Exploring Regionalazation and Centralization in İzmir: A Dual-Phase Analysis of Urban Morphology Using Sub-Fractal and Space Syntax Methods

Sıla Özdemir
Ministry of Environment, Urbanization and Climate Change,
Protection of Natural Assets
sila1299@gmail.com

Mustafa Raşit ŞAHİN
Ankara Altındağ Municipality, Financial Services
mustafarasit@gmail.com

Emine Yetişkul Şenbil
City and Regional Planning
Faculty of Architecture
Middle East Technical University
emineyetiskul@gmail.com

Abstract
This study explores İzmir's spatial evolution from the 1950s to the present through an integrated dual-phase methodology combining sub-fractal and space syntax analyses. Grounded in complexity science, the city is conceptualized as a self-organizing system influenced by nonlinear urban dynamics. The exogenous phase applies sub-fractal analysis to assess macro-scale morphological changes across four time periods, identifying a progression from fragmented rural complexity to consolidated urban form, especially along a north–south axis. The endogenous phase analyzes changes in centrality through space syntax, revealing a decrease in spatial embeddedness until the 1990s, followed by renewed centralization. This multi-scalar approach contributes to planning strategies for managing regional complexity and urban growth.

Keywords: Urban Morphology, Regionalization, Centralization, Sub-Fractal Analysis, Space Syntax

1. Introduction

The transformation of urban systems in the 21st century is increasingly characterized by the recognition of cities as self-organizing, open systems shaped by dynamic, nonlinear, and adaptive processes. The complexity of an urban region emerges from micro-level changes that generate macro-level transformations. In other words, regional complexity arises intrinsically. Within this framework, fractal and syntactic methods have increasingly been used to explore the hierarchical and self-similar characteristics of urban form, aligning with the core tenets of complexity theory in urban studies.

This study adopts such a complexity-informed perspective to examine the evolution of regionalization and centralization tendencies in İzmir from the 1950s to the present. A dual-phase methodological approach is employed, integrating both exogenous and endogenous analyses by combining sub-fractal and space syntax methods at the regional scale. This integrated approach addresses the methodology of complexity studies by bridging analyses of macro-regional patterns and local spatial centrality.

The exogenous analysis focuses on İzmir's 30 districts, each exhibiting distinct development patterns shaped by tourism, industry, agriculture, services, and logistics. This phase investigates regionalization dynamics through macro-scale morphological changes, using district boundaries as analytical frames and applying sub-fractal analysis to road networks and administrative divisions. By disaggregating the urban system into smaller spatial units, sub-fractal analysis reveals variations in spatial complexity that diverge from the system's overall fractal dimension, highlighting the heterogeneous and often non-self-similar nature of urban growth. Four temporal intervals are considered: 1950s–1960s, 1970s–1980s, 1990s–2000s, and post-2010.

The endogenous phase explores centralization tendencies through space syntax analysis, focusing on the configurational properties of the urban road network. Drawing on patchwork theory, the study evaluates inter-segment relationships across radii ranging from 500 meters to 50,000 meters, capturing scales of both pedestrian mobility and vehicular commuting. Correlations between syntactic measures at different radii were used to determine the most representative scales of local complexity, which then informed the box sizes for sub-fractal analysis. The results indicate a contraction in centralization radii until the 1990s–2000s, followed by a subsequent expansion, reflecting a more dispersed urban structure and shifts in spatial centrality.

By combining these two analytical perspectives, the study demonstrates main findings of how regionalization and centralization processes interact over time to shape İzmir's urban morphology. The exogenous component reveals system-wide patterns of spatial integration, while the endogenous analysis captures internal structural dynamics. This multi-scalar approach contributes to a deeper understanding of urban and regional complexity and offers a foundation for more adaptive and responsive planning strategies in the face of spatial transformation.

2. Fractal and Syntactic Approaches to Urban Complexity

The term "fractal" was introduced by Mandelbrot in 1967 to describe shapes characterized by intrinsic asymmetry, scale invariance, and self-similarity. Fractal geometry serves as a spatial representation of chaos theory, reflecting interactions between chaotic and orderly elements across multiple scales in complex systems. Baranger (2000) emphasizes that fractals maintain their complexity at every scale, resisting simplification upon closer examination. Richardson's (1961), work on measuring the length of coastlines and national boundaries prompted Mandelbrot to expand the concept through his paper "How Long Is the Coast of Britain?" (1967). Fractals typically have a Euclidean parameter between 1 and 2—shorter than a plane but longer than a straight line. As with other natural fractals, such as mountain ranges, these features may have fractal dimensions ranging between 2 and 3, indicating greater complexity than a surface but less than a volume.

Unlike the classical Euclidean framework, which uses whole-number dimensions—0 (point), 1 (line), 2 (plane), and 3 (cube)—fractal analysis introduces fractional dimensions (Fd). Figure 1 illustrates how geometric complexity evolves with increasing dimensionality: from isolated points (0D), to a branching fractal (~1.2D), to nested cubes (~2.3D). This progression highlights how higher dimensions contribute to greater structural complexity in fractal and spatial systems.

Since the publication of Batty & Longley's seminal work Fractal Cities in 1994, numerous studies have adopted the complex systems approach to analyse urban morphology. These studies aim to calculate the fractal dimensions of cities and urban fragments, producing a range of insights into the structural complexity of urban form. One core theoretical contribution is the observed alignment between fractal dimensions, power-law distributions, and central place theory (Batty & Longley, 1994; Frankhauser, 1998; Lu & Tang, 2004; Chen, 2008; Myint & Liam, 2005; Thomas & Frankhauser, 2013).

Fractal dimensions of urban components can be measured using a mesh that identifies the minimum number of non-overlapping boxes (Ns) needed for a given box size (S). The optimal mesh size is achieved by adjusting the coverage-to-resolution ratio. As emphasized by complexity theory, urban systems are dynamic, involving scaling behaviors, power laws, and spatial centrality. Therefore, appropriate grid sizes may vary depending on centrality. To better understand the spatial complexity—or "metabolism"—of parts within an urban region, the most suitable mesh size can be identified through space syntax methods that assess spatial centrality in large urban systems. While fractal analysis emphasizes morphological characteristics, space syntax complements this perspective by focusing on the relational configuration of space. Space syntax analysis is a morphological method developed to identify spatial characteristics of urban environments using axial maps and convex spaces. This set of theories and techniques, collectively referred to as space syntax provides tools to analyze spatial configurations(Hillier & Hanson, 1984; Volchenkov & Blanchard, 2008). Although space syntax is often applied to urban neighborhoods, several studies have extended its use to larger urban or regional contexts to investigate spatial hierarchy and boundary definition. On a regional scale, space syntax has been employed to understand spatial hierarchies, with centrality commonly represented by accessibility measures (Serra, 2013; Yamu et al., 2017; Yamu & van Nes, 2020).

As urban systems involve scaling, power law behaviour, and centrality, grid sizes used in fractal analyses must be adapted accordingly. The appropriate grid size—whether for measuring fractal dimension or evaluating connectivity—can be determined using space syntax by examining centrality across various spatial scales. Given these shared conceptual foundations, fractal analysis and space syntax have been jointly applied in several studies. Axial line maps, central to space syntax, exhibit fractal characteristics because urban street networks typically include a small number of long lines and a large number of short lines (Vaughan, 2007; van Nes & Yamu, 2018), noting that this results in a statistically nonlinear, long-tailed curve akin to power laws. This property aligns with fractal logic, where self-similarity across scales is expressed through hierarchical spatial organization (Yamu, 2014). Urban structures are therefore self-similar and partially scale-free. In line with this, studies have found that the distribution of integration values, choice values, and open space configurations in cities such as Rothenburg, Bielefeld, Amsterdam, Venice, and Manhattan conform to power-law behaviour (Volchenkov et al., 2008). Hillier et al. (2010) and Molinero & Thurner (2021) further argues that when power laws are observed, the scaling dimension remains relatively stable across all node pairs, consistent with fractal dimensionality. Since transportation networks themselves are fractal in nature, axial maps inherently reflect these properties (Hillier et al., 2010).

Although both fractal analysis and space syntax offer valuable tools for investigating urban complexity—particularly through the analysis of transportation networks—studies that integrate the two remain relatively limited.

Kaya & Bölen (2017) examined the morphogenetic structure of Istanbul using both approaches, likening settlement patterns to the DNA of living organisms. They classified spatial parameters into four categories: (i) geometrical, (ii) topological, (iii) visibility-perception, and (iv) complexity. The second and third categories were based on syntactic values, while fractal dimension analysis was incorporated as a complementary measure of complexity. Similarly, Yamu and van Nes (2017, 2020) and Frankhauser et al. (2018) proposed integrated models that combine space syntax and fractal analysis. These models, applied to metropolitan regions in Southern France, Vienna, and Bratislava, use space syntax to support the identification of multifractal strategic development patterns.

3. Methodology

Fractal analysis studies conducted at the scale of the entire city or region can focus on the macroform, road network, and built environment. In this study, the fractal dimensions of the road network were examined, taking into account both the preservation of comparability of historical data sources and the blurriness between the distinction of urban and rural areas. Urban road networks are commonly recognized as fractal systems and are considered effective for assessing complexity (Batty & Longley, 1994; Shen, 1997; Chen & Luo, 1998; Shen, 2002; Lu & Tang, 2004; Avineri, 2010; Thomas et al., 2011; Thomas & Frankhauser, 2013; Wang et al., 2016; Sreelekha et al., 2015; Lu et al., 2016; Lan et al., 2019; Wen et al., 2023; Yang & Fu, 2023; Abid, 2024).

Road network data for İzmir were obtained from 1:25,000-scale maps produced by the General Directorate of Mapping of the Republic of Turkey. These maps cover four historical periods—1958–1964, 1974–1980, 1996–2000, and 2012–2020—and include comprehensive depictions of roads, terrain, and infrastructure. A total of 123 sheets were digitized and georeferenced using NetCAD software to support comparative analysis across periods.

Fractal analysis was conducted using the box-counting method, which determines spatial complexity by counting the number of non-overlapping boxes of a given size required to cover the road network. The relationship is expressed as:

$K = A.\ \varepsilon^{-Df}$

Where "K" denotes the number of boxes, "ε" represents the grid size, "A" is a constant coefficient, and "Df" is the fractal dimension.

A consistent legend across all periods ensures uniform representation of road thickness, which is essential for understanding infrastructure hierarchy and changes. The analysis also integrates satellite imagery and open-source road maps to align historical data with current urban configurations. The road maps were analysed using Fractalysis software with non-linear estimation ($R^2 > 0.999$).

For endogenous analyses, space syntax tools are integrated with fractal analysis to evaluate centrality. As an important aspect of complex relational networks, centrality is one of the key elements sought by the analysis. The growth of settlements involves a reorganization of spatial systems, including the hierarchy of centres and sub-centres—referred to as 'centrality' and 'periphery.' Space syntax measures two primary relationships: (1) the to-movement potential of each street segment with respect to all others, and (2) the through-movement potential of each street segment with respect to all pairs of others. The integration measure indicates how well a street is connected to other lines, based on the shortest path from one node or line to the others. As a result, shorter paths correspond to higher integration values. The other measure, also based on shortest distance, is the "choice" measure, which evaluates the extent to which a given street lies along the shortest path between pairs of streets. In other words, choice shows how frequently a street would be used if pedestrians always selected the shortest path. The two primary centrality measures used in this study are choice and integration, along with total node count. Integration represents "to-centrality," while choice represents "in-between centrality" (Van Nes & Yamu, 2018).

Three main distance-based measures for system analysis can be defined as:

- **Metric:** Measures the network as a system of shortest paths
- **Topologic:** Measures the network as a system of fewest-turn paths
- **Geometric:** Measures the network as a system of least angle-change paths

Serra (2017) analyzed the road network of inside of Oporto's municipal metropolitan borders from local scale (400 meters) to the regional scale (30.000 meters) by closeness centrality analysis which is a measure of the average distance of each node to the entire network. The main outcomes of this study can be summarized as; at local scales like 400 meters, small centers can be visualized including small ancient towns, inner cores of larger settlements and emergent centers. By increasing the spatial scale, small centers disappear while the metropolitan core began to appear. This observation is reported to be maximized at 3800 meters while centrality disappears at larger scale while a very large central zone dominates the entire metropolitan region (from 14700 to 30000 radii). With respect to correlations depending on principal component analysis, three centrality scales are determined as; neighbourhood (400-1200 meters), city (1200 to 8200) and region (8200 to 30000).

A wider study is conducted for the complete road network of United Kingdom that the results of the study are compared by spatial socio-economic variables and movement flows by correlation analysis (Serra, et al., 2015). Three graphs for centrality algorithms are used by metric radius as; node count, angular integration and angular choice. The metric radiuses attained from 10 kilometres to 50 kilometres. For vehicular movement it is found that all measures are capable of measuring centrality in terms of movement flow for medium radii (from 10.000 meters to 20000 meters as the best fit).

The other study based on the differentiated radii effect is the study of Hillier et al. (2010). It is aimed to explore the nature of boundaries including internal structure of urban space and how this relates to external structure by exploring properties of the context rather than simply focusing on internal morphology. The suggested representation is called as fuzzy boundaries. Each axial line or segment in the whole map is taken as the root of the graph then by increasing radius, the rate of change of the numbers and axial lines are calculated. The rate of change value is assigned to original axial line and neighbouring trends can be observed for the central areas of London and Beijing. The other sole explanation of the study of Hillier et al. (2010) is to find which syntatic variable can be used to illustrate the process of embeddedness of urban space. One of the sole approaches identifying the radius in a larger urban system is "patchwork theory". It is based on spatial differentiation of the background urban network into a patchwork of local areas. The patchwork structure represents metric and local effects. The effect of radius on centrality is explained as;

"μ(v,r), of node v for radius r as local metric mean depth as;

$$\mu(v,r) = \frac{1}{N(v,r)} \int_0^r x \frac{\partial N(v,x)}{\partial x} dx$$

where $x = x(v, u)$ is metric depth of node from the reference node v and $N(v, r)$ is the number of nodes with $x(v, u) \leq r$ and

$$N(v,r) = \int_0^r \frac{N(v,x)}{\partial x} dx$$

$$\Theta(v,x) = \frac{\partial \log N(v,x)}{\partial \log x} = \frac{x}{N(v,x)} \cdot \frac{\partial N(v,x)}{\partial x}$$

Where the rate of change of node count Θ(v,x) of metric mean depth so;

$$\frac{\partial N(v,x)}{\partial x} = \frac{N(v,x)\Theta(v,x)}{x}$$

By substuting (22) into (20);

$$\mu(v,r)\, N(v,r) = \int_0^r N(v,x)\, \Theta(v,x)\, dx$$

where μ(v,r) N(v,r) is total metric mean depth; differentiating both sides of equation (5) with respect to r;

$$\frac{\partial \mu(v,r)}{\partial r} N(v,r) + \mu(v,r) \frac{\partial \mu(v,r)}{\partial r} = N(v,r)\, \Theta(v,r)$$

$$\frac{\partial \mu(v,r)}{\partial r} N(v,r) + \mu(v,r) \frac{N(v,r)\Theta(v,r)}{r} = N(v,r)\, \Theta(v,r)$$

$$\frac{\partial \mu(v,r)}{\partial r} + \frac{\Theta(v,r)}{r} \mu(v,r) = \Theta(v,r)$$

Since metric mean depth and radius have the same linear dimension, the first derivative term in equation (26) must be independent of r as; ∂μ(v,r) / ∂r < 1. Sı equation (26) can be expressed as;

$$\mu(v,r) = r\left(1 - \frac{c(v)}{\theta(v,r)}\right)"$$

By those equations it is expected that there is a positive correlation between node count change and metric mean depth. If radius increases, Hillier et al. (2010) explains three possible routes of development can be observed as;

(i) μ(v,r)can increase while decreases,
(ii) μ(v,r)can increase while remains stationary,
(iii) μ(v,r)can increase while increases

It is noted that these different development routes induce an inversion of centrality, whereby more central nodes at smaller radii tend to become decentralized at larger radii. This relationship depends on the scaling between the radius and its node count (Hillier et al., 2010)**.** Another key explanation in the study was to identify which syntactic variable can be used to illustrate the process of embeddedness of urban space. As Hillier et al. (2010) state, Yang's measure of node count change—(NCr+r/2) / (NCr-r/2)—produces a result very similar to MMDr (Metric Mean Depth at the given radius), meaning that one measure explains the other. In addition, Dalton (2005) explains that for restricted radii, simple segment count is the strongest component of the integration measure, whereas the local urban correlations between total depth and integration break down for larger radii.

The centrality measures of this study are determined as choice, integration, and total nodes, based on a region-focused literature survey in the field of space syntax. The validity of the mapped representations is evaluated with respect to real-world data observed from the 1:25,000 scale maps, as well as from the narrated regional history. The reliability of the centrality measures for restricted radii is examined through principal component and correlation analysis (Serra & Pinho, 2013; Serra et al., 2015).

Three centrality measures are defined: integration, choice, and total nodes, including their segment length–weighted versions. For each of the four periods, different radii from 250 meters to 50,000 meters are analysed—including 250 m, 500 m, 1,000 m, 2,000 m, 5,000 m, 10,000 m, 20,000 m, and 50,000 m—to identify patterns ranging from the neighbourhood pedestrian scale to the entire regional system. The 50,000-meter radius is determined based on the system size, where the widest elliptical approximation of the network is around 100 kilometres, and the narrowest is 25 kilometres. To identify the global system, an analysis with radius "n" is also calculated.

The axial model corresponds to a total network length of 7,469, 11,206, 25,660, and 32,671 kilometres for each of the four periods, respectively. First, the axial maps are produced via the digitized road network for each period. Then, these maps are converted into segment maps. As identified by Serra & Pinho (2013), segment analysis allows for a finer-grained assessment. The historical space syntax terms of "integration" and "choice" are equivalent to the more general terms of "closeness" and "betweenness centralities" (Hillier & Iida, 2005; Serra et al., 2015; Vaughan et al., 2025). Therefore, three centrality measures are investigated: angular integration, angular choice, and metric node count, for different radii ranging from 500 meters to 50,000 meters.

For each period, correlation analyses are run to identify the radius at which the correlation level is highest before decentralization effects are observed. The results of the process of embeddedness of urban space—analysed through varying radii—are observed and compared with the centrality measures and with real-world data acquired from maps and a literature review on regional history. For each period, a "breaking point" is identified as the centrality-embeddedness scale—in other words, a radius at which local centrality becomes most evident. Subsequently, sub-fractal analysis is conducted using the Frac_Lac software and the box-counting method, with the mesh size set equal to the radius obtained from the syntactic measure.

4. Main Findings

The major findings discussed here encompass the results of both the exogenous and endogenous phases. In the exogenous analyses, which were conducted for 30 districts within the entire city-region of İzmir, the findings reveal that during the initial period (1959–1964), rural areas exhibited higher spatial complexity than urban cores, suggesting a fragmented pattern of urbanization. In the second period (1976–1980), regionalization trends intensified, and the system's overall complexity surpassed that of its individual components. Notably high fractal values were recorded in central İzmir, including Karşıyaka and Bayraklı. By the third period (1996–2000), a pronounced north–south axis had emerged, reflecting spatial consolidation. In the most recent interval (2012–2017), a general decline in fractal dimensions was observed across the region, including coastal districts, indicating a plateau in growth and a redistribution of spatial complexity. Changes in the fractal dimensions of the districts from the first to the fourth period are presented in Figure 1.

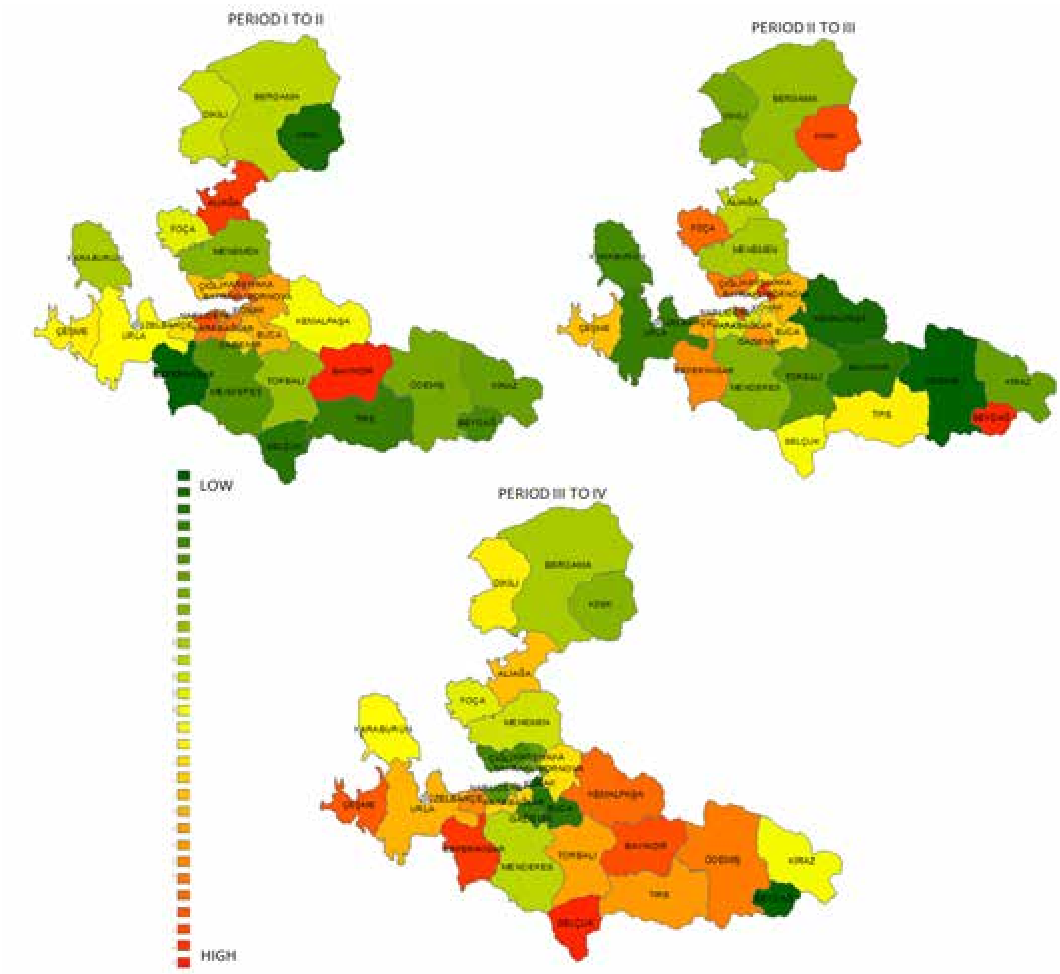

Figure 1: District-level changes in fractal dimension in İzmir across the first to fourth periods

For endogenous analyses proposing main arguments about centrality and regionalization, space syntax analyses and sub-fractal analyses are run for the third period. This period is selected since the highest fractal dimension values are observed during this time interval from 1996 to 2000 both in terms of parts (districts) and the whole system.

In space syntax analyses it is observed that the local betweenness centrality are observed for small radii by segment length weighted measure. In addition, the local centres can be observed for the radiuses of 500 meters to 1000 meters while could be best observed for the radius 500 meters. The medium scale is observed between the radii 2000 to 20.000 meters that until the radius of 10.000 meters, only the paths connecting the central core could be visualized (Figure 2).

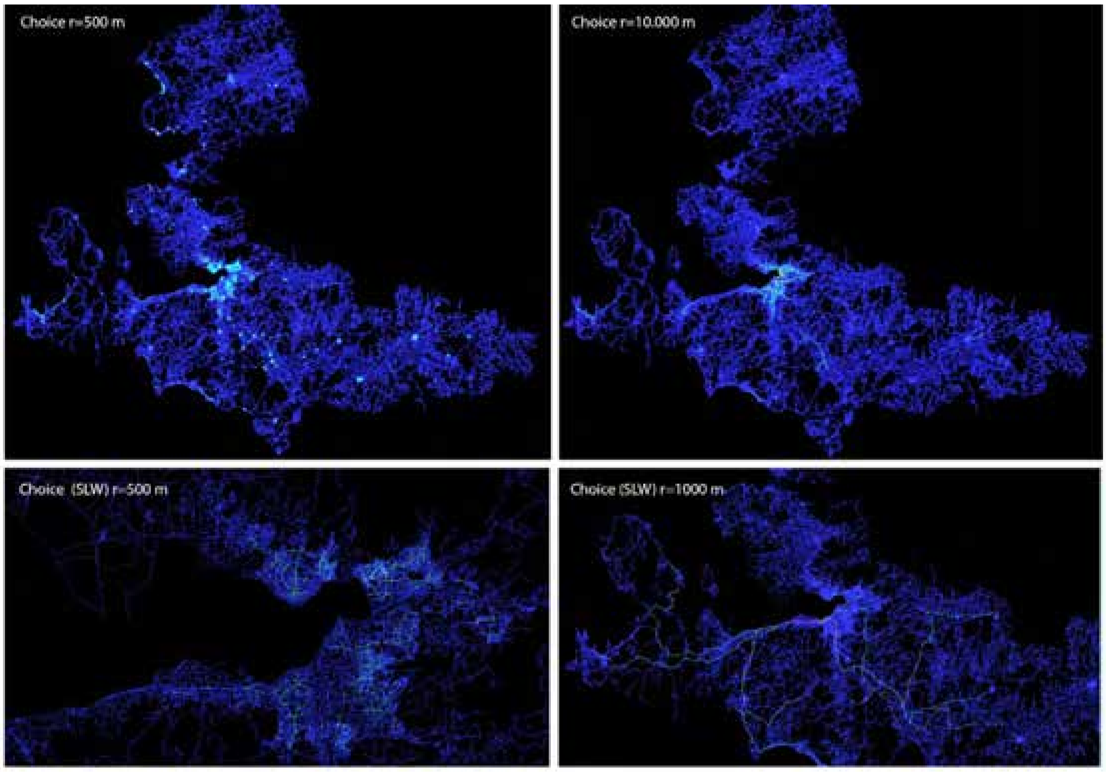

Figure 2. Angular choice analysis for small and medium radii during the third period (1996-2000)

For small radii, the main differences in centrality are not clearly visible for the declining core of Konak. However, the central paths of Alsancak and Eşrefpaşa Road can still be visually identified. Aside from the informal housing stock identified through the analysis—particularly around Tepecik and Kadifekale—local central paths have shifted toward Bayraklı. The highest choice value is calculated for Girne Avenue, the main artery of Karşıyaka. Karabağlar has gained betweenness centrality, while İnönü and Mithatpaşa Roads are identified as central paths near the Poligon area. These altered centrality measures closely correspond with the core's development trends in the late 1990s.

When the regional system is analyzed for small radii, the dominance of central İzmir persists. Although all district centers can still be distinguished, the rural pattern is no longer clearly identifiable. On the other hand, coastal developments become increasingly visible in Çeşme, Dikili, Seferihisar, and Urla. This finding aligns with the expansion of coastal towns, particularly those focused on tourism and seasonal housing during the mid- to late-1990s. Although the regional rural network has declined, decentralization of the central paths can be observed around the core—toward Çiğli-Menemen in the north, Gaziemir in the south, and Kemalpaşa in the northwest. The primary central paths are concentrated in the southern part of the Bay. The highest centrality is observed along the İzmir–Çeşme Highway. Connections from the highway to Seferihisar, and from the core to Torbalı, are also identified as central paths. Additional central paths can be differentiated along the coastal route toward Karşıyaka, and in the connections to Buca, Kemalpaşa, Çeşme, and Karaburun. The larger radii range—defined as 20,000 to 50,000 meters—applies to the third period based on the information from the choice measure maps. The highest choice value within the central core is observed along the coastal road connecting Kültürpark to Bayraklı. The connections between Karşıyaka and Bayraklı, as well as between Kültürpark and the Gaziemir junction, represent secondary central paths. Links to peripheral districts such as Çiğli, Gaziemir, Bornova, and Kemalpaşa constitute the third-level differentiated central paths for the restricted 20,000-meter radius. For the 50,000-meter radius, a similar pattern emerges, with areas like Çiğli and Torbalı gaining centrality due to the expanded metric radius (Figure 3).

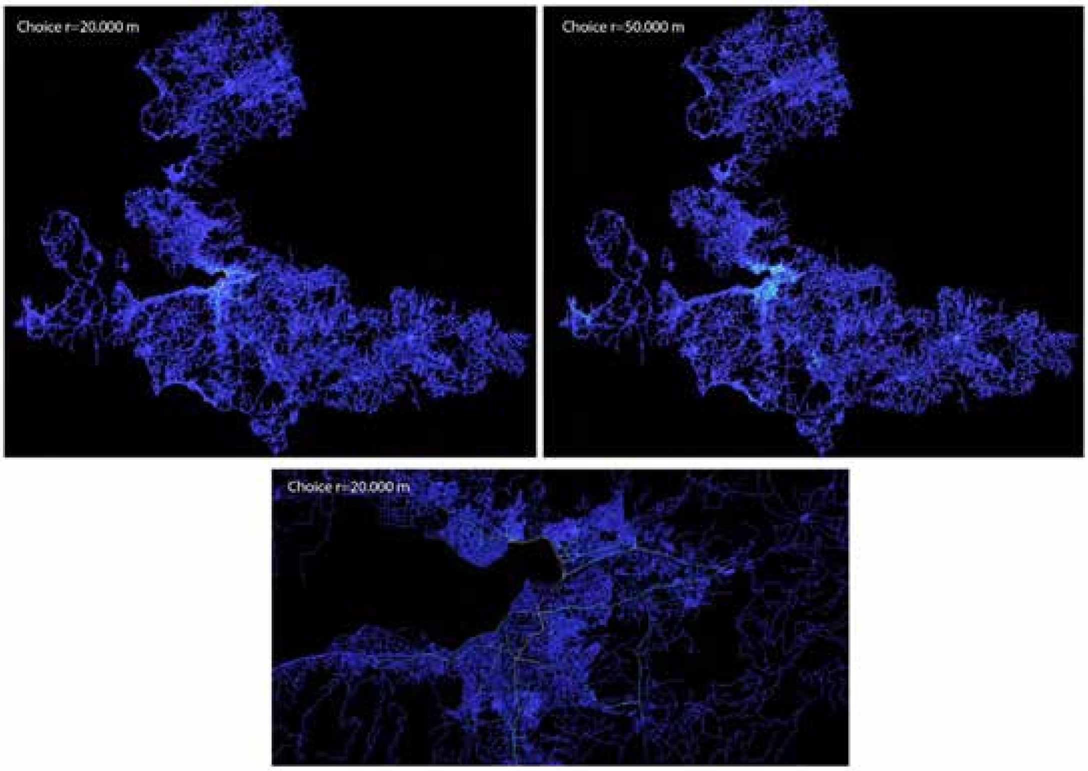

Figure 3. Angular choice analysis for large radii during the third period (1996-2000)

Angular integration analysis is also employed as a centrality measure. For small radii, similar to previous periods, irregular housing quarters are identified as distinct features exhibiting higher integration values within the central core. The main difference compared to earlier periods is the decline in integration values in the Konak vicinity. This result aligns with the findings from the choice measure and real-world data. The most integrated quarters are observed in Bayraklı, followed by Karşıyaka. As with the choice measure, differentiated integration patterns are seen around the metropolitan core. Additionally, coastal developments such as Çeşme, Dikili, and Seferihisar display higher integration values. For medium radii, a more regionalized pattern emerges. Within the central core, the highest integration values are observed along the coastal road from Kültürpark to Bayraklı, Gaziler Road, and the connection to Gaziemir. The regional medium-radius analysis, conducted at 20,000 meters, provides insight into the broader network. The strongest regional connection is observed between the central core and Torbalı. Linear development patterns radiate from the center toward the south and north, accompanied by coastal development along the Çeşme Highway (Figure 4).

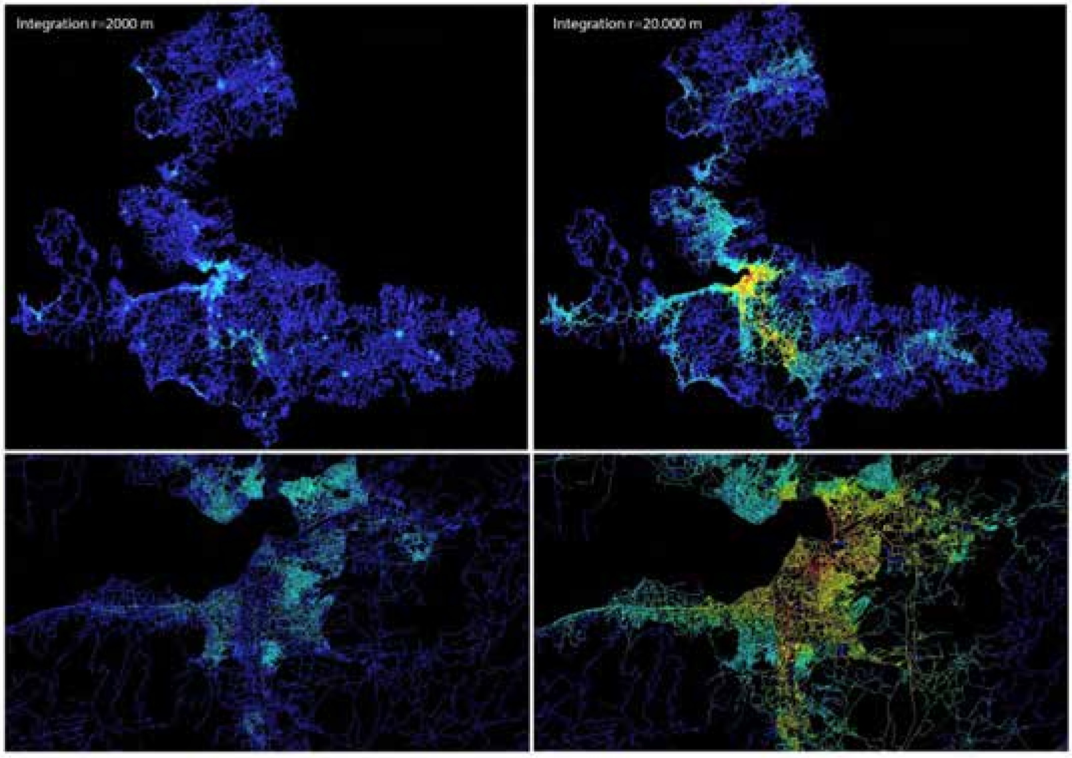

Figure 4. Angular integration analysis for small and medium radii during the third period (1996-2000)

During the initial period, sub-fractal analyses reveal higher fractal values in rural areas located in the northern, southern, and eastern parts of the region. These elevated fractal values are associated not only with urban activity but also with fertile agricultural land reserves. Despite exhibiting higher levels of spatial complexity, these areas did not display notable centrality. In the second period, the complexity of agricultural patterns decreased, while centrality increased alongside spatial expansion. Both complexity and centrality became more visibly aligned with urbanized areas, although some agriculturally dominant central districts still retained elements of centrality.

A significant transformation of the network system is observed during the third period. The complexity of former ex-urban areas rose once more. The key difference is the emergence of centrality nodes throughout the region, indicating a shift from purely rural characteristics to a more transitional spatial pattern. Moreover, the metropolitan core began to disperse along major corridors, blurring the distinction between rural and urban structures. In this context, peripheral and coastal towns gained both centrality and complexity, functioning increasingly like urban cores.

When sub-fractal analyses are integrated into the endogenous analysis, the results are found to closely align with those of the exogenous phase, indicating that centrality continues to manifest in the metropolitan core and in select districts that function as rural centers. An integrated representation of the sub-fractal analysis with a 1% pixel ratio and the connectivity map is presented in Figure 5. The sub-fractal analysis for this period reveals higher fractal values compared to previous decades. The lowest calculated value is 1.02, while the highest reaches 1.903. The most elevated values are observed in the central core, particularly in Karşıyaka–Bayraklı, Buca, Karabağlar, and Gaziemir. Although the urban core exhibits high sub-fractal values, regional complexity becomes more spatially varied compared to the second period. High sub-fractal values also appear in peripheral urban centers such as Urla, Çeşme, Aliağa, and Menderes. Additionally, scattered high fractal values are found around Kemalpaşa, Torbalı, and Seferihisar. The transition from agricultural divisions to peripheral development has resulted in increased complexity along key corridors. The eastern part of the region shows generally lower fractal values, punctuated by isolated complex nodes. Although Bergama retains its sub-regional pattern, the dominance of its integrated network has diminished relative to the first and second periods. A significant macro-form transformation is observed for the İzmir metropolitan area: formerly peripheral districts have become functionally integrated into the core. A continuous and cohesive urban structure now includes Buca, Bornova, Karabağlar, Çiğli, Menemen, Menderes, and Gaziemir, with coastal development extending southward along the Bay toward Urla.

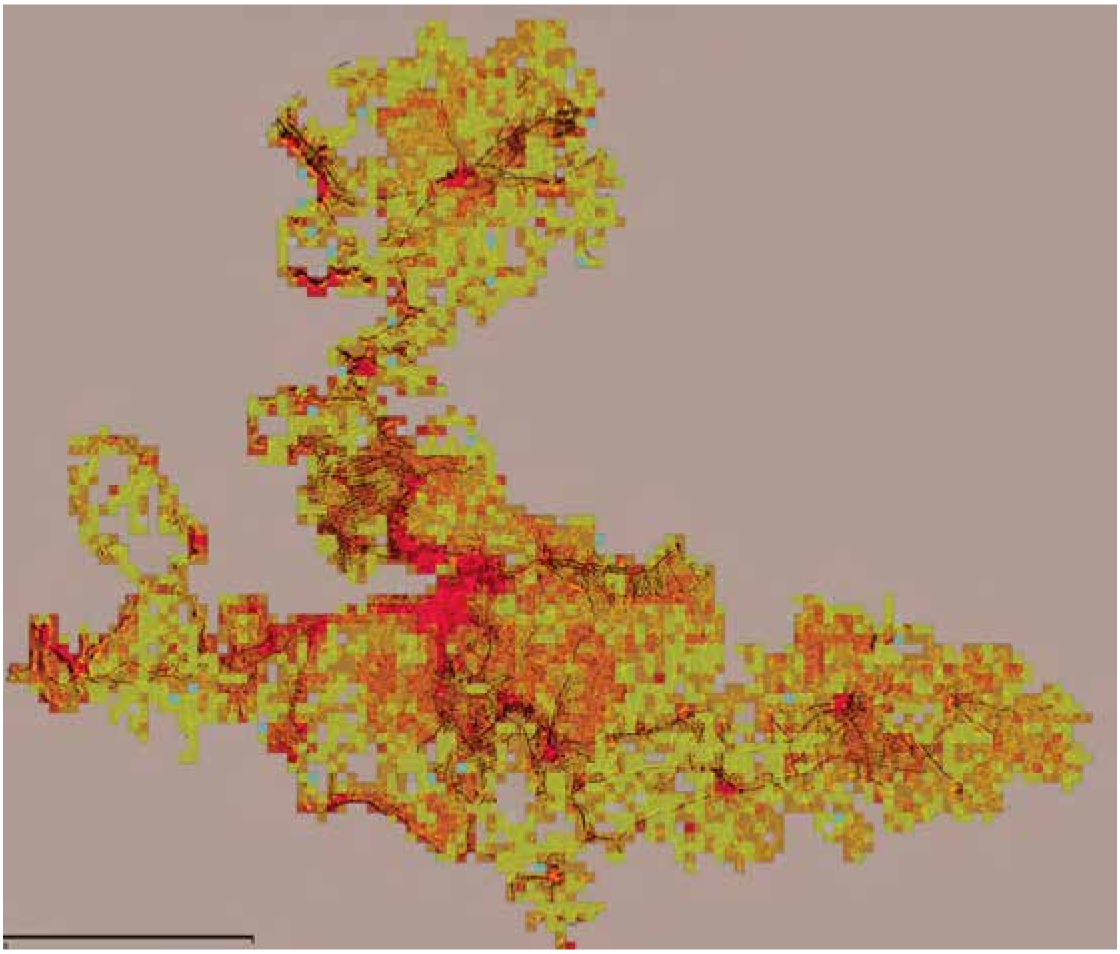

Figure 5. Integrated representation of the road network of İzmir in the third period using sub-fractal and space syntax analyses (1996-2000)

When centrality is assessed in conjunction with the revised patchwork theory, the radius exhibiting the highest correlation before decentralization begins is found to be the smallest during the third period (1996–2000). This suggests that spatial embeddedness declined up to the third period but increased again in the fourth period. Notably, the fractal dimensions of both the overall system and its constituent parts reached their highest levels during this final period. The results of the centrality and fractal dimension measures are presented in Table 1.

Table 1. Change of embeddedness and complexity

	r (m)	FD of the whole system	Mean FD of the parts
Period I (1959-1964)	5000	1,502	1,313
Period II (1976-1980)	1000	1,581	1,343
Period III (1996-2000)	500	1,819	1,521
Period IV (2012-2017)	5000	1,724	1,492

5. Conclusion

This study presents an integrated method for exploring the regional complexity of İzmir, a multi-layered and multi-sectoral city-region. By combining sub-fractal and space syntax analyses, the research advances a dual-phase approach to investigate the interplay between regionalization and centralization across different historical periods. Unlike conventional studies that narrowly focus on urban macroforms or the internal structure of road networks, this analysis extends to the broader regional fabric—capturing complexity within both urban and non-urban contexts, including agricultural, touristic, and industrial landscapes.

Fractal analysis serves as a quantitative measure of spatial complexity, spatial coherence, and urban sprawl. In parallel, space syntax analysis captures the relational properties of urban form, such as connectivity, integration, and centrality. The integration of these two methodologies enables a multi-scalar assessment of urban morphology, revealing how systemic shifts in complexity and centrality shape urban evolution over time. This approach uncovers critical transitions—from fragmented rural complexity in early decades to concentrated centrality and integrated regional structures in later periods.

The analysis identifies several key findings: In the initial period (1959–1964), rural areas displayed higher spatial complexity than urban cores, indicating fragmented urbanization. The second period (1976–1980) showed increasing regionalization, with complexity and centrality rising in core areas like Karşıyaka and Bayraklı. By the third period (1996–2000), a north–south urban development axis emerged, while peripheral districts such as Çiğli and Kemalpaşa began integrating into the urban network. In the final period (2012–2017), a decline in overall fractal dimensions was accompanied by a rise in complexity and centrality in coastal towns, revealing the influence of touristic and seasonal dynamics. Centrality shifted from traditional hubs like Konak to emerging centers such as Bayraklı, Karabağlar, and Karşıyaka, while roads like the İzmir–Çeşme Highway and Girne Avenue gained strategic importance. These changes reflect a blurring of rural–urban boundaries, as transition zones expanded and spatial embeddedness fluctuated. Correlation analyses identified threshold radii at which centrality peaked before decentralization, reinforcing the relevance of patchwork theory and multiscale syntactic measures. Sub-fractal values were highest in central and peri-central areas and validated through their spatial alignment with syntactic centrality, demonstrating the coherence between complexity and movement networks. Ultimately, İzmir has evolved into a polycentric metropolitan region, where formerly peripheral districts now function as secondary centers in a distributed urban system. From a planning perspective, the study highlights the utility of complexity-informed tools in guiding spatial development strategies. Two key applications are proposed: (1) employing fractal and syntactic measures as diagnostic indicators to inform regional planning frameworks, and (2) using complexity analyses as evaluative tools to assess compactness, sprawl, green space distribution, and development potential. As the conceptualization of cities as complex adaptive systems continues to gain traction, the integration of these methods offers valuable insights for planning resilient and adaptable urban futures.

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