar Street, a pedestrian zone, has long served as a landmark for urban actors. It is a central meeting and activity site. This site is also one of the few places where cultural crafts, such as copper and silver work, are still practised. As noted by Üstün Demirkaya and Kırcı (2020), the persistence of these traditional crafts and local travellers provides valuable insights into how Trabzon's urban memory, along with cultural practices, has been maintained over the centuries. The main bazaar axes, where most of the centrum's density is concentrated, are shown with dashed lines on the map in Figure 2.

Figure 1. Single entrance to Alacahan with a narrow street, adjacent to the historical bazaar
(Source: Unarcode Project Archive, 2025)

Other well-regarded historical buildings are included on the map along the main bazaar axes to better situate the case study within the rich urban fabric of Trabzon. As a niche in Semerciler Street, Alacahan was constructed in the 18th century and features a rectangular layout with three storeys, including the ground floor, and an open courtyard accessible through a single main door (Figure 1 and Figure 3). Alacahan was built as an inn for merchants and travellers, similar to many other khans. As part of Trabzon's historical role as a key commercial hub connecting Anatolia, the Caucasus, and the Black Sea, these inns functioned as crucial nodes for trade and social exchange (Aygün, 2021). Today, Alacahan remains a vital part of the city as a living heritage site, hosting craft-based educational services (Gözübüyük Tamer, 2024). The inn's connector role makes it notable for a detailed analysis of its habits, meanings, and memory, which will be highlighted in sketches and narratives.

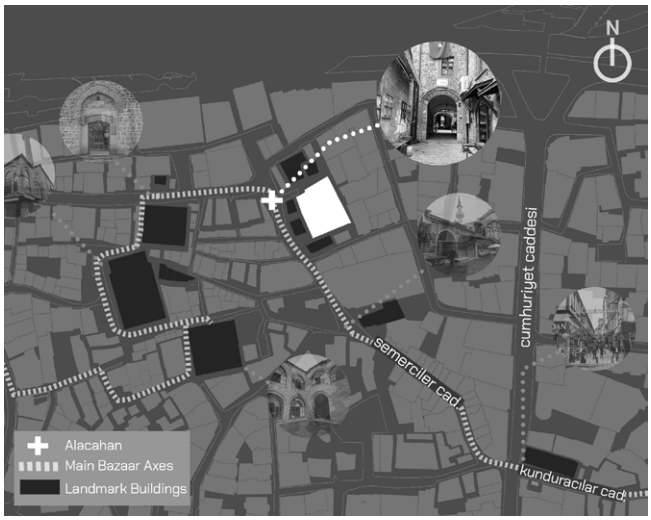

Figure 2. The location of Alacahan, along with the landmark points and main pedestrianised bazaar axes of the historical centre of Trabzon (Source: Unarcode Project Archive, 2025)

As Gibson underscored, the singular and ordinary points afforded by any environment vary with each actor's perception. Alacahan appears as a *niche* within the bazaar, a key concept which Gibson defines as a set of affordances. A "niche" (Gibson, 2015, p. 120) in an environment, for him, offers insight about how people or animals live there, rather than where they live and what the qualities of that place are. For example, the vital meaning of a bazaar is not based solely on architectural elements, such as arches, vaults, stones, and spatial organisation, but also on how these elements are situated within their context. The way local people and shop owners give meaning to this place may stem from its role as an effective node in the local economy and in tourist circulation, and this aspect is directly connected to the city's historical, still-functioning long open-air bazaar axes (Figure 2). Some of the meaningful movements for these actors are the flow of money, goods and tourists. These enacted movements shape the perception of the khan as a dynamic niche within the bazaar. Historically, Alacahan's adjacent Bedesten area, which is one of the crowded bazaar axes, forms a dense collection of craftsmanship. This intensity of goods and the reverberation of hammer clanks make it one of the most vibrant nodes, both in the acoustic and social accounts of the term (Seymen Aksu and Aydın Türk, 2021). Even if the building no longer maintains some of its past affordances as an inn, these craft ateliers are still in operation today. This persistence makes it valuable for investigation into its new affordance as a niche in the flow of the contemporary city. The behaviours of actors arise from affordances, showing how structural elements may affect the specific behaviours of buying and attracting. Where to

place goods, how to arrange them to enhance their appeal, and how to leverage the authentic flow of the adjacent long bazaar, create affordances of wonder-on-ability and appeal-to-ability. These affordances enhance the goods' contextual charm for buyers.

Figure 3. The inner courtyard of Alacahan (Source: Unarcode Project Archive, 2025)

If one views Alacahan from a tourist's perspective, this building embodies the authenticity of Trabzon by standing out from the contemporary modes of sterile, standardised malls and supermarkets. This meaning is closely tied to its location, as it is next to a vibrant historical bazaar. All the products a tourist buys can evoke vivid memories of the city, the bazaar, and the khan as embedded yet independent parts of them, embodied by the building's own distinct courtyard. While the shop owner values the affordances of attracting diverse customers, as well as the accessibility and displayability of goods, tourists, on the other hand, may be more interested in extending the city's vibrant energy and memorability into Alacahan's marketplace and café. As an architectural assemblage, Alacahan's affordances build on each other, and all these afforded points of view can be understood as a mutual scaffolding of its urban memory. In this transformation, different abilities, needs, anticipations, and active participation shape the urban fabric. What is crucial at this point is to investigate the conditions and habits that make this architecture and its urban memory vital and authentic, rather than overfocusing on the specific aspects that define its given function and form (Stiegler, 1998). For Gibson, labelling and categorising these qualities can only come after a "phenomenological" (Gibson, 2015, p. 126) process of meaning-making.

As the 4EA scholars show, the richness of sources and means of expression extend the mind and the body. This richness also catalyses the recollection of memories and the incorporation of movement into dynamic habits. Such vitality does not come from the accumulation of detached and sterilised facts about the building, such as a signpost filled with details. Rather, it comes from the building's situated and enlivened character within actors' habits. These insights can be analysed further from in situ experiences. The next section will follow a situated approach to analysing the "unexamined habits of mind" (Barad, 2003, p. 802) and the urban fabric. Urban memories are the productive meanings people produce within buildings, which is the primary motivation for the current study's empirical section. This paper aims to complement sketches with storytelling, in order to investigate the dynamism of urban memory. In short, urban sketches and narratives provide insights into the extended cognition of habitual ways of living in urban fabrics. This paper aims to highlight the vitalising urban affordances, which go beyond understanding how the mind overrules the environment, as in anthropocentrism.

TRANSLATING THE EXPERIENCE IN A KHAN THROUGH WORDS AND SHAPES

Within the scope of a TUBITAK project on the codes, joints, and constraints of the urban narratives and memories of Trabzon, students were asked to experience the city's intensified architectural nodes and to express their meanings. They followed routes surrounding many historical buildings. Some of the buildings visited and experienced during the project are shown in Figure 2. No theoretical framework or methods for storytelling or sketching were imposed on students beforehand. At different times, five groups of students visited and expressed what Alacahan means to them, embodying their memories through technological apparatuses. Their different ways of perceiving and acting, and their habituated understanding of meaning-making, are examined here. By using two tools of expression, students conveyed their values, vital memories, codes, and enacted perceptions of Alacahan. The project aims to produce a mobile application as another technological apparatus to convey the vital experiences of the urban fabric, enabling visitors to discover more meanings without following conventional modes of guidance. This paper focuses on the project's emphasis on the enacted perception of the urban fabric.

Alacahan's narratives can be understood as action-oriented accounts of the city, using movements as points of integration with perceptions of the more structural aspects (Durmuş Öztürk and Bali, 2024). A story depicts an ongoing movement that later evolves within its structure. The sketching of Alacahan follows the same path but begins with what is afforded within structures through dynamic drawings that lead them to understand the building's movement more intelligibly. This is the point of how these two apparatuses complement each other, in the form of "mutual scaffolding" (Juarrero 2023, p. 120).

The insights from student narratives will be presented first. Students were asked to convey their narratives in the lived experience of Alacahan without being descriptive. In this part of the study, recurrent themes in these narratives are highlighted. The word sizes in Figure 4 depict the frequency of keywords in narratives. Some student narratives about the building's entrance highlight the emotional affordance of its iron door, its opening, and its arch. The door, as the sole entrance and explicit threshold, catalysed a sense of *belonging* to the building's *secluded* character. This threshold for students is complemented by *detachment* and seclusion from the vibrant flow of the bazaar, as in narratives with keywords such as *different* and *secluded*. This meaningful tension between the inner courtyard and the outer bazaar was also accompanied by the narrow street. The connecting street is surrounded by copper *reverberations* and the sound of water flowing from the nearby mosque's fountains (Figure 2). The inn's secludedness is coupled with the reverberation of water and the *forging sounds* of smiths, echoing within the inner

courtyard. For some students, this repetitive forging, the humming of conversations from the outer bazaar, and the *sharp odours* of paint and copper gave rise to a sense of *radiating out* from the building (Figure 5).

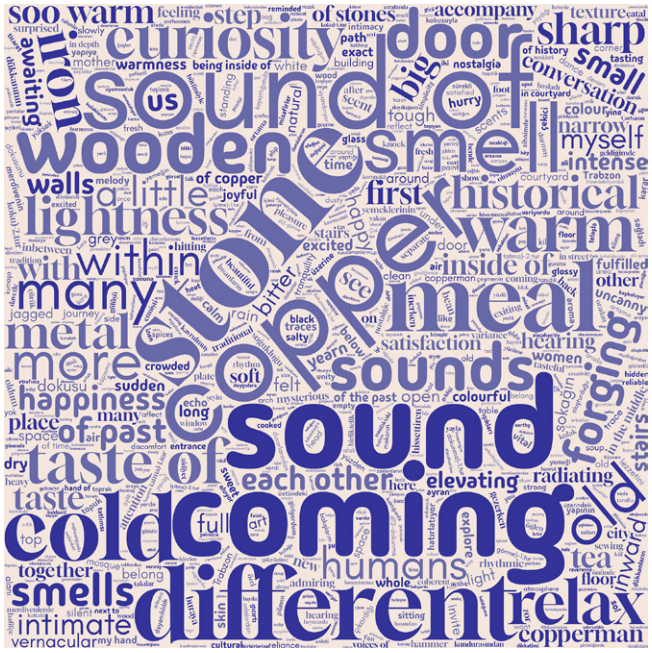

Figure 4. The word cloud of student narratives on Alacahan, where word sizes are depicted according to frequency (Source: Authors, 2025)

The building acts as both a receptor and a producer of rhythms in the environment, ranging from sounds and sights to smells and tastes. The creaks and echoes from the wooden doors and steps in the inner galleries were also noted by the students, which can be called the embodied perception of the building. This awareness of small sounds was strongly affected by the intense flows of bodies and behaviours encountered just before visiting this courtyard. This shift shows one of Alacahan's affordances: creating a silent, relaxed inner space that filters out the confusion of the bazaar. This filter maintains the productive tension between the urban vibrancy of the bazaar and the building's inner relaxation and silence. Some students repeatedly emphasised the building's *calm*, *relaxing* atmosphere. This sense catalysed a feeling of intimacy for them, as a corresponding sense of the entrance's secludedness. The material of the stone walls, which occupies a considerable space in the word cloud, catalysed a sense of coldness for several students. Unexpectedly, this coldness for them is accompanied by a sense of intimacy. This observation shows that even what is widely regarded as detached and cold, as dark stone in this example, can evoke an intimate feeling. This new meaning may come from being in tension with overly displayed products and the bazaar's noise. This unexpected association returns one to Gibson's (2015) emphasis on analysing how actors relate to one another and their phenomenological affordances before definitive qualities. The senses and meanings a material affords might differ across embodied experience, underscoring the importance of analysing affordances.

Figure 5. A coppersmith next to Alacahan's entrance (Source: Unarcode Project Archive, 2025)

The other notable enactive perception in narratives is a shift in gaze directionality. The bazaar leads actors to perceive the noise and crowds horizontally within their flow. This ongoing movement of horizontality, noisiness and openness is interrupted in the students' unexpected encounter with Alacahan and its vertical perception. This emphasis can be seen in the repeated words *inside, coming in, coming out, the metal door* with an arch (Figure 1), and a *narrow* path that is hidden yet *reliable*, which makes one *excited*. They note that moving in and out of different atmospheres made them more aware of the characteristics of materials, such as stone walls, wooden stairs, and window frames. This novel affordance of permeating in and out transforms many affordances within the bazaar, such as redirecting the gaze vertically towards the sky. Some students connected the sensing of relief and reassurance with the allegory of someone being elevated from the ground of Alacahan to the sky, a narrative in which the affect of the vertical directionality of the open courtyard is evident. This affect is emphasised by the gradual elevation in its inner galleries, which is seen as unique compared to the long and seemingly never-ending bazaar axes, as in Figure 6.

The voices of copperwork permeate the inn's secluded structure and echo in the closed courtyard. This experience intensifies the shift in the directionality of hearing, prompting students to acknowledge what has remained unexamined yet still exists outside the building. These affordances later on show that new meanings of directionality are catalysed by its rectangular, enclosed courtyard, surrounded by shops and tables (Figure 6). These insights from narratives

Figure 6. A top-down view of Alacahan's inner courtyard. (Source: Unarcode Project Archive, 2025)

show how sound, smell, materials, and the directionality of gaze and hearing complementarily shape the architectural perception and action of its courtyard. Neither of those aspects can be categorised by using clear-cut distinctions. One may propose that Alacahan acts as "the point of inflection" (Deleuze, 2011, p. 15) (in terms of change in the motion of the act to produce something new) of the senses through the affordance of being a secluded niche.

From the perspective of student sketches, a shared effort among students to depict a movement embedded within the site can be observed. The perception of Alacahan as an adjacent, secluded area with its own centre created a feeling of transforming the existing movement of the other parts of the urban area. This inflection point was expressed by various students, and the affordance can be traced in sketches of cyclical movement, in contrast to other linear movements within the city. Twelve student sketches of Alacahan are investigated in this study. The first sketch depicts horizontal and vertical red axes intersecting at a point, with a red circle enclosing the right side. The student described this sketch's theme as an inclusive variety with a feeling of a feminine touch. This affordance of inclusiveness highlights how the urban flows are transformed and inflected through the khan. The second sketch shows dispersed long rectangles with blue shadows. One small, short square in green appears as a reliable minor reference point amid the confusion. The sketch's creator defined it as a familiar smell around mixed odours. The third one is illustrated as a small, cell-like red circle covering the entire canvas, with a void amid the tight coexistence. Many urban threads are coming together within its fabric with small gaps. The main theme for the student is discomfort caused by the bazaar's high-pitched noises. A highlight of the directional shift can be seen in the fourth, which is themed integration. This sketch depicts scattered black squares and rectangles at the periphery, and a cohesive grouping of other shapes at the centre of the paper outlining a square. The student defined the building's sense of place as a whole, where small hints of sound come together in the middle through integration. The fifth illustrates a flow of a thin, black, curved line meeting a widening blue line, with the threshold hatched with dashed lines. This transforming threshold stands out and is themed as an unexpected touch by the student. This sense for the student is provoked by a leather canvas that appears wooden in the distance. As one may interpret, this sketch also illustrates a motion starting from the curved lines of topology towards the inclusive unity of the sky.

These rhythmic aspects, as also observed in narratives, depict a flow of senses transformed into something different. For philosophers Deleuze and Guattari, one of the most operative aspects of a rhythm is its ability to leap into "a different plane than that of its actions" (Deleuze and Guattari 1987, p. 401). Rhythm arises from its inscription into the fabric of the environment beyond given flows, norms, and functions. One can observe this rhythmic leap in some of the sketches. The student of the sixth sketch expressed this rhythmic point through many squares with inner layers. In each square, a different layer is coloured red. The student's theme for this sketch is a sense of niche, as an urban pocket that is visited when attempting to escape from the intense fabric of the city. A similar rhythmic sense of the building is also evident in the seventh one, where the edges of two black squares define a narrow pass with a red dot. Diagonal hatches between the inner and outer sides differ by their watercolour effect, which defines the sense of a threshold shaping flows and meanings. The student's theme for this sketch is the haptic transformation. A rhythm that derives from a void of calmness in the midst of chaos can also be seen in the third sketch. The eighth sketch illustrates a stone-like rectangle shape with shades of brown. This shape is pierced by yellow, blue, and green lines of varying thickness. The shape absorbs all these penetrations. The sketch's theme for the student is a deafened mass. In this example, the building's node-ability is demonstrated through having a cold yet intimate inwardness.

The ninth sketch depicts many lines radiating inwards from a centre. Its theme is reunion, as in the yearning to return home. For the student, this sense of finding what you are after can be felt in Alacahan both for a foreigner and a local. This description shows that the sense of radiating in and out also applies to feelings and meanings, as well as to directionality. Another similar sketch of radiating in and out is the tenth one, with a spiral layer that becomes increasingly intricate and dense in each layer, hatched with diagonal lines. Its theme is the sense of hiding behind thick stone walls. The eleventh sketch illustrates a three-sided rectangle in the middle of the paper, enveloped by two curves, with small lines of connection to the central space. Its theme for students is the continuity of traditional values sustained in the heart of the city. One might say that this sketch depicts a figure of a connector of disparate tensions. The tension over centrality among many flows is also evident in the drawings, which highlight the dominant role of the historical bazaar axes. In the twelfth sketch, this aspect is expressed by articulating three pink circles with wind-like, flowing lines that envelop and continue along them. Its theme for the student is intimacy, which conveys a sense of affinity rather than its literal meaning of temperature (the student used the Turkish word "sıcaklık," with the double meaning of temperature and intimacy). A similar sense of filtering confusion through a threshold into calmness can also be found in the seventh sketch.

Up to this point, one can argue that the affordance of radiating in and out of meanings and senses is a central theme in sketches. Most of the sketches do not emphasise a single architectural quality or depict abstract ideas. This study proposes that these sketches focus particularly on how the urban fabric is enriched through their enacted perception of movement. Also, this active understanding of what remains from an urban experience allows us, as a further step, to develop a meaningful framework for analysing architectural dynamism. The enacted perceptions of students are not derived from an isolated position in which the actor and the building are separated by distance. In this case study, students' affordances are produced where the lives of coppersmiths, shop owners, tourists, local people and students coincide within the bazaar, khan, blue sky, inner galleries, echoes, and creaks. This interwoven fabric shows how stories and the sketches strongly resonate with one another.

The analysis of narratives showed that Alacahan's capacities for action include being a receptor and producer of rhythms, filtering out the movement and sounds of the bazaar to make them meaningful. From sketching their perspectives, students depicted Alacahan as an inflection point, transforming what exists into something new via a rhythm. Also, the building is depicted as a reliable reference, a node and connector of tensions. This study aimed to enable students to explore this intricate relationality. These concepts are developed to situate what can be learned from students' shared efforts to express urban memory, habits, and meanings. Even if this empirical study may be seen as a recognition of long-established habits and behavioural patterns in the city, it is crucial to emphasise how these architectural habits actively shape urban memories.

SENSING BY DOING: COUPLING OF URBAN PERCEPTION AND ACTION IN THEORY AND PEDAGOGY

A broad discussion of the coupling of perception and action within urban memory can help extend our perspective on what we have learned so far from Alacahan. What made the experience of Alacahan more engaging for students was their ability to affect Alacahan by means of conveying meanings, while, in doing so, being affected by Alacahan. "Joy", for the philosopher Baruch de Spinoza (Spinoza, 1996, p. 70), comes from the ability to increase one's affect towards the world and, in turn, to be affected by it. From an architectural perspective, the question is not how we can increase our ability to represent ideas through architecture, because it risks being anthropocentric. In fact, any investigation should centre on how an actor perceives and is transformed within it, building on Sennett's emphasis (1996) on the meaning of the body. Doing this Spinozian ethical move can address the first question of this paper: how can one reevaluate urban actors and memory in the Anthropocene beyond ready-made schemas?

The way we sense and understand the world operates through associative and reciprocal processes that both shape and are shaped by the environment (Goldhagen, 2017). This reciprocal scaffolding of Spinoza's affect theory highlights how the lived experience is, in the first place, being produced. In this paper's case, what is effective for students' attunement are the habits of the milieu, such as the forging sounds of copper and water, the secluded niche of the building, and the radiating in-and-out effect as urban affordances (Figure 6). All these assemblages among different elements have evolved dynamically over time in the urban fabric.

Continuing the project of Spinozian affect theory (A of 4EA), philosopher Brian Massumi (2021) argues that what is experienced in the milieu is first operated through the tendencies and habits of actors in a passive consciousness, but in active doing. Massumi argues that people usually act out most aspects of their lives at the level of tropism, where established tendencies and reflexes in daily routines create habits. People do not tend to think about them until something disturbs this flow in the level of consciousness. These habits in Alacahan lay the foundations for active perception, as can be seen in students' productive expressions. This passivity of consciousness via dynamic habits differs from Gibson's previously mentioned critique of passive perception, which describes a linear process from the receptive beholder to the active doer. For Massumi, habits are still acted out, yet they do not always involve a cognitive level. When tendencies and habits become useless, this cognitive level leads one to attend to the form and its configurations. This study illustrated this shift in the use of sketches and narratives. This step is the ground of enactive perception, which builds on contextual foundations through habits (Massumi, 2021). In other words, these repetitive acts become more intelligible and sensible when they encounter a destabilising experience with different affordances and habits. The students conveyed their meanings via a sense of thresholds and tensions. Sensation is meaningful only when it is coupled with the act of integration called perception, which gives value to the sense (Simondon, 2020).

The potential field of tendencies and habits is the source of the richness of urban experience (Massumi, 2021). These are the potential meanings and values yet to be embodied within the environment. This virtual potential is similar to Noë's (2006) emphasis on how virtual capacities of action and perception are as real as actual objects in terms of their enabling of expressions. Neither of Alacahan's potential urban fields is an actual object that can be directly sensed from photos or audio recordings, since they require enacted habits. What these expressive recordings tell becomes more meaningful as students become more attuned to the environment.

After discussing the crucial role of embodied perception via habits, the crucial roles of expressions and their apparatuses become more apparent. To situate the meanings in architectural experience, the relational potential needs to be actualised through expressions capable of transforming one field's effects on the threshold into another (Massumi, 2021). This is yet another form of rhythm in which the in-situ expression is transformed into recordings. This is the point at which active interventions take on meaning through the rhythms of habits. Architecture has a special potential to enable this rhythm. Architectural theorist Juhani Pallasmaa (2020, p. 16) argues that architecture's ambiguity between its "utilitarian and poetic, technological and artistic,

economic and existential, collective and individual" sides results in an impurity. Because of this, architecture has the potential to have dynamism. This leaping is opening up the architectural potential of pluralistic perspectives of sensing and valuing the world.

Phenomenologist Hubert Dreyfus (2009) critiques the meaningless effort to translate and formalise worldly activities into codes, rules, and laws by neglecting lived experience. This assumption of this translation leads one to consider the world to consist of independent atomic facts. Following Dreyfus, this paper's starting point for understanding architectural experience as a continuous journey is not to dissect parts into chunks and analyse them in categories. Offering readers only images of copperwork and the narrow street or allowing them to listen to audio recordings cannot be sufficient to comprehend the whole assemblage, given the importance of habits and affordances. Drawing on the anthropologist Gregory Bateson, Radman (2022) shows the absurdity of the architectural approach of dissecting architecture into isolated elements, analogising it to cutting a chicken in half and trying to understand how its anatomy operates.

Instead, this paper adopts a situated approach to how experiences evolve within architecture and how these perspectives can be actively expressed through the translations of words and shapes. This paper complements two technological modes of expression to prevent a one-sided emphasis. Drawing on Radman (2022), the perception through apparatuses is neither a direct presentation of what already exists there, nor a representation. The perceptual content and affordances of a building are vitalised expressions through thresholds of transformation. Sketches and narratives may demonstrate that the intensive thresholds at which meanings emerge constitute a form of recording. Through these perspectives recorded via technological means, someone who has not experienced this place before can trace the genealogy of lived experience and be intrigued by it, leading them to experience another journey.

Examining these dynamic habits leads one to investigate how values are generated reciprocally. The city is not just a physical construct but a dynamic phenomenon continuously experienced, sensed, and engaged with by people. Ingold argues that various ways of moving in the milieu transform all the modes of perception. The capacities of perception and action are "neither innate nor acquired but undergo continuous formation within processes of ontogenetic development" (Ingold, 2001, p. 268), demonstrating that they are embedded within the habits of urban experience. These daily experiences of cities are interwoven through various registers and fields that constitute the urban memory. The affective understanding of senses, affordances, and experiences within a broader perspective may enable one to acknowledge "the complexity and multiplicity of social life across and through relational times and spaces" (Walker *et al*., 2023, p. 8). It highlights a moment when everyday experiences can reveal a city's potential. The last discussion aims to explore what sketching and storytelling offer, both pedagogically and practically, in conjunction with these theories.

Regarding the importance of words and shapes in architectural practice and pedagogy, architect and scholar Perry Kulper defines architectural practice as a relational structuring that complements many "mini-cosmologies" (Kulper, 2020, p. 192). All the value structures of the relational structuring need to be open to various points of view, as this paper's discussion of urban affordance perspectives demonstrates. In this case, architecture students negotiated between various senses to bind their meaningful experiences into architecture. Following Kulper's (2020) question about how to increase potential while mitigating rigid certainty and control, the students did not produce any concepts and terms beforehand. This would have led them to follow a linear way to offer novelty arising from the mind's intention. But this study named these concepts after they emerged from lived urban conditions, giving rise to new perspectives. These perspectives became more attuned through the embodiment of their senses. The architectural drawings that create frameworks-in-action, for Kulper (2020), can be understood within, first, new notions in the language to exceed what is overly focused on and taken for granted, and second, potential overlaps between similar yet distinct materials, forms, and operations. These corresponding steps may offer more situated ways of understanding the design process and thinking. The generativity of architectural drawings, both figurative and non-figurative, for Kulper (2020) expands this potential field of architecture and gives designers more tools to explore what is embedded in the environment. The practice of drawing leads designers – in this case, students – to demonstrate what coexists, all with their disparate values and perspectives, creating room for oscillation between different points (Kulper, 2020). Most importantly, Kulper argues that drawings can highlight cultural relevance and care because of their conversational capacity (Kulper, 2020).

This study followed a similar approach to Kulper's three steps (2020) and his emphasis of cultural relevance throughout the paper by analysing:

- how structures are framed through drawings as relations between parts and wholes;
- how certain words open up new architectural directions of potential meanings beyond established terms; and
- how these discussions can be integrated with affordance theory and recent 4EA perspectives on cognition and technological apparatuses.

This study followed students' changing positions and their coexistence by exploring conditions depicted differently, yet with a shared effort, as this study named the rhythmic inflection points. This paper's empirical findings, through Kulper's perspective, show that a more productive and pedagogical way to explore the urban fabric is to focus on its conditions rather than on linear efforts in solving problems. Havik and Sioli offer a similar perspective of cultural care in narratives, configuring multiple voices and fostering empathetic accounts of lived experience and design thinking (Havik and Sioli, 2021). By emphasising how storytelling pedagogically shapes architectural imagination, researchers argue that this mode of expression increases receptivity and productivity to meanings and atmospheres (Havik and Sioli, 2021). While problem-solving can be viewed as a

structured attempt to narrow the field of potential relations, condition-delving can be understood as more indeterminate wonderings about the architectural experience. The pedagogical aspect of this study attempted to demonstrate this mutual scaffolding as a form of urban dynamism of shared memories.

CONCLUSIONS

To question an alternative perspective on how to situate urban actors in the Anthropocene, this study began by investigating Gibson's affordance theory. Drawing on Gibson, this study aimed to analyse Alacahan's offerings and habits that are important for catalysing an urban dynamism. This study aimed to investigate how the affordances of a building, as part of the living urban memory, can shape its meanings and values in intensive ways. To achieve this end, this paper drew on recent perspectives in the field of cognitive sciences that criticise approaches to expanding human control over the mind and linearity in action and perception. The approaches of 4EA mainly investigate the extent to which technological apparatuses can integrate perception and action processes beyond clear-cut categorisations. After complementing affordance theory and 4EA, Alacahan and its meanings and values for students are evaluated through sketches and narratives. Based on the shared effort in these expressions, the importance of dynamic habits in the production of values and meanings was highlighted. Some notable affordances in narratives included Alacahan's in-and-out movements, shifting the directionality of gaze and hearing, filtering out the movement and sounds of the bazaar, and serving as a receptor and producer of rhythms. In terms of sketches, an effort to depict the building as an inflection point was noticed, acting as a connector of movements and directionalities. Students' narratives and sketches do not aim to provide the most precise and accurate account of an urban fabric to enhance the experience to the maximum. This study concluded that a living urban fabric can convey diverse meanings to disparate actors by serving as a mutual scaffolding of experiences and values.

The meanings of Alacahan and its experience are not confined to the body of an actor or to isolated investigations. The building extends the experience through sketches, stories, and experiences, embedding architecture into the embodied cognition of architectural environments. This study argues that these insights offer a sense of the dynamism of urban memory. Urban memory is not a static archive of historical events but rather a performative, continuously negotiated dynamism. The lived conditions and affordances of architecture – whether structural or operational – do not serve solely as limitations but facilitate as generative structures that actively form new configurations of behaviours and perception. Alacahan exemplifies how heritage sites can support environmental, social and psychological ecology by fostering experiential learning and sensory awareness. This synthesis of pedagogical and architectural values points to an expanded notion of sustainability that extends beyond material conservation. This perspective envisions cities as affective, cognitive, and as shared ecosystems where embodied interactions continue to generate urban meaning.

As a further step based on these insights, the importance of a new digital application that uses narrative, sketches, or other forms of expression can be highlighted. Such an application could integrate these multimodal and rhythmic insights, along with an appreciation of the urban fabric, including spatial, sensory, auditory, and visual elements. It may actively enhance the perception of the dynamism of urban experience within its living fabric and dynamic habits. Additionally, it could serve as a platform for participatory storytelling, allowing other actors to contribute their personal memories and expressions as an extended and shared cognition. By facilitating dynamic interactions, such digital architectural archives would not merely document urban memory but would be actively involved in its ongoing evolution.

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ORCID

Serap Durmuş Öztürk https://orcid.org/0000-0001-6902-069X

Abdullah Yasin Dündar https://orcid.org/0000-0002-5333-1618

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OBJECT CONTENT OF THE RESIDENTIAL ENVIRONMENT IN INTERIOR DESIGN: PRINCIPLES OF ORGANIZATION AND STYLISTIC TRENDS

Ihor Bondar[1], Kyiv National University of Culture and Arts, Faculty of Design and Advertising, Department of Design and Technology, Kyiv, Ukraine
Olha Lavrenyuk, Kyiv National University of Culture and Arts, Faculty of Design and Advertising, Department of Design and Technology, Kyiv, Ukraine
Viktoriia Malaniuk, Kyiv National University of Culture and Arts, Faculty of Design and Advertising, Department of Design and Technology, Kyiv, Ukraine
Bohdan Skovronskyi, Kyiv National University of Culture and Arts, Faculty of Design and Advertising, Department of Design and Technology, Kyiv, Ukraine
Oleksii Dubovyi, Kyiv National University of Culture and Arts, Faculty of Design and Advertising, Department of Design and Technology, Kyiv, Ukraine

This article examines contemporary residential interiors as adaptive systems shaped by spatial organization, material composition, and the integration of digital technologies. The study is based on the hypothesis that residential environments designed with flexibility, sensory comfort, and supportive technologies have a measurable positive impact on occupants' well-being, productivity, and daily routines. The aim of the research is to identify and systematize key design principles that define high-quality contemporary housing. The methodological framework combines qualitative analysis of scientific literature published between 2021 and 2025, a review of international residential comfort standards (including WELL for Residential), and comparative analysis of contemporary interior design solutions using digital spatial modeling tools. The results demonstrate that effective residential interiors prioritize adaptability through mobile furniture, concealed storage, multi-scenario lighting, and zoning strategies that allow rapid functional transformation, while maintaining visual calm through natural materials, biophilic elements, and restrained aesthetics. Digital modeling tools are shown to enhance spatial efficiency and support everyday household routines without dominating the living environment. The scientific contribution of the article lies in framing the residential interior as a user-centered, dynamic system in which spatial flexibility, material quality, and technology are integrated to support personal autonomy, privacy, and contemporary life rhythms.

Key words: **furnishing, interior, object design, spatial zoning.**

INTRODUCTION

Housing is increasingly viewed not only as a sleeping and cooking space but also as an environment that directly affects a person's daily condition, from mood to behavior around others. A special place in this regard is occupied by the material components: furniture, lighting, household items, and technology that act as a "bridge" between the space and the user's bodily experience. At present, interior components are no longer viewed as a purely aesthetic addition but as an integral system that provides support for everyday needs, psychological comfort, and the functional efficiency of the space. The interior also can be regarded as a strategy of organizing life, which defines the paths of movement, rest areas, and the overall sense of comfort in the house.

[1] 36 Yevhen Konovalets Str., Kyiv, Ukraine 01133
ihor_bondar@edu-iosa.org

In recent years, the perception of the home has changed dramatically. The pace and uniformity of everyday life have led people to reconsider how they live and many have started to pay more attention to their surroundings. Since the home is often the only place where people can truly relax, its organization has gained new importance. In smaller apartments, adaptability is essential, for example the same table may serve as a workstation and a dining area to save additional space, while a wardrobe often functions as storage and a spatial divider. This method helps to maintain comfort without sacrificing functionality, with minimal efforts. Studies in residential environmental ecology show a consistent pattern: lighting, furniture, acoustics, and spatial organization directly influence well-being, particularly among older adults (Rojas *et al*., 2024; Hashemi and Dungrani, 2025; Kurmanbekova *et al*., 2025).

The role that modern technologies and digital tools play in our lives is becoming increasingly integral. The "smart" home, in which temperature and lighting are automatically regulated, is now viewed more naturally. There is also a bigger demand on natural materials and safe, non-toxic finishes. Earlier, no one could imagine a smart home, yet it has quietly become an ordinary part of many people's life, with, for example, automated lighting, climate control and security systems integrated into daily routines. Research in machine learning and parametric design indicates that digital modeling tools can analyze everyday patterns of space use and suggest the most rational layouts (Na *et al*., 2025; Zhang and Zheng, 2025). Standards such as the International WELL Building Institute (2024) have begun to set new benchmarks, defining the balance between ergonomics, health, and aesthetics as central to high-quality housing.

Another significant transformation concerns the concept of the home. It is increasingly perceived as an extension of the self, where physical and psychological well-being are shaped by the surrounding objects. Furniture and interior elements act as intermediaries between the individual and the external world, influencing the sense of control, comfort and privacy. Consequently, a lot of attention is paid to how the material layer of the home should be organized, not only in terms of functionality, but also with regard to style, atmosphere and its ability to foster harmony.

At the same time, while the technical and environmental aspects of housing have been extensively researched, the psychological aspects of human interaction with the physical environment have been relatively less explored. Academic research has focused primarily on ventilation, materials, and furniture ergonomics, while the impact of style and spatial arrangement on psychological comfort and cognitive adaptation has been overlooked. It is precisely this research gap that underscores the relevance of the present article. Many studies focus on ventilation, materials or ergonomics, overlooking how objects shape the atmosphere, spatial character, and the emotional sense of home. It is precisely at the intersection of human experience, aesthetics, and algorithmic design that this study positions itself.

The object of the research is the residential interior as an integrated system of interaction between the individual and the object-spatial environment. The subject of the research includes the principles of organization and stylistic characteristics of the material content of residential spaces that determine their functional efficiency and psychological comfort. The aim of the article is to identify the key elements of contemporary residential space that ensure comfort, efficiency in everyday life, and the psychological well-being of residents. Accordingly, the study proposes the following hypotheses:

- object content structured according to the principles of functional-scenario zoning and adaptability enhances spatial efficiency and resident satisfaction;
- a stylistic framework based on biophilic motifs, natural materials, and a neutral palette helps reduce psycho-emotional stress and promotes a positive perception of the environment; and
- the integration of intelligent systems and algorithmically optimized furniture configurations in small apartments increases spatial flexibility and improves indicators of subjective comfort.

The research methodology is based on a combined approach, which involves an analysis of recent scientific literature (2021-2025), a comparative analysis of standards for the residential environment, and observations of 20 modern residential projects. Such data processing is made possible by using qualitative content analysis, as it allows for a comparison of the principles of spatial organization, styles of material and interior components, as well as digital technologies.

Thus, the article makes a scholarly contribution by systematizing knowledge about the formation of the material layer of the residential environment, as well as providing conceptual recommendations for creating comfortable spaces that take into account ergonomics, aesthetics, and technology.

BACKGROUND OF THE RESEARCH

The research presented here relies on inter-disciplinary sources from architectural design, residential environmental ecology, interior design, and computational design, and dates from 2011 to 2025. The sources include empirical research, conceptual frameworks, and practical applications directly related to the organization of the material layer of residential buildings, the influence of spatial solutions on user experience, and the integration of technology into the domestic environment. This enables not only the identification of trends, but also an understanding of material and interior elements as factors in the functional and psychological quality of residential space.

Within existing research, the physical layer of the interior is increasingly seen not as an aggregation of separate objects, but as an integrated system of human-space interaction and its effect on behavioral scenarios. In such an understanding, the metaphor "physical language" of the home is used to refer to the communication of the furniture, lighting, and objects with the inhabitants based on their arrangement, scale, and materials. The first analytical block of the literature is dedicated to spatial and ergonomic solutions, as well as the composition of elements inside the interior. The literature in this area has shown that even minor changes to furniture arrangements can affect social interaction, movement, and subjective comfort levels. For example, Lee *et al*. (2017) have

shown that furniture orientation in residential spaces affects interaction among residents, making it more or less isolated in terms of room use. This means that the material layer is not only functional in nature but also social and regulatory.

This logic is further supported by Saruwono *et al.* (2012), who examined the layout of compact apartments in Malaysia. They identified consistent life zones, which are created for communication, dining, and relaxation that are shaped less by architectural boundaries than by the configuration of furniture. In these studies, interior objects are treated as tools for navigating daily life, and organizing the actions of residents. However, as a result of analyzing this literature, it is necessary to note that a methodological limitation of these studies is that, as a rule, the ergonomic features of a space are not examined in conjunction with its stylistic features, which does not allow for a complete evaluation of the psychological impact of the material environment. Natural materials, plants, and daylight patterns have been shown to foster calmness and a sense of warmth. In the urban context, such a natural presence serves as a counterbalance to sensory and informational overload. The second analytical block considers research on stylistics and biophilic design as psychological comfort factors. In these studies, the material layer is considered a factor of the psychological ecology of the home, mediating the relationship between humans and nature's rhythms. It has been found that natural materials, plants, and scenario lighting are related to lower stress levels and increased coziness, particularly in densely built cities. Further, Gong (2023) proved that greenery and natural light are related to higher levels of life satisfaction in residential complexes. Marte (2020), employing the BID-M matrix, proved that it is possible to record biophilic factors in interior spaces in a quantitative manner, pointing out the potential of formalizing this approach. However, most of these studies examine individual stylistic factors without combining them with the spatial and functional properties of the material layer.

The third set of literature relates to incorporating technology into residential interior design. In these studies, the idea of "programmable partners" is introduced. It refers to how interior design and furniture can change according to human behavior. Yu (2011) carried out one of the pioneering studies on using automated interior furniture arrangement based on ergonomic principles. Later studies, like Wang (2025), further extended these ideas by suggesting interior design based on an analysis of human activities and then adapting according to them. However, these studies are mainly conducted in a virtual or office environment.

After analyzing and synthesizing the sources, it became evident that there was a clear research gap. The previous studies either focus on ergonomics, stylistics, or technologies separately or focus on them independently of the subjective experience of the resident. The research gap in methodology is the lack of holistic models that combine material parameters, stylistic solutions, and algorithmic spatial adaptation into one framework. The filling of this gap, through the combination of spatial, aesthetic, and digital parameters, is the scientific objective of the study, which logically precedes the choice of methodology and the definition of the research goals.

MATERIALS AND METHODS

The study employed a mixed-methods design, combining qualitative content analysis, comparative visual analysis, and elements of empirical research. The work was carried out in three sequential stages:

- compiling a case corpus and creating an analytical database of interiors;
- systematically analyzing the material layer according to pre-defined parameters; and
- verifying the identified patterns through expert surveys and field observations.

This structure made it possible to compare conceptual propositions with real-world residential practices and to test the hypotheses put forward.

To systematize current trends, 60 residential interiors were analyzed that were selected from leading professional platforms, such as Dezeen, ArchDaily, and Interior+Design over the period 2020–2025. The examples included modern apartments ranging from 35 m^2 to 120 m^2, and for each interior key parameters were recorded: stylistic and compositional features, materials and textures, color schemes and accents, furnishing density and the presence of biophilic elements. A mandatory requirement was the availability of floor plans, photographic documentation, and the designer's project description, which enabled both spatial and material analysis. In each case, a standardized analytical tool, or "interior passport," was developed and employed as a working unit for comparative analysis. The interior passport documented the following parameters: layout type and spatial usage scenarios; density and configuration of furniture; materials and tactile qualities of surfaces; color scheme; presence and types of biophilic elements; and technology integration levels. This method enabled a uniform analysis of various cases and revealed common patterns in the material composition of the interior spaces.

The color analysis process took place in two phases: a primary visual coding, followed by a secondary verification through a digital platform called Adobe Color. The colors that covered at least 15% of the total visible surface area (walls, large pieces of furniture, etc.) were considered to be in visual dominance, as this approach to understanding visual dominance in environmental design studies suggests. The choice of this percentage helped to avoid subjectivity in interpretation.

To assess whether the obtained findings align with professional perceptions, a survey of practicing designers and architects was conducted (N = 42). The sample comprised professionals with a minimum of three years of experience in residential space design. The instrument used to collect data was a structured questionnaire posted on the internet, employing a five-point rating scale to measure the criteria of functional efficiency, stylistic consistency, and the psychological comfort of the material layer. The data gathered were subjected to descriptive and comparative analysis.

Moreover, the field observation method was used in 10 small apartment settings up to 45 m^2, which had a clarifying and illustrative character regarding the verification of hypotheses concerning spatial adaptability and furniture use

in scenarios. At this stage, parameters concerning the "reach radius" were collected, as well as the distance between important functional objects, corridor width, user movement patterns, and the proportion of furniture area in the room area, all of which were analyzed based on floor plans and site measurements using laser and regular tape measures.

In general, the methodology used was directly related to the testing of the hypotheses developed: the case analysis and the "interior passport" relate to the assessment of functional efficiency and scenario efficiency; the color and style analysis relate to the psycho-emotional effects of the space; and the field survey relates to the verification of subjective comfort. The limitations of the study include the lack of biometric data used in the study and the small sample size, which points to the need for further study based on a wider sample.

RESULTS

In order to clearly separate the empirical results from their subsequent interpretation, the results will be presented in relation to the proposed hypotheses. The information presented is based on the results of the analysis of 60 residential interiors, the results of the expert survey (n = 42), and observations in small apartments (n= 10). The tables and figures presented (Tables 1-4, Figures 1-3) contain the authors' own research data, which was collected through standardized case analysis and aggregation of measurements, rather than relying on pre-existing research.

The first hypothesis focused on the effect of functional and scenario zoning, the flexibility of the interior space, the efficiency of space use, and the psycho-emotional comfort of residents. The second hypothesis posited that the use of biophilic design and natural materials correlates with reduced psycho-emotional stress. The third hypothesis focused on the effectiveness of intelligent systems and flexible furniture arrangements in increasing the flexibility of small apartments.

The analysis of 60 selected residential interiors and the survey of professional designers revealed an important pattern: what we call the object layer of the interior depends not so much on the quantity of furniture, but on the quality of interaction between objects and the inhabitant's body, habits, and emotions. Even in visually simple and restrained spaces, design decisions tend to revolve around how a person moves, reaches for things, rests, focuses, and switches between activities.

A clear tendency emerged: the object space is increasingly designed within the natural range of human reach (approximately 1.2–2.5 m from the body). This observation aligns with findings from Tsinghua University, in which maintaining optimal proximity to key objects was found to reduce cognitive load and create a sense of spatial intuition – that is, furniture works as expected rather than forcing a person to adapt to it (Choi *et al.*, 2023). In the apartments observed for this study, this logic manifested in clear circulation paths, the ergonomic placement of work surfaces and carefully considered movement routes. Where objects disrupted this intuitive order, residents more often mentioned a feeling of broken rhythm.

Visual and textural observations confirmed what environmental researchers have already pointed out that materials with natural textures are being confidently returned to home interiors. Wood with visible grain, stone, and textured clay finishes create a sense of groundedness and calm, consistent with findings from the Korean Institute of Environmental Design (Kim and Park, 2025). According to their data, textured surfaces increased tactile satisfaction and even reduced stress levels (measured by HRV). In our observations, users of apartments featuring natural textures were more likely to describe their spaces as calm, warm, and alive. The analyzed interiors also illustrate the affordance theory: objects seem to suggest their intended use. An open shelf invites the organization and visibility of essentials; a closed cabinet encourages decluttering and reducing visual noise. This simple yet powerful pattern proved universal across practical examples, and when objects supported life scenarios, spaces were perceived as more organized and pleasant (Norman, 2004; Gibson, 2015).

Color and texture analysis, together with expert feedback, showed that emotionally warm materials and textiles combined with neutral backgrounds naturally formed "rest zones." This corresponds to findings by Attaianese *et al.* (2025), whereby warm accents helped create psychologically safe areas within the environment. Conversely, when decorative elements were excessive, an opposite effect emerged – aesthetic overload, as described by Kaplan and Kaplan (1989). Although this study did not use EEG or eye-tracking, existing literature offers convincing indicators: a balanced object rhythm and the coherent composition of forms and shadows can reduce the brain's stress reactivity. In practice, interiors with clear composition, repeated motifs, and "air" between objects received the highest comfort ratings.

Across the analytical sample, a distinct trend was observed: what contemporary literature calls intelligent object minimalism. This approach does not imply empty space, but rather a space that evolves with its user: transformable tables, adaptive lighting, and movable shelving systems that respond to changing needs. In real-life apartments where objects "worked as needed," residents described feelings of lightness and freedom of movement. A comparison of 60 interiors from platforms such as Dezeen, ArchDaily, Interior+Design, and the Sustainability Journal revealed a clear shift toward thoughtful object economy and adaptability. Random accumulation of items is disappearing, replaced by a structure in which every element has a defined role and can transform when necessary. Three parallel processes stand out in the practical examples: a rejection of decoration for decoration's sake, the growth of mobile and multifunctional elements, and a preference for natural materials that convey stability and calm. Visual stylistic analysis also highlighted another emerging quality of modern interiors – an aspiration toward the psychological lightness of the environment (Table 1).

The analysis of contemporary cases revealed a clear trend: within the material structure of the home, design solutions were predominantly shaped by two strategies – minimalism and biophilic design. Among the 60 interiors examined, more than half gravitated toward these two strategies: compositions marked by restraint, the use

Table 1. Stylistic structure of the analyzed residential interiors (2020–2025)

Stylistic trend	Share of the interiors analyzed (%)	Key characteristics
Minimalist/Scandinavian	32	light neutral colors, open layouts, multifunctional furniture
Biophilic/Eco-design	21	natural materials, plant elements, daylight, use of wood
Contemporary	18	combination of geometric forms, textiles, metallic accents
Loft/Industrial	15	exposed textures, concrete, black metal, open storage
Neoclassical/Japandi	14	symmetry, calm color palette, light-toned wood

of natural materials, clean lines, and a distinct focus on light and tactile natural textures. This pattern aligns with broader transformations in the design field, namely that psychological comfort, sustainability, and the conscious reduction of material clutter have already become part of the global professional discourse (Zhao *et al.*, 2023 Gong *et al.*, 2023).

This preference for simplicity is not about creating emptiness but about shaping a space that breathes. In many interiors, nature functions not as a decorative accent but as part of the environment's sensory logic: wood, light fabrics, natural daylight, and living plants generate a sense of warmth and stability. Similar findings appear in international studies that link the use of natural materials and open spatial layouts with higher satisfaction and improved stress resilience among residents (Zhao *et al.*, 2023; Gong *et al.*, 2023).

Another consistent pattern emerged: spaces were perceived as more harmonious when the balance between filled and open zones was maintained. Interiors overloaded with objects, even in visually sophisticated styles, tended to feel more tense and heavy. This effect corresponds with the findings of Rui and Firzan (2025), who argue that the air between objects contributes significantly to psychological comfort. Even in restrained, minimalist dwellings, there is a tendency to introduce small emotional markers – one or two artworks, a plant, a handcrafted item, or a symbolic detail. Though minor, these elements add a sense of individuality and soften the geometric austerity of the environment. This mechanism, described as emotional accessorizing (Na *et al.*, 2025), proved significant in shaping a "warm" spatial identity.

Overall, the results indicate an evolution of residential design toward rational harmony: fewer, yet more meaningful, objects; more natural materials; and a role for space that extends beyond functionality to emotional and psychological support. The interior is no longer merely a frame for life; it becomes a partner in it, creating a subtle balance between logic and tactility (Figure 1).

The analysis of the material layer in 60 interiors revealed that it functions as a kind of ecosystem of objects, a network where individual elements do not exist in isolation but form a shared spatial and psychological logic. Furniture, lighting, textiles, décor and technologies collectively shape not only the organization of space but also how a person feels within it, whether grounded, tense, or conversely, relaxed and engaged.

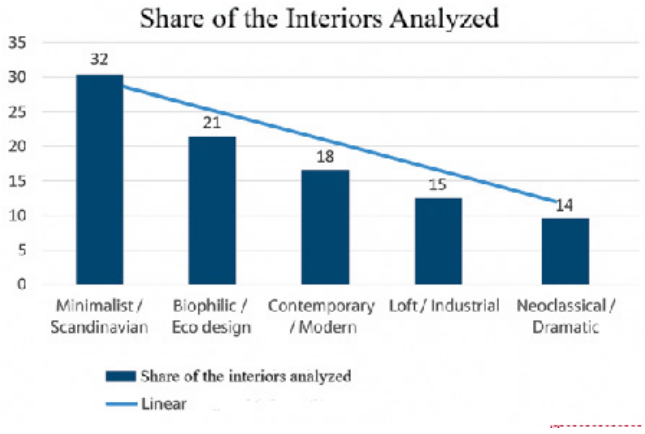


Figure 1. Stylistic structure of the analyzed residential interiors (Source: Authors, 2025)

Each component in the analyzed sample effectively played a dual role. On one hand, it served a utilitarian function, supporting everyday domestic activities. On the other, it carried an emotional-semantic meaning, creating a sense of home, reflecting the resident's identity and defining the rhythm and character of the environment. In most interiors, furniture established the structure of movement and zoning. The height of work surfaces, the depth of seating, and the modularity and ratio of open to closed storage volumes directly influenced the level of comfort and user satisfaction, aligning with the findings of Rui and Firzan (2025). Spaces where furniture adapted to daily life scenarios were perceived as more organized and lighter.

Artworks, green plants, ceramics, and handmade objects often acted as emotional markers, making the environment feel warm and distinctive. In several cases, natural materials themselves took on the decorative role – an approach consistent with the trends described by Gong *et al.* (2023). Lighting, both natural and artificial, played a crucial role. Warm light settings (3000–3500 K) enhanced the feeling of coziness and privacy, while cooler tones (>4000 K) were more frequently associated with work or technical areas. This effect is also well-documented in the literature (Lee *et al.*, 2017; Marte *et al.*, 2020). Light literally sculpted the depth of the space, set the mood, and helped distinguish active zones from resting areas. Textile materials, such as curtains, throws, and carpets formed a tactile background and influenced the acoustic comfort. Natural fabrics (linen, wool, cotton) reinforced feelings of warmth and safety, whereas synthetic surfaces were more often associated with impermanence. This observation fits well within the broader tendency toward natural sensory qualities.

As noted by Na *et al.* (2025) and Sun *et al.* (2025), such elements not only optimize space but also enhance the sense of environmental control and manageability. Expert designers echoed this view – interactivity is increasingly perceived as a hallmark of a mature and thoughtfully designed interior. Summarizing these observations, five functional groups of material components were identified, each serving a specific role in maintaining comfort, facilitating movement and supporting residents' emotional stability (Figure 2).

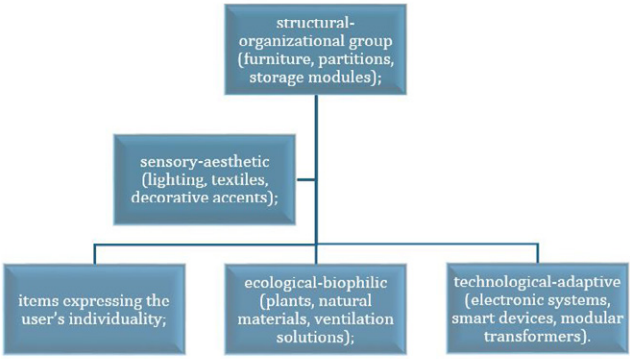


Figure 2. Functional groups of material components (Source: Authors, 2026)

Synthesis of the collected data revealed that all elements of the material environment function not in isolation but as parts of a single, interconnected system. Furniture, lighting, storage solutions, décor, and technological modules interact to create a unified home ecology in which objects do more than occupy space – they shape daily movement patterns, habits, emotional states, and even the mood of residents. For this reason, the contemporary interior is increasingly perceived not as a static image but as a dynamic interaction between people, objects, and digital tools – a balance where rationality and comfort coexist with warmth and a sense of personal security. The results of the classification of material components are presented below (Table 2).

The comparison of interiors revealed a consistent shift toward scenario-based dynamics, manifested in a reduction of fixed furniture elements by approximately one-third and a corresponding increase in transformable and mobile solutions. This trend was further supported by a survey of designers (N = 42), who identified adaptability (4.8/5), ergonomics (4.6/5), and emotional comfort (4.4/5) as the most valuable qualities of the material environment. These findings align with the conclusions of Saruwono *et al.* (2012) on the defining role of furniture in shaping interaction scenarios, as well as with the color analysis of 60 interiors, which revealed a preference for calm, natural palettes correlated with the broader trend toward psychological comfort and biophilic design (Na *et al.*, 2025). More details are presented below (Table 3).

Observations in small apartments (≤45 m^2) clarified the optimal parameters for shaping the material environment, which resulted in a fill coefficient of 0.32–0.38 that proved to be the most comfortable. Exceeding the 0.4 threshold created a sense of crowding and distraction, which is consistent with the findings of Lee *et al.* (2017). It was also confirmed that having more than half of the materials in a composition made of natural elements was associated with a 12–15% reduction in psycho-emotional tension (Zhao *et al.*, 2023; Gong *et al.*, 2023). The summarized indicators are presented in the sequel (Table 4).

The quantitative indicators shown in Tables 1-4 were calculated on the basis of the aggregated data of the full analytical sample (N = 60), except for the ergonomic indicators, which were also checked by field observation (n = 10). The shares of stylistic directions, functional groups of interior elements, and material-color solutions were calculated as the percentage of cases in which a particular feature was noted out of the total number.

A one-third reduction in rigidly fixed furniture signifies the comparative analysis of furniture arrangements in interiors designed between 2020 and 2025, where transformable and mobile components gradually substitute fixed structures. The furniture coverage coefficient (0.32-0.38) was calculated as the ratio of total furniture area to room area, with regard to floor plans and actual measurements.

Table 2. Main functional groups of material components in residential spaces

Group	Average share in the object layer (%)	Key function	Examples of solutions
Storage	29	space optimization, concealed systems	sliding wardrobes, built-in modules
Relaxation	25	ergonomics, relaxation	sofas, armchairs, poufs
Work area	14	flexible use of space	transformable desks, partitions
Lightning	18	atmosphere, visual comfort	combined LED systems
Decorative-identification	14	self-expression, cultural identity	artworks, textured panels

Table 3. Color and textural priorities in contemporary residential design (2020–2025)

Material/Color Group	Frequency of use (%)	Psycho-emotional effect
Natural wood (light tones)	46	sense of warmth and stability
White and gray textiles, paint	35	cleanliness, calmness, spaciousness
Stone, concrete, marble	22	reliability, contrast
Green and earthy accents	28	relaxation, naturalness
Metal, glass	17	high-tech aesthetic, modernity

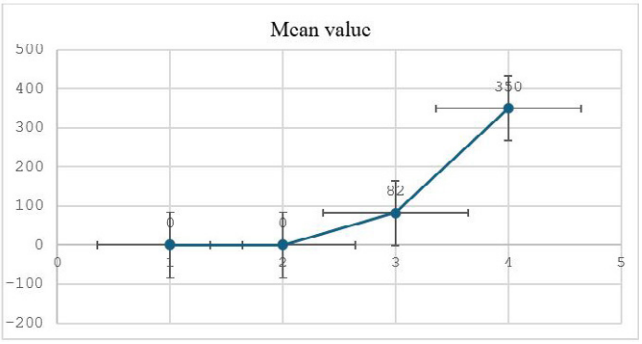
Table 4. Ergonomic indicators of space utilization

Indicator	Average value	Optimal range	Impact on comfort
Furniture fill coefficient	0.36	0.32–0.38	maximum comfort
Work surface height (cm)	73.5	72–75	ergonomic convenience
Distance between furniture (cm)	82	≥ 80	spatial freedom
Illumination level (lx)	350	300–500	visual comfort

These data confirm the first hypothesis, which states that there is a positive correlation between the adaptive interior layout and the subjective comfort of residents, based both on quantitative parameters (optimal coverage coefficient, passage widths, ergonomic heights) and experts' opinions.

The data confirm a strong correlation between ergonomics and cognitive efficiency. Specifically, users who stayed in optimally organized interiors (with a fill coefficient of 0.35) demonstrated an 11% improvement in their attention concentration (Stroop test) and a 5% decrease in their resting heart rate (Marte *et al.*, 2020). The data are presented in Figure 3.

Figure 3. Average values of ergonomic indicators of space use



A clear pattern emerged after reviewing and comparing the interiors, analyzing notes from observations in real apartments and gathering designers' insights. The most comfortable living spaces were those where objects did not merely stand in place but interacted with the person, adapting to their needs, avoiding visual overload, and at the same time adding warmth and individuality. In such interiors, the furnishings seem to move in rhythm with the resident's life, for example, the work desk becomes a dining table when needed, a partition provides privacy, and soft elements create coziness where relaxation is desired. The space does not dictate – it listens, responds and adjusts.

In relation to the second hypothesis, based on the analysis of materials, color schemes, and expert opinion, it can be concluded that it is partially confirmed. Although direct measurements of psychophysiological parameters were not carried out in this research, the fact that natural materials, neutral colors, and biophilic design are predominant in more than half of the interiors analyzed, and are positively evaluated by designers and residents, points to a strong link between stylistic decisions and psychological comfort, indirectly confirmed by existing literature.

The third hypothesis, which deals with the integration of intelligent systems and algorithmically optimized furniture, is confirmed based on the level of observed trends. While the number of cases with implemented "smart" scenarios was not large, these cases demonstrated more positive levels of satisfaction with regard to spatial flexibility and environmental control. Observing small apartments, it is clear that it is exactly these elements of transformable and scenario-controlled furniture that are essential for maintaining the functional efficiency of the space.

To improve the clarity of the research results, the article presents a visual database of typical examples, which includes floor plans, photographs, and analytical diagrams (Figures 1-3). The illustrations demonstrate typical examples of the material layer configuration, stylistic solutions, and ergonomic parameters. They are used as illustrative evidence for the obtained patterns rather than as an additional source of information.

Visual balance also proves important. Where colors and textures appeared calm and light emphasized form, the interior felt airy and harmonious. Conversely, an excess of details or contrasts created a sense of clutter, even in larger spaces. A further consistent feature across most cases was the use of natural, tactile materials. Wood, fabric, living plants, and warm tones grounded the space, making it humane and soft. Even a single clay vase, piece of textile, or artwork could shift the emotional tone of a room and add individuality. Another key factor was the degree of spatial fill. Too many objects quickly made the room feel overloaded, while too few rendered it cold and lifeless. The best results were found in interiors that maintained the golden mean: enough room to move freely, but also several meaningful objects that anchor the atmosphere. Taken together, these observations lead to the simple conclusion that interior design is not about things – it is about the person who lives among them. A well-organized space can support, calm, focus, and restore; it becomes an extension of one's personality and, at times, a quiet partner in everyday life (Gong *et al.*, 2023; Wang, 2025). For illustration and verification of the results, several representative interior cases were selected from the overall sample (N = 60), chosen for their ability to most fully reflect the identified patterns in the material composition of residential spaces.

Case 1. The apartment has an open-plan layout, with the kitchen, living area, and workspace being combined within a single room. The primary functional elements are located in the room's perimeter area, leaving a free space for movement in the center. The widths of the paths passing between furniture are at least 80 cm, and the workplace is within the user's reach (at a distance from 1.2 to 2.0 m).

Case 2. Biophilic organization of the material space. Elements of biophilia are presented in the form of natural wooden finishes in the floor covering and furniture, plants

in the space with natural lighting, and the use of natural textures in textiles. The placement of plants near space of prolonged use (living space, workspace) ensures the presence of a constant background for the senses, which positively affects the perception of spatial comfort. In the analyzed examples, the biophilic elements not only play the role of decoration but also regulate the emotional state.

Case 3. Functional interaction scenarios with the material environment. The interior is structured according to three basic scenarios: active (work, cooking), restorative (rest, relaxation), and transitional (movement, storage). These scenarios are facilitated by the corresponding set of objects positioned in the user's natural reach. This allows for seamless transitions between activities and maintains the natural logic of the environment.

Thus, the visual materials (plans, photographs, analytical diagrams) are not used just as illustrations but as an analytical complement to the study's quantitative and qualitative results, providing clear visual verification of the findings.

DISCUSSION

The results suggest that the material composition of residential space should be seen not as a set of individual objects, but rather as a system of interactions between humans and their environment. In this study, such a system is operationalized through the analysis of media cases of modern interiors (2021–2025), including object types, location rules, the presence of biophilic elements, visual density levels, and scenario-based spatial usage. Such parameters serve as the basis of the following conclusions, whereas interpretations of the impact of these parameters on user experience are based on interdisciplinary literature. This happens not abruptly or deliberately, but on the level of habit: how easily we sit down at the table, where our hand naturally reaches or whether we want to linger in a room for a few more minutes simply because it feels good to be there.

This view of space as an active participant in human life aligns with the approaches of Rui and Firzan (2025), Gong *et al.* (2023), and Zhao *et al.* (2023). The analysis of the content revealed that, in most cases, the material environment is organized based on recurring functional scenarios rather than static compositional principles. More specifically, it was revealed that there are stable scenarios of use, such as working, resting, dining, and temporary transformations, all present in a single space, designed with the help of mobile elements. This means that the scenario-based approach is the most widely used in modern residential interiors, but this is based on the analysis conducted in the present paper, not on an analysis of existing theories.

The quantitative indicators used in this study, such as the percentage of interiors with biophilic-minimalist features and the object ratio, are descriptive in nature and are employed to detect structural trends in the media-case sample. They are not intended for statistical generalization on the level of user behavior and psychophysiological responses, but rather are indicators of the prevalence of certain spatial solutions. In this regard, the values of correlation (r; p) cited in the text should not be considered as experimental measurement results, but rather as a tool for comparing the observed structural trends with the results of previous empirical studies cited in the literature.

The construct of space as a cognitive-sociological ecosystem, as used in this study, is based on a synthesis of the results of this study and the theoretical models of space as proposed by Demirkan *et al*. (2016), Gong *et al*. (2023), and Zhao *et al*. (2023). Based on the results of case analysis, three interrelated levels of the cognitive-sociological ecosystem of residential space were identified: the object-functional, the sensory-material, and the scenario-temporal levels. It is the combination of these levels, rather than any of them separately, that can be regarded as a holistic model of modern residential space, representing a generalization of the results of the study.

The presence of biophilic-minimalist solutions in the sample, as a constant variable, represents an empirical fact identified within this analysis. The conclusions regarding the potential impact of biophilic-minimalist solutions on attention restoration, sensory load reduction, and comfort enhancement were drawn based on a comparison of the findings from this research with the results of independent studies (Lee *et al*., 2017; Zhao *et al*., 2022; Kim and Park, 2025). As a result, user experience was not directly measured within this research; rather, it was indirectly identified based on the interpretation of spatial characteristics, as suggested by experimental studies.

Special attention is drawn to the identified factor of so-called "intuitive access zones," which are objects within the predictable reach of the user. The empirical basis for the systematic occurrence of the media cases lies in the analysis, and the theoretical basis for the effects of predictability and control can be found in the theories of affordances (Gibson *et al*., 1979) and contemporary empirical research in spatial cognition (Choi *et al*., 2023). This approach avoids ascribing psychological effects without a corresponding methodological foundation.

The impact of technologies and tools on residential environment design is also evaluated from the point of view of the study results and literature. In the course of the analysis, an increasing trend of using digital modeling and scenario planning in spatial planning was identified as part of the design stage. Conclusions on improved user satisfaction are based on external sources (Slater and Sanchez-Vives, 2016).

A significant point that should be addressed is that of the relationship between the architect's creativity and algorithmic solutions. Based on the results obtained, it can be stated that algorithmic solutions, such as digital models and scenario simulations, are becoming more and more significant when it comes to optimizing the functional characteristics of space, whereas the final form of the material space still largely relies on the designer's interpretation and particular context. This makes it possible to speak of contemporary residential interior design as a hybrid model, where algorithmic solutions provide a framework and creativity determines the quality of the space.

In summary, the discussion shows that residential space in modern society can be adequately characterized as a

multi-level ecosystem in which objects, materials, lighting, and usage scenarios constitute an integrated structure. At the same time, it should be noted that the results of the current study are restricted to the analysis of interior representations in media, and it is not possible to make direct conclusions regarding the subjective experiences of users without additional research.

CONCLUSIONS

The goal of this study was to reveal structural patterns in the material composition of modern residential spaces and to examine the implementation of these patterns in real interior solutions. The results were synthesized in accordance with the set goals and formulated hypotheses, making it possible to distinguish between empirical findings and interpretive generalizations. The analysis of the material environment of 60 media cases of residential interiors revealed that the material environment in contemporary residential spaces acts as a systematically organized level, rather than a set of individual design decisions. The empirical analysis provided evidence of specific configurations in the arrangement of furniture, functional spaces, and material accents, which are directed toward the scenario of daily usage. Therefore, the material composition is integrated within the spatial logic of the residential space and cannot be reduced to merely decorative and/or utilitarian purposes. This is one of the main findings of the research.

The results showed that a decrease in object density and the application of restrained material and color solutions are related to a more ordered spatial structure of the interior. The above-mentioned quantitative ratios, recorded during the observation (e.g., the proportion of dominant colors and objects), are applied in this research only as analytical tools for comparing cases and are not considered as standards. The correlation between simplified material structures and their effectiveness ($r = 0.68$; $p < 0.01$) is a direct outcome of this research and confirms the hypothesis that moderate object density is preferable in residential spaces.

The analysis helped reveal the role of adaptability in the material layer, especially in small apartments, and the empirical research demonstrated that multifunctional elements, mobile partitions, and furniture solutions facilitate overcoming spatial limitations that are typical for small apartments. It should be emphasized that these findings are not based on descriptions of user experiences but are grounded in the analysis of spatial characteristics and logic of object usage that have been recorded in cases and empirical research. Therefore, the above-mentioned statement can be considered analytical rather than declarative in nature. In the current research, the idea of an interior as an ecosystem has been formulated into a generalized model that integrates the results of the research. The solutions of spatial planning, material composition, and sensory-material properties are viewed as interrelated elements of a unified system. The changes in one system necessarily influence the operation of the other systems, as confirmed in the comparative case analysis. In the current research, the ecosystem approach is not a metaphor but a tool for systematic organization of the results.

It should be noted that the study is careful to avoid making specific claims about the psycho-emotional experiences of the user, and assessments of comfort, control, and stress reduction are not based on a direct analysis of the media cases, but rather on what they might imply as a consequence of the observed spatial-material patterns. This is done to avoid any form of methodological overreach and maintain the rigor and validity of the scientific generalizations. The contribution of this research to science is in developing and checking a method for analyzing the material layer of interior spaces in residential buildings using quantitative and qualitative parameters without reducing architectural solutions to strict algorithms. The model offers possibilities for revealing patterns in modern residential space while leaving room for the architect's personal creative decisions.

The guidelines for further research follow naturally from the limitations of this study. The sample size and lack of direct behavioral and biometric measures suggest the need for further research to test the observed patterns on a wider scale. The most promising prospect is the integration of spatial-material analysis with user experience assessment tools, enabling a deeper exploration of the interrelation between residential organization and the daily practices of its users.

In conclusion, it can be argued that the physical environment of modern housing is not only composed of various visual decisions but also represents a well-structured system that has the potential to support the functional and spatial/sensory balance of living spaces. This constitutes its key role in shaping the quality of the residential environment and highlights its potential for further interdisciplinary research.

ORCID

Ihor Bondar https://orcid.org/0000-0001-8972-0941

Olha Lavrenyuk https://orcid.org/0000-0003-0862-796X

Viktoriia Malaniuk https://orcid.org/0000-0002-8002-4613

Bohdan Skovronskyi https://orcid.org/0000-0001-5413-6630

Oleksii Dubovyi https://orcid.org/0000-0003-1103-8840

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THE CONCEPT OF NEGATIVE SPACE IN ARCHITECTURE

Đorđe Alfirević [1], Faculty of Contemporary Arts, Belgrade, Serbia
Sanja Simonović Alfirević, Institute of Architecture and Urban & Spatial Planning of Serbia, Belgrade, Serbia
Ana Vignjević, Itecom Art Design faculty, Nice, France

This paper examines the concept of negative space in architecture, with the aim of determining its structural, perceptual, and organisational roles within architectural composition. The study addresses the lack of a unified theoretical framework in which negative space is treated as an active architectural element rather than a residual by-product of form. The central hypothesis of the research is that negative space becomes architecturally meaningful only when it possesses clearly defined geometric boundaries, perceptual legibility, and an organisational role within the composition. These conditions enable its recognition as an active component of architectural structure. The paper develops a framework that integrates formal, phenomenological, and perceptual interpretations of the relationship between solid and void. The methodology relies on qualitative analysis of selected architectural examples, evaluated through criteria that distinguish three positional types of negative space: internal, peripheral, and external negative space. The findings confirm the hypothesis, demonstrating that negative space influences spatial hierarchy, visual clarity, and ambient qualities, and therefore operates as a formative principle rather than a passive absence. The study further identifies limitations of the concept, particularly in dense urban contexts and in culturally diverse models of spatial perception. These observations indicate the need for future empirical work focused on user perception and applied case studies. The paper thus provides a coherent basis for advancing methodological tools and for incorporating negative space more systematically into contemporary architectural design practice..

***Key words*: anti-space, void, architectural perception, spatial organisation.**

INTRODUCTION

Negative space is a term most commonly used in the visual arts, denoting the environment surrounding the elements of a composition or the space between them. Its presence becomes particularly evident when the arrangement of forms generates a recognisable contour or geometry of the void. In the visual arts, the primary function of negative space is to accentuate the figurative qualities of a composition through the contrast between solid and void, thereby contributing to its perceptual organisation. While many authors have employed this principle to articulate the relationship between figure and background, as exemplified in the works of Escher and Hantai, in the practice of certain artists, most notably Hasegawa Tōhaku, the void itself emerges as the central subject of investigation.

In a broader sense, the figure–ground principle extends beyond the visual arts and becomes relevant for understanding spatial perception in architecture. In the same way that the background in a painting influences the legibility of the figure, voids in architecture can define, direct, or emphasise the material structures that surround them. This analogy enables architectural composition to be understood as a system in which meaning arises not only from material elements, but also from the relationships produced by their absence.

In architecture, negative space is not merely an empty volume between masses but functions as a structural and perceptual component of composition. It may be experienced as an internal void at the core of a volume, as an interstitial zone along its perimeter, or as an external space mediating between the object and its wider context. This multiplicity of roles highlights the research potential of the concept.

In recent architectural discourse, negative space has increasingly been linked to openness, continuity, interstitiality, and the relationship between an object and its context. However, despite its broad usage, the term remains insufficiently defined in professional and scholarly

[1] Pariske komune 8, 11070 New Belgrade, Serbia
djordje.alfirevic@fsu.edu.rs

literature, and its analytical value is rarely addressed systematically. This study examines the ways in which negative space manifests in architecture and identifies the conditions that enable its recognition as a constitutive element of architectural composition.

The primary aim of the research is to determine the spatial, morphological, and perceptual conditions under which negative space can be identified as a relevant conceptual category in architecture. The secondary aim is to analyse representative contemporary examples in which negative space appears in different positional configurations (internal, peripheral, and external), and to systematise its typologies on that basis.

Hypothesis: Negative space becomes an active component of architectural composition when the design structure fulfils a set of conditions that allow it to be clearly perceived and spatially distinguished. These conditions include geometrically defined or implied boundaries, a discernible difference in morphological or luminous characteristics relative to the surrounding context, and a positional role that enables its recognition as an autonomous spatial entity.

Definition: In this paper, negative space refers to a spatial unit that can be clearly distinguished within a composition, according to the following criteria:

- geometrically defined boundaries;
- perceptual legibility in relation to adjacent masses; and
- a recognisable organisational role within the structure of the object or its context.

The research questions arising from the hypothesis focus on the following aspects:

- How can negative space be identified and analytically described within architectural composition?
- Which spatial and perceptual conditions enable negative space to become a constitutive element of architectural organisation?
- How does the positional configuration of negative space (internal, peripheral, and external) influence its appearance and function?
- To what extent does negative space contribute to the legibility, functionality, and organisational characteristics of an architectural work?

The answers to these questions are based on a qualitative analysis of architectural examples in which negative space is recognised as an active component of composition. The analysis combines morphological, perceptual, and phenomenological approaches, examining:

- morphological characteristics (form, proportion, and boundaries);
- perceptual parameters (light, contrast, and visual clarity);
- contextual relations (relationship to surroundings, openness, and continuity); and
- functional and semantic effects.

Through a comparative analysis of representative examples, the study identifies the circumstances under which negative space transitions from a passive to an active element of architectural organisation.

This research establishes a theoretical framework that contributes to a more precise understanding of the concept of negative space, the conditions of its manifestation, and its potential for application in contemporary architectural analysis and practice.

PREVIOUS RESEARCH

The concept of negative space in architecture has its theoretical foundations in several disciplines, from Gestalt psychology and the visual arts to contemporary architectural theories of space and anti-space, from which its current understanding emerges through the interweaving of perceptual mechanisms of visual cognition, artistic figure–ground principles, and morphological approaches that interpret a void as an active component of architectural composition.

Gestalt principles of figure and ground

One of the fundamental principles of Gestalt psychology concerns the perception of the relationship between figure and ground as a unified whole. According to this theory, the human perceptual system organises visual stimuli by distinguishing figural elements, which attract attention, from background elements, which constitute a neutral field or void perceived as negative space (Lidwell *et al*., 2003).

Wagemans *et al*. (2012) provide a comprehensive overview of the century-long development of Gestalt psychology, with particular emphasis on the figure–ground principle as a primary mechanism of perceptual organisation. They affirm its continued relevance in contemporary research, as it explains how relationships between an object and its surroundings are formed, an essential aspect of understanding negative space in architecture (Wagemans *et al*., 2012).

Dresp-Langley and Reeves (2020) highlight Viktor Vasarely's contribution to understanding figure–ground perception through the use of colour and perceptual contrast. They demonstrate that the visual system interprets chromatic and luminance differences as indicators of spatial hierarchy, confirming that figure–ground perception depends on visual context rather than solely on geometric form. This is particularly pertinent to architecture, where the perception of solid and void is shaped by conditions of light and materiality (Dresp-Langley and Reeves, 2020).

In a subsequent study, Dresp-Langley (2019) quantitatively confirms that bilateral symmetry enhances figure–ground readability regardless of orientation or contrast level. These findings indicate that formal relations within a composition directly influence perceptual differentiation. In architectural terms, they explain why clearly articulated geometric relationships facilitate the identification of negative space as a distinct spatial entity.

Taken together, Gestalt research suggests that the recognisability of negative space in architecture depends on an interplay of geometric, luminous, and perceptual conditions, not merely on volumetric configuration.

Negative space in visual art and photography

Within photography, Suler (2013) defines negative space as any area the brain perceives as surrounding, between, or behind the subject, regardless of its content. He further argues that negative space may act as a perceptual buffer, offering relief from the density of the primary motif. This understanding emphasises the psychological dimension of negative space as an active participant in composing visual meaning, which also applies in architecture, where void acquires spatial and semantic presence.

Chuang *et al*. (2023) employ eye-tracking methods to examine how Gestalt principles influence visual perception and aesthetic experience in photography. They show that images with pronounced Gestalt attributes, such as closure or similarity, affect the viewer's focus and distribution of attention. Their findings confirm that perceptual organisation shapes the experience of negative space. In architecture, this implies that the arrangement of volumes, rhythm of openings, and light contrasts guide the perception of a void and contribute to its legibility.

Lange-Küttner and Vinueza Chavez (2022) study drawing techniques focused on negative space, directing attention to the areas around and between objects rather than to the objects themselves. They conclude that such methods shift perceptual focus and improve understanding of the full–void relationship, supporting interpretations of negative space as an active agent in both art and architecture. This approach demonstrates that negative space becomes perceptible only when sufficiently stable boundaries or visual anchors define it in relation to surrounding forms.

The common conclusion of these studies is that negative space is not a physical void alone but a perceptually constructed category dependent on the organisation of visual relations. Applied to architecture, this implies that negative space is recognised when certain perceptual conditions are satisfied – clarity of boundaries, perceptual contrast, and rhythm.

Architectural interpretations: space and anti-space

The figure–ground principle is equally present in architectural theory. Peterson (1980) argues that architecture consists of two fundamental elements: space, corresponding to figure, and anti-space, corresponding to ground. Anti-space (negative space) is characterised as indeterminate, continuous, and open, while space (positive space) is enclosed, static, and structured. Peterson's contribution lies in recognising a void not as an absence but as an active component enabling formal intelligibility.

Cook (2007) expands this dichotomy, emphasising the interdependence of space and anti-space, and argues that the two elements generate spatial qualities that do not exist when considered independently. This viewpoint introduces the notion that negative space becomes architecturally relevant only when explicitly related to material structure.

Martínez Cuaresma *et al*. (2025) analyse processes of urban regeneration and adaptive reuse, demonstrating that empty urban sites are not passive remnants but potential generators of new functional and social environments, confirming the role of negative space as an active factor within spatial organisation.

Kuloğlu (2013) examines architectural and urban voids, arguing that masses and voids constitute fundamental spatial elements at both scales, and that void can define, guide, and emphasise spatial relations, thus becoming an operative factor in forming architectural and urban structures. Her approach provides a basis for linking negative space to its positional role within architectural structure – internal, peripheral, or external.

Bourque (2015) situates architecture within philosophical notions of the sublime and the negative, drawing on Kant and Adorno to interpret relations between space, aesthetics, and social context, and introduces the notion of negative architecture to describe how absence and void may assume reflective roles in contemporary spatial practice. Although philosophical, this perspective reinforces the understanding of negative space as conceptually relevant when it produces distinct experiential value.

Shivani (2016) emphasises that negative space is a constitutive part of all spatial compositions, enabling balance, functional clarity, and organisational coherence, and argues that negative space should not be interpreted as an unused void but as an active agent shaping relationships between volumes and material elements.

The shared premise of these authors is the understanding of a void as a functional and integral component of spatial organisation. While previous studies examined formal, perceptual, or contextual aspects individually, the present research approaches them as interdependent, examining situations in which geometric relations, lighting conditions, and spatial position collectively act as conditions for recognising negative space. These studies therefore form an integrated theoretical framework that combines perceptual, morphological, and spatial interpretations of void, drawing on a range of complementary architectural and spatial theories, and situating the concept of negative space within a broader disciplinary discourse, thereby providing the conceptual basis for analysing the circumstances under which negative space may be identified as a coherent category within architectural practice. The selection of references is therefore not exhaustive, but focused on those theoretical approaches most directly applicable to the analytical operationalisation of negative space within the scope of this study.

RESEARCH METHODOLOGY

The research methodology is based on a qualitative approach that combines morphological, comparative, and phenomenological analysis of architectural examples in which negative space is recognised as an active component of composition. The aim of this approach is not to quantify the phenomenon, but to understand it conceptually, perceptually, and spatially through different configurations and contextual conditions. Such a method enables examination of the interrelations between geometric properties, perceptual effects, and the organisational role of negative space, which aligns with the stated hypothesis.

The criteria for selecting case studies are based on three fundamental conditions required for the recognisability of negative space:

- a clearly discernible relationship between solid and void within the architectural structure;
- the presence of a void defined by material or geometrically implied boundaries; and
- an interaction between the object and its physical context that allows the void to be perceived as a distinct spatial entity.

On the basis of these criteria, a broader preliminary review of architectural examples from different typological and temporal contexts (residential, public, and sacral buildings, as well as selected urban spaces) was first undertaken in order to identify recurring positional patterns and underlying organisational principles of negative space. The final examples included in the paper were then selected through theoretical sampling as representative cases that most clearly illustrate the three identified positional types: internal, peripheral, and external negative space.

The analytical process comprises three complementary levels of investigation:

- Morphological analysis, examining spatial relations, proportions, boundaries, and geometric characteristics of the void within the architectural composition;
- Perceptual and phenomenological analysis, considering the influence of light, materiality, and perceptual contrast on the legibility of negative space within the architectural whole; and
- Comparative analysis, comparing the examples to identify patterns and conditions under which negative space acquires functional, organisational, or conceptual significance within the architectural configuration.

All three analytical segments apply a unified observation matrix that enables comparison and synthesis of results. On this basis, the classification into internal, peripheral, and external negative space is systematically established through the cross-analysis of spatial position, boundary conditions, and organisational role. The matrix includes: a) type of boundary; b) degree of perceptual legibility; c) position of the void in relation to the volume; d) functional and organisational consequences. Through their systematic cross-referencing, the transition from theoretical criteria to the classification into internal, peripheral, and external negative space is established. This ensures methodological consistency and the possibility of verifiable conclusions.

The aim of the methodological approach is to identify the conditions under which negative space can be recognised as a constitutive element of architectural composition through the analysis of space, its boundaries, and its contextual relations within a broader analytical corpus. The selected case studies serve as representative examples of the identified positional types, providing a theoretical and analytical framework for its understanding and application in contemporary architectural analysis and practice. The method ensures a direct connection between the findings and the hypothesis. Each analysis considers how negative space affects the structural organisation, perceptual clarity, and ambient qualities of the architectural work according to the same set of analytical parameters, thereby enabling the procedure to be followed and replicated at the interpretative level.

Limitations of the methodology: The qualitative approach and theoretical sampling limit the potential for generalisation; and the operationalisation of criteria involves a degree of interpretative assessment inherent to qualitative spatial analysis. Accordingly, the findings should be understood as analytically grounded interpretations that provide a structured basis for further empirical verification through quantitative or experimental methods.

INTERNAL NEGATIVE SPACE

Internal negative space denotes a type of void formed within the volume of an architectural object, whose legibility is enabled by clearly defined material or geometric boundaries. In such cases, negative space does not function as an exterior intermediate zone, but as a central element of interior organisation, influencing the morphology, orientation, and perceptual legibility of the whole. This type of negative space emerges as the result of deliberate architectural articulation and possesses spatial characteristics that allow it to be recognised as an autonomous constructive category within the composition. In this sense, internal negative space is not merely a void within the mass, but a stable element of interior geometry that participates in shaping sequences, visual axes, and relationships among functional units.

In accordance with the methodological criteria, internal negative space in this study is defined as a geometrically stable and clearly bounded void exhibiting continuous boundaries, high perceptual legibility, and a recognisable organisational role within the interior structure of the object. Its identification rests on the degree of autonomy in relation to enclosed volumes and on the role it plays in establishing a spatial hierarchy. Such an approach enables negative space to be examined as an active mechanism of the internal structure, rather than as a formal outcome of subtracting mass.

House in Litoral Alentejano, Aires Mateus, 2000

In the House in Litoral Alentejano, designed by Aires Mateus in 2000, internal negative space is structured as a fragmented courtyard system that organises the interior geometry of the house (Figure 1). The square exterior form produces a clear and homogeneous volume, while its interior accommodates open and semi-open spaces of varying proportions (ArchDaily, 2016). This interior void is not a residual space, but the primary organisational element through which the hierarchy and legibility of spatial sequences are established. The courtyard negative space acts as a regulator of the composition, determining the rhythm of solid and void within the enclosed volume. Clearly defined boundaries, materially articulated on the outside and geometrically articulated on the inside, enable the courtyards to be perceived as a coherent spatial whole. It also affects the microclimatic conditions, daylight availability, and visual connections between rooms, confirming its organisational significance. This example shows that negative space becomes clearly identifiable when the criteria of geometric stability, continuity of boundaries, and organisational function within the composition are met.

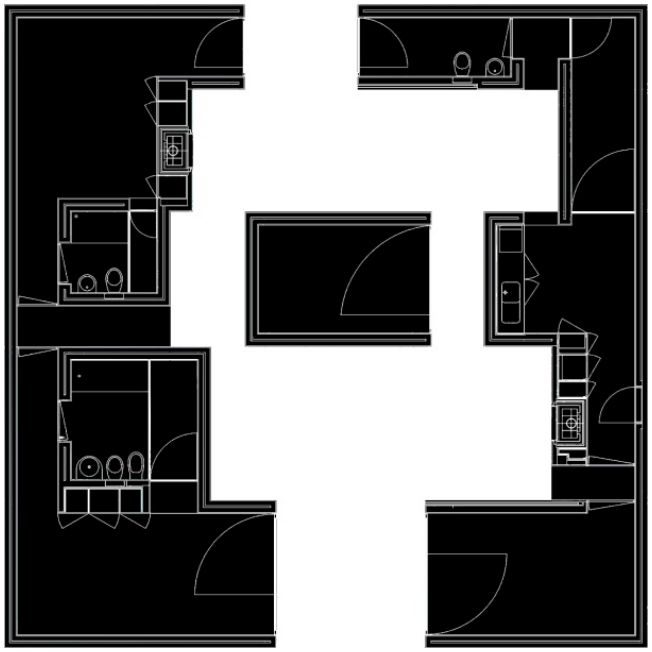

Figure 1. House in Litoral Alentejano, designed by Aires Mateus in 2000 (Source: Author's drawing based on publicly available photographic material, 2026)

Niyang River Visitor Center, Nyingchi, Zhaoyang Architects & Standardarchitecture, 2009

In the Niyang River Visitor Center in Nyingchi, completed in 2009, negative space emerges as an interior carved void within a compact stone volume (Figure 2). The exterior envelope is designed as a massive geometric form drawing on local building traditions, while the interior is organised around a central atrium and recessed openings (ArchDaily, 2014). This internal negative space is formed through a combination of material mass and light cuts, creating clearly perceptible boundaries. Spatial intervals produced by subtracting mass allow negative space to function as an active compositional element. Light contrasts and controlled openings articulate the continuity of the void, reinforcing its perceptual legibility even within a monolithic envelope. Moreover, the interior void acts as an orientational device, enabling intuitive visitor movement through the building and structuring its overall spatial logic. The analysis indicates that negative space becomes architecturally relevant when it is geometrically precise, materially distinct, and functionally integrated into the organisation of interior space.

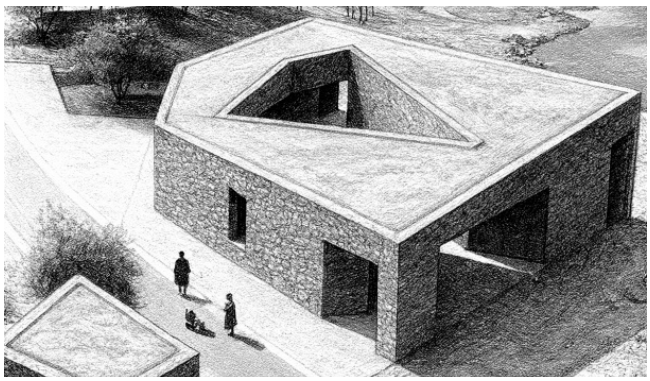

Figure 2. Niyang River Visitor Center, Nyingchi, designed by Zhaoyang Architects & Standardarchitecture in 2009 (Source: Author's drawing based on publicly available photographic material, 2026)

Villa beside a Lake, Go Hasegawa and Associates, 2023

In the project Villa beside a Lake, designed by Go Hasegawa and Associates in 2023, internal negative space takes the form of a central circular atrium that constitutes the core of the house's spatial organisation (Figure 3). Although open to the sky, the atrium is fully defined by its perimeter geometry and therefore belongs to the category of internal negative spaces (Hasegawa, 2025). The circular atrium functions as a geometric and perceptual reference around which residential units and circulation are arranged. Clearly articulated curvilinear boundaries ensure the perceptual legibility of the void in relation to the enclosed masses. The contrast between the open central zone and the fragmented periphery enhances the organisational role of the atrium. The central void also regulates lighting conditions by enabling vertical illumination and visual contact with the exterior, shaping the overall interior character. Hasegawa's approach confirms that negative space becomes methodologically recognisable when it simultaneously fulfils the criteria of geometric definition, boundary consistency, perceptual legibility, and organisational function, regardless of its formal expression.

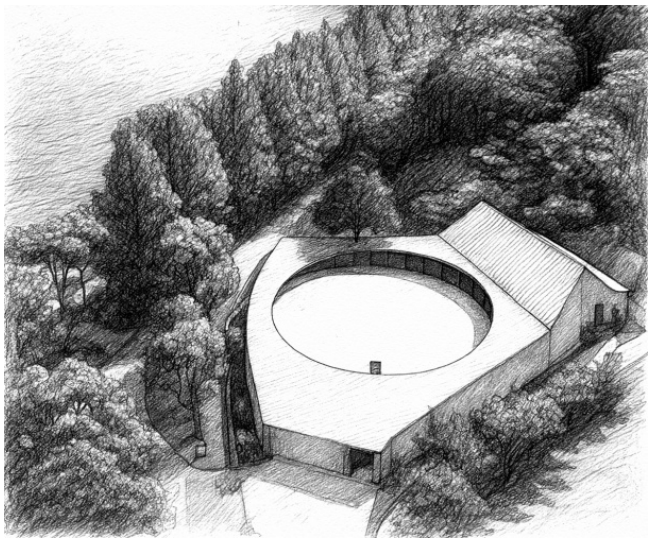

Figure 3. Villa beside a Lake, designed by Go Hasegawa and Associates in 2023 (Source: Author's drawing based on publicly available photographic material, 2026)

Comparative analysis of the examples

All three examples confirm that internal negative space becomes architecturally relevant when the void does not appear as a residual intermediate area, but as a stable and geometrically controlled spatial unit. Regardless of the type (courtyard system, carved mass, central atrium), a shared characteristic is the presence of continuous boundaries and high perceptual legibility. In all cases, negative space acts as a spatial regulator, structuring the relationship between solid and void, directing visual sequences, affecting the distribution of light, and reinforcing the organisational logic of the interior. These examples also confirm the methodological assumption that internal negative space can be identified only when the void possesses geometric stability, perceptual legibility, and an organisational role within the composition.

PERIPHERAL NEGATIVE SPACE

Peripheral negative space denotes a type of void formed at the boundary between an architectural volume and the external environment. Unlike internal negative space, which is fully contained within the mass of the building, peripheral negative space emerges as a spatial cut, recess, or hollowed segment articulating the transition between interior and exterior domains. Such spaces play a key role in defining the building's relationship to its context, as they enable perceptual, luminous, or functional distancing between the structure and its surroundings. At the same time, they can serve as mechanisms for redefining volumetric proportions, since the presence of a void at the perimeter influences how the mass of the building is perceived within its immediate setting.

In theoretical terms, peripheral negative space corresponds to the type of "intermediate space" which, according to Kuloğlu (2013), simultaneously belongs to and is separate from the architectural mass, thereby becoming an active regulator of the relationship between solid and void at the interface of the building and its context. For the purposes of this study, peripheral negative space is defined as a geometrically determined and spatially stable void positioned at the edge of the volume, whose perceptual distinctiveness results from clearly articulated material or geometric boundaries, and whose organisational function transforms the building's relationship to its external environment. Such spaces mediate between different ambient conditions and contribute to the formation of more complex perceptual regimes through the directing of views, the control of light, and the shaping of micro-environmental transitions. In the analysed examples, peripheral negative space does not operate as a decorative device, nor as a technical remainder, but as a primary morphological mechanism structuring the transition between interior and exterior space.

San Carlino Church, Lake Lugano, Mario Botta Architetti, 1999

A paradigmatic example of peripheral negative space is the San Carlino Church at Lake Lugano, completed in 1999, in which the void is conceived as a geometrically precise perimeter incision articulating the contour of a historical archetype (Figure 4). The negative space is positioned at the edge of the volume and functions as a clearly defined spatial unit due to its stable boundaries and strong light contrast (Shuangyu, 2019). The hollow carved into the compact cube possesses continuous boundaries, materially articulated external surfaces, and light-emphasised inner planes, ensuring high perceptual legibility. The contrast between the dark exterior cladding and the illuminated internal surfaces defines the negative space as an autonomous spatial category, confirming that the absence of matter can assume an organisational role in the shaping of volume. This example also shows how peripheral negative space can reinterpret traditional forms: the void redefines the classical silhouette of the church and establishes a new visual relationship with the lakeside landscape. The analysis confirms that this type of negative space is architecturally relevant, as it satisfies the methodological criteria of geometric stability, clear boundaries, and organisational function in relation to the external context.

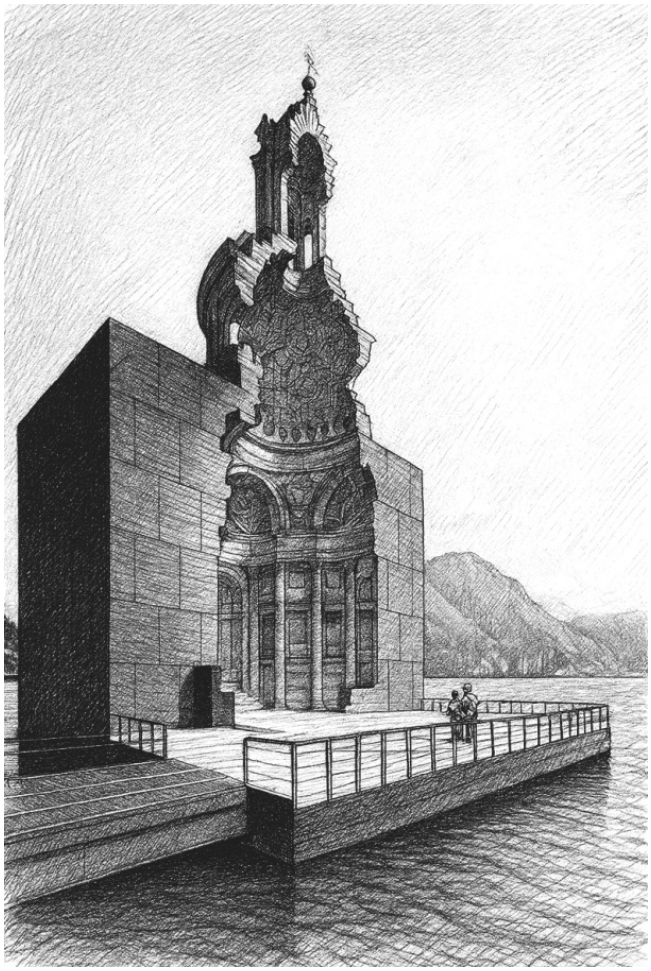

Figure 4. San Carlino Church, Lake Lugano, designed by Mario Botta Architetti in 1999
(Source: Author's drawing based on publicly available photographic material, 2026)

0914 Flagship Store, Gangnam-gu, TRU Architects, 2017

In the 0914 Flagship Store in Seoul, the peripheral negative space is shaped as a carved void within the façade plane of a monolithic volume (Figure 5). The absence of material reveals the internal structure and introduces a strong contrast between the external homogeneous envelope and the interior finished in red brick (Abdel, 2020). The recessed geometry functions as a clearly defined spatial unit with stable edges and a high degree of perceptual legibility, confirming its classification as peripheral negative space according to the methodological criteria. This void acts as an organisational element, establishing a visual and functional link between the street and the interior, rather than serving as a decorative gesture. It also introduces ambient depth into the façade, integrating the building into the rhythm of the street frontage and enabling a gradual unveiling of the interior. The example confirms that peripheral negative space can be unequivocally identified even in dense urban conditions, provided its geometry, material contrast, and continuity of edges ensure stable perceptual legibility.

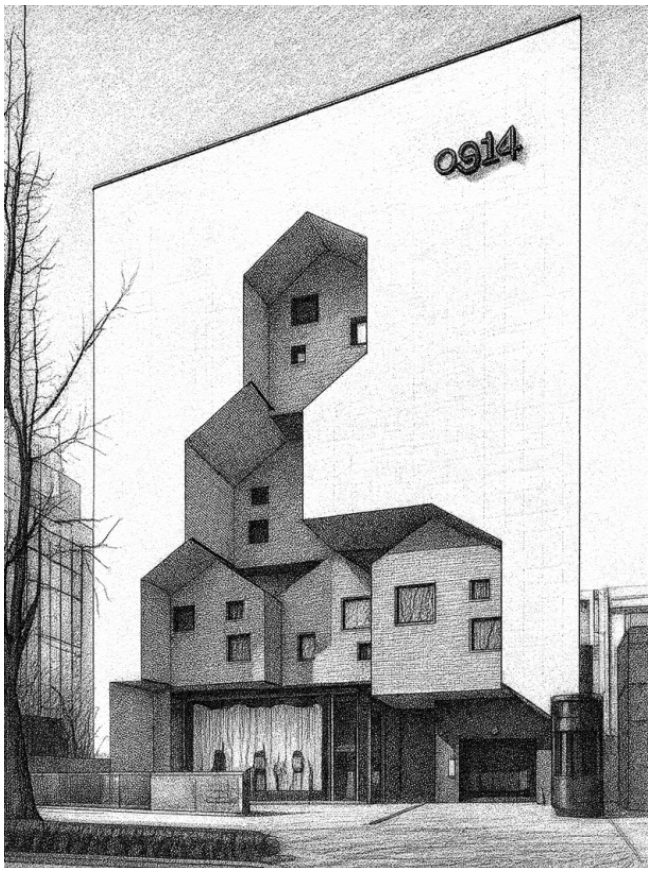

Figure 5. 0914 Flagship Store, Gangnam-gu, designed by TRU Architects in 2017
(Source: Author's drawing based on publicly available photographic material, 2026)

Faculty of Architecture, Tournai, Aires Mateus, 2017

In the project for the Faculty of Architecture in Tournai, the peripheral negative space is formed as a geometrically pure and precisely positioned spatial cut within a monolithic volume (Figure 6). This cut operates as a threshold mediating between external and internal domains, exceeding the function of a conventional opening (Vada, 2021). The void possesses clear geometric definition, boundary continuity, and high perceptual legibility, enabling its unambiguous recognition as peripheral negative space. Due to its boundary position, it assumes an organisational role in determining how the building is entered, traversed, and perceived. It also guides movement across the campus and frames views, confirming that peripheral negative space can generate effects beyond the immediate volume of the building. The example validates the methodological criteria: stable boundaries, geometric precision, and organisational function in structuring the transition between two spatial domains.

Whitney Museum of American Art, New York, Marcel Breuer, 1966

The Whitney Museum of American Art represents an early example in which peripheral negative space appears as an active layer mediating between architecture and the city (Figure 7). The negative space arises from the recession of the façade relative to the street line, producing a clearly defined and spatially stable intermediate zone (Sveiven, 2011). This interstitial layer has precisely defined boundaries: the

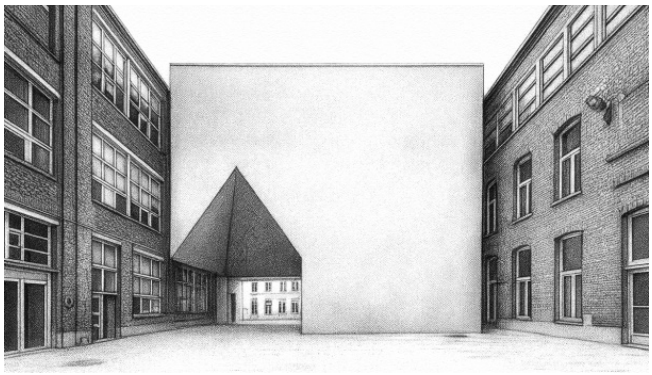

Figure 6. Faculty of Architecture, Tournai, designed by Aires Mateus in 2017
(Source: Author's drawing based on publicly available photographic material, 2026)

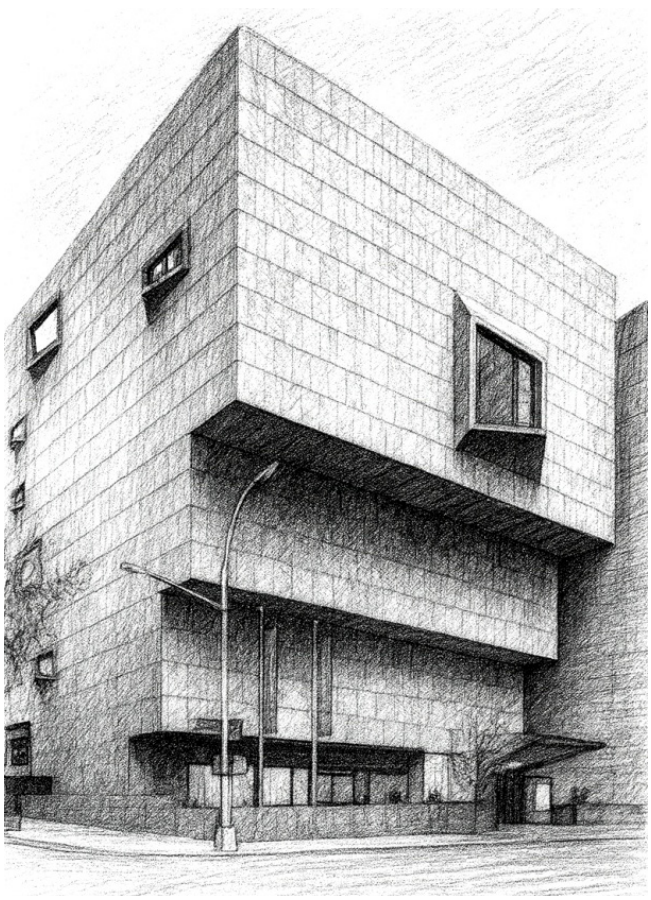

Figure 7. Whitney Museum of American Art, New York, designed by Marcel Breuer in 1966
(Source: Author's drawing based on publicly available photographic material, 2026)

massive stone volume on one side and the street space on the other. Perceptual legibility is achieved through controlled lighting, shadows, and material contrasts, enabling its identification as peripheral negative space. Breuer's strategy confirms that such a space may assume an organisational function in defining the building's relationship to the urban environment, as it introduces an ambient transition between public space and the architecturally controlled domain. The recessed façade also extends pedestrian flow and enables temporary gathering, giving the space the character of a micro-public environment.

Comparative analysis of the examples

The analysed examples demonstrate that peripheral negative space becomes architecturally relevant when the void is formed as a geometrically stable, clearly bounded, and perceptually distinct unit at the edge of the volume, rather than as a residual spatial remnant. Despite formal differences, ranging from a carved volume designed by TRU Architects, through a memory-inflected void by Botta, to a geometrically defined threshold by Aires Mateus, and an urban interstitial layer by Breuer, shared characteristics include boundary continuity, geometric control, high perceptual legibility, and the structuring of transitions between interior and exterior domains. These examples further demonstrate that peripheral negative space can enrich the relationship between the building and its context, as the perimeter void becomes a spatial mediator shaping visual axes, patterns of movement, ambient depth, and the perception of mass. The examples confirm the methodological premise that peripheral negative space becomes a constitutive element of composition only when criteria of geometric definition, perceptual distinctiveness, and organisational function are fulfilled.

EXTERNAL NEGATIVE SPACE

External negative space denotes a type of void formed outside the architectural volume but in immediate relation to it, thereby becoming an active component in articulating the relationship between a building and its wider context. Unlike peripheral negative space, which appears at the boundary of a volume, external negative space operates on an urban, landscape, or ambient level, shaping visual axes, spatial flows, and perceptual regimes in the surroundings of an object. In theoretical terms, these spaces function as "urban voids" (Kuloğlu, 2013), capable of structuring the landscape and enabling the legibility of broader spatial sequences. Peterson's distinction between space and anti-space is particularly relevant here, since external negative spaces may be understood as anti-spatial frameworks: voids that do not belong to an individual building but become part of the city's broader spatial logic.

For the purposes of this study, external negative space is defined as a geometrically determined, spatially stable, and perceptually distinct void formed in the immediate environment of an architectural object, influencing the organisation of visual, ambient, and functional relationships. Such spaces may assume a regulatory role within a broader spatial-ambient system, as they affect movement patterns, ways of perceiving urban space, and the formation of public flows. They are not residual or accidentally generated gaps, but deliberately articulated spatial units with an active role in structuring urban and landscape settings. Additionally, external negative space may operate as an initiating element of an urban scenario, determining the relations between architecture, open space, and the broader urban structure.

Grande Arche de la Défense, Paris, Johann Otto von Spreckelsen, 1989

The concept of negative space as an organisational element of the surroundings is clearly expressed in the Grande Arche de la Défense in Paris, completed in 1989, where the monumental frame functions as a materialised void within the urban landscape (Figure 8). In this example, the negative space becomes part of the primary urban axis, with the void assuming an active role in structuring the city (Edwards, 2011). Spreckelsen shapes a monumental frame whose meaning relies on the absence of mass and on geometrically controlled boundaries rather than on an enclosed interior. The 112 m high void establishes the continuity of the historic axis from the Louvre, along the Champs-Élysées, to La Défense. The boundaries of the negative space are clearly defined by the regular geometry of the frame and light contrasts, ensuring high perceptual legibility. In this case, external negative space becomes a structural element of urban composition, enabling the perception of the city through a precisely framed visual corridor. The example confirms that external negative space may act as a carrier of urban continuity and as a mechanism linking distant parts of the city into a single spatial sequence.

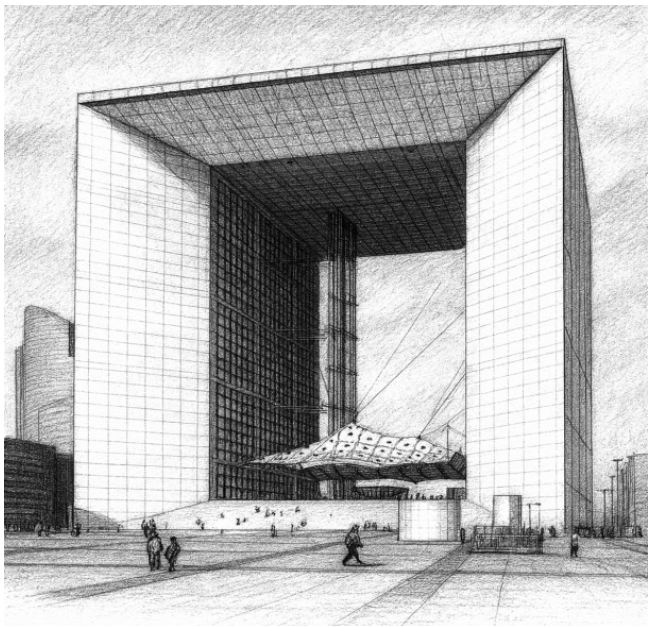

Figure 8. Grande Arche de la Défense, Paris, designed by Johann Otto von Spreckelsen in 1989
(Source: Author's drawing based on publicly available photographic material, 2026)

House N, Oita, Sou Fujimoto Architects, 2008

The layered character of external negative space is evident in the House N project in Oita, completed in 2008, where the basic volume of the house is enveloped by an outer shell forming a clearly defined intermediary space between the architecture and its context (Figure 9). In this project, external negative space is created between three successive layers of spatial organisation, with the intermediary zone functioning as the primary living environment rather than as a secondary area (ArchDaily, 2011). The geometry of the external negative space is defined by wall perforations, varying heights, and roof openings, establishing a stable perceptual sequence. The external negative space produces a gradual transition between public and private, introducing controlled transformations of light, views, and movement. This example demonstrates that external negative space may also be integrated into an intimate residential context, where it assumes the role of mediator between the private

home and the external environment. It further shows that, beyond urban applications, external negative space can operate as a micro-ambient regulator, generating a specific spatial identity even at a small scale.

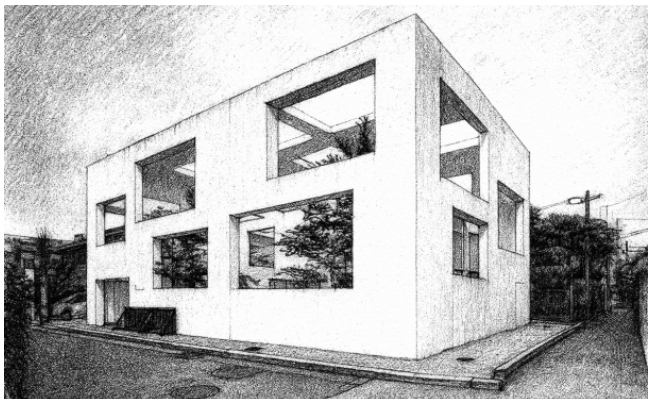

Figure 9. House N, Oita, designed by Sou Fujimoto Architects in 2008 (Source: Author's drawing based on publicly available photographic material, 2026)

MÉCA Cultural Centre, Bordeaux, BIG + Freaks, 2019

In the MÉCA Cultural Centre in Bordeaux, external negative space is defined as a monumental carved void within a compact volume, becoming a key element in organising the relationship between the building and the city (Figure 10). This spatial incision forms a large public plateau and ramp that act as a transition between the city's riverfront and the cultural district (Walsh, 2019). The boundaries of the negative space are delineated by sharply cut surfaces that provide geometric precision and perceptual stability. Unlike the Grande Arche, where the negative space primarily performs a visual function, in MÉCA it acquires the role of an active public space. Visitors experience the building through movement along the ramp and staircases, with the negative space assuming an organisational function in structuring public life. The example demonstrates that external negative space can operate as a public environment that physically, visually, and socially connects different parts of the city. At the same time, the carved void alters the perception of mass, making the building spatially permeable and open to its surroundings.

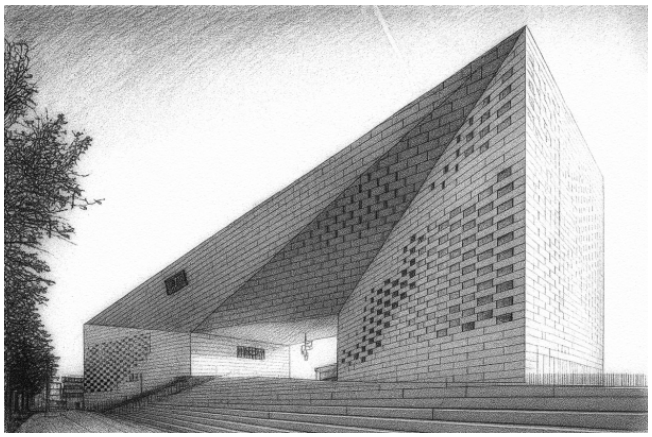

Figure 10. MÉCA Cultural Centre, Bordeaux, designed by BIG + Freaks in 2019
(Source: Author's drawing based on publicly available photographic material, 2026)

Comparative analysis of the examples

The analysis of *Grande Arche de la Défense*, *House N*, and *MÉCA* shows that external negative space becomes architecturally relevant when it meets the following criteria: clear geometric definition, boundary continuity despite the open context, perceptual stability, and organisational function. In the first example, external negative space operates as the supporting element of an urban axis; in the second, as a layered micro-context of residential architecture; and in the third, as an activated public space integrated into the wider urban system. Despite differences in scale and purpose, the shared characteristic is that negative space becomes a mechanism of spatial organisation, structuring visual flows, ambient transitions, and patterns of movement.

The analysis of internal, peripheral, and external negative space demonstrates that these types differ according to their position in relation to the building volume, the type of geometric articulation, and their organisational function within architectural composition. Internal negative space operates as a stable and geometrically controlled void within the mass, establishing internal hierarchy. Peripheral negative space appears at the boundary of the volume and functions as an intermediary zone transforming the relationship between the object and its immediate context. External negative space is formed in urban or landscape settings and influences the organisation of visual flows and public environments. In all three cases, the identification of negative space is based on the criteria of geometric definition, stable boundaries, perceptual legibility, and organisational function. This typology provides the basis for further discussion on the theoretical implications and operational possibilities of the concept of negative space in contemporary architectural practice.

DISCUSSION

The analytical part of the study demonstrates that negative space may be defined more precisely when its geometric, perceptual, and organisational dimensions are interpreted as interdependent parameters. Together, these parameters determine how negative space is identified, understood, and evaluated within architectural composition. The differentiated typology (internal, peripheral, and external negative space) makes it possible to observe voids as a complex category. Their characteristics change depending on their position in relation to the building volume, while relying on the same fundamental methodological criteria. In this sense, the findings align with broader theoretical debates that associate negative space with aesthetic and philosophical concepts of absence and the sublime (Bourque, 2015).

A comparison of the examples within the three typological groups confirms that the function of negative space depends on its position. Internal negative space operates within a closed material mass and affects the hierarchy and legibility of interior sequences. Peripheral negative space shapes the transition between the architectural volume and its immediate context, influencing perceptual regimes of viewing the object. External negative space operates on a broader urban or landscape scale, shaping visual axes,

spatial sequences, and public flows. This range of operations shows that negatively defined spatial units possess the capacity to act across different spatial levels, consistent with research attributing a role in structuring landscapes and public environments to urban voids (Kuloğlu, 2013; Martínez Cuaresma *et al*., 2025).

The findings also nuance existing theoretical models. Peterson (1980) primarily interprets negative space as a counterpoint to material mass, whereas Kuloğlu (2013) highlights its ambivalent relationship to the volume, a perspective further discussed by Cook (2007). The results of this study indicate the need for a more systematic differentiation of types of voids, based on the criteria of geometric stability, boundary continuity, and perceptual distinctiveness. These three criteria provide a consistent analytical basis for classifying different manifestations of negative space, thereby reducing terminological and interpretative ambiguity in the literature. In this context, conclusions drawn from Gestalt theory are particularly relevant, confirming that perceptual grouping, contrast, and clearly defined contours directly influence figure–ground separation and, consequently, the legibility of the void (Wagemans *et al*., 2012; Dresp-Langley, 2019; Dresp-Langley and Reeves, 2020).

The analysis further suggests that negative space contributes concretely and operationally to the legibility of architectural composition. In internal configurations, it acts as a regulator of spatial hierarchy; in peripheral settings, as an instrument for articulating boundaries and establishing relationships between mass and void; and in external environments, as a mechanism structuring urban sequences and public flows. These considerations confirm that negative space is not a static category but a variable instrument of perceptual and spatial organisation within architecture.

It is particularly significant that the observed patterns correspond with empirical research on perception, including studies of bilateral symmetry, light contrast, and visual guidance (Dresp-Langley, 2019; Chuang *et al*., 2023). Additionally, research on spatial representation in drawing and photography indicates that modes of visual depiction influence the identification of negative intervals (Lange-Küttner and Vinueza Chavez, 2022; Suler, 2013). Such findings confirm that perceptual criteria have a legitimate role in the architectural analysis of negative space.

The limitations of the study relate to its qualitative approach and selective corpus of examples, which restrict the capacity for generalisation. Furthermore, the perceptual characteristics of negative space have not been empirically tested through user experience, representing an avenue for methodological improvement. Nonetheless, the observed coherence between theoretical, morphological, and perceptual parameters confirms the relevance of the analysed concept and opens possibilities for its further development.

Overall, the discussion confirms that negative space is an analytically productive and theoretically significant category. Its understanding can be systematically advanced by integrating geometric, perceptual, and organisational criteria. In doing so, it establishes a foundation for the more consistent application of the concept in architectural theory and design practice.

CONCLUSIONS

The aim of this research was to clarify the concept of negative space in architecture and examine its analytical and theoretical value. This was achieved by differentiating three typological forms: internal, peripheral, and external negative space. The analysis of the selected architectural examples supports the initial hypothesis, indicating that negative space can be identified and interpreted through the interaction of geometric, perceptual, and organisational criteria. Given the qualitative and illustrative character of the analysed sample, the conclusions should be understood as typological and interpretative rather than statistically generalisable. The results further indicate that this interaction enables an analytical understanding of negative space as a stable and functionally relevant spatial entity.

Synthesis of the findings demonstrates clear distinctions between the three types of negative space. Internal negative space operates within the volume and influences the hierarchy of interior sequences. Peripheral negative space forms at the junction of the object and its context, participating in the visual articulation of boundaries and the perception of the volume. External negative space functions within a wider urban or landscape environment, influencing the organisation of visual directions, public flows, and spatial-ambient sequences. The identification of these differences indicates that negative space can be understood not as a single phenomenon, but as a set of spatially defined entities whose functions change depending on their position within a composition.

The contribution of this research lies in establishing a theoretical and analytical framework that enables a more precise definition and classification of negative space in architecture. The criteria of geometric stability, boundary continuity, and perceptual distinctiveness have proven to be a reliable basis for analysis. A differentiated approach to negative space reduces terminological ambiguity in existing literature and enables a more consistent interpretation of voids as constitutive elements of architectural composition. The findings also indicate that negative space has operational potential as a design tool, influencing the legibility, organisation, and contextual integration of architectural units.

The limitations of the study relate to the qualitative nature of the sample and the absence of empirical data on user perception. Future research should incorporate experimental methods of examining visual attention, comparative studies of perception, and quantitative analyses of typological variants of negative space. Further development of the concept may also be directed towards the analysis of specific programme typologies, the regeneration of urban voids, and the application of digital tools for spatial evaluation.

Overall, the research confirms the significance of negative space as an analytical and design category and demonstrates that its systematic understanding can contribute to a more precise interpretation of architectural composition and its relationship to context.

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ORCID

Đorđe Alfirević https://orcid.org/0000-0002-5384-0922

Sanja Simonović Alfirević https://orcid.org/0000-0003-1243-8459

Ana Vignjević https://orcid.org/0009-0005-0329-2330

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