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EFFECTS OF A MATRIX ROUTE ON THE THIRD DIMENSIONALITY OF A TOWNSCAPE

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Street systems are fundamental elements of cities, and they include many hierarchies that determine the structure of the urban fabric. It is possible to identify some basic typologies of streets as routes found in all spontaneous building fabrics. The matrix route is the oldest and most important one, as it has led to the development of settlements and often formed naturally without a planned design. The study focuses on the matrix route's three-dimensional impact on the urban form, specifically analyzing Karakolhane Street's role in shaping the Yeldeğirmeni district in Kadıköy, Istanbul. The street was chosen due to its evolution being traceable on historical maps, and the changes in its three-dimensional structure can be identified based on zoning laws and personal observations. The analysis methodology comparatively focuses on the street structure and nodes, height changes, height differences at polar nodes, and their impact on the urban landscape. The inquiry aims to document these changes using historical maps, records, texts, illustrations, and photographs. Historical maps are the primary source of information as they display the layout of streets, urban blocks, and buildings, preferably dating back to the 18th century.

Key words: **urban morphology, matrix routes, townscapes.**

INTRODUCTION

Streets are fundamental elements in the formation and development of urban landscapes. Whether deliberately planned or organically produced, they structure the patterns of urban fabrics and influence spatial organization at multiple scales. The classification and analysis of street structures based on both quantitative and qualitative characteristics have long been central to urban morphology (Panerai and Castex, 1970; Krier, 1979; Hillier and Hanson, 1984). As Lynch (1960) argued, streets are also primary perceptual elements, through which individuals understand and navigate the city. From a configurational perspective, they constitute the underlying system of movement and potential, shaping the distribution of activities and densities (Hillier, 1996). Although this study acknowledges these conceptual foundations, its primary focus is on the *matrix route* – the generative path that precedes and organizes urban development – and its relationship to the three-dimensional urban landscape.

Urban morphology has traditionally been examined through two-dimensional plan analysis. Conzen's (1960) classic town-plan approach, for example, emphasized street systems, plot patterns, and building arrangements at the ground plane. However, cities are not solely two-dimensional entities; the vertical dimension is equally critical in producing urban character, perception, and identity. Scholars have increasingly emphasized the need to understand cities through their three-dimensional structures, particularly as new technologies facilitate volumetric and height-based analysis (Ratti *et al.*, 2005; Xu *et al.*, 2017). Despite the methodological advances, studies explicitly connecting the role of matrix routes to three-dimensional transformations remain limited.

A growing body of research demonstrates how verticality, building height, and volumetric growth reflect broader urban processes. Domingo *et al.* (2023) conducted two- and three-dimensional analyses of Spanish cities using cadastral and

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LiDAR data, revealing significant increases in urban volume despite a reduction in average building height. Similarly, Rao *et al.* (2020) integrated horizontal and vertical metrics to examine growth patterns in 58 Chinese cities, highlighting the importance of clustering, height, and compactness in understanding contemporary urbanization. Shen *et al.* (2024) showed how three-dimensional morphological data can capture spatial complexity at neighborhood scales, offering valuable insights into local development dynamics. These studies underscore the importance of three-dimensional analysis for understanding long-term change, density patterns, and sustainable development strategies.

In addition to volumetric approaches, the urban block continues to serve as a central morphological unit. Historically, European cities were shaped by medieval fabrics until the 18th century, after which the city block became a dominant organizational element (Panerai *et al.*, 2004). Advances in digital technologies have enabled more detailed analysis of block structures, built–unbuilt ratios, and height patterns (Vanderhaegen and Canters, 2010). Complementing these approaches, the Urban Parterre Modeling (UPM) technique developed by Psenner and Kodydek (2018) demonstrates the inadequacy of purely planar cadastral maps, and highlights the need to integrate streets, ground floors, and courtyards to reveal three-dimensional relationships.

A range of methodological approaches has been developed to analyze the three-dimensional morphology of cities. These techniques are increasingly vital for understanding and managing urban landscapes, especially where vertical precision is required to assess urban character. Ren *et al.* (2020), for example, proposed an approach that integrates building footprints obtained through the Maps Static API with height information from the ALOS World 3D model. This method enables the calculation of key morphological parameters – including the sky visibility factor, building coverage ratio, building volume density, and frontal area density. When applied to the highly complex urban context of Hong Kong, their methodology proved both accurate and broadly applicable. In a related contribution, Koomen *et al.* (2009) developed a framework for quantifying urban volume using detailed elevation data and topographic information. Their case studies in Amsterdam and four major Dutch cities demonstrated how urban-volume indicators can reveal patterns of spatial expansion, intensification, and the emergence of multi-core development structures.

Within these broader morphological traditions, Istanbul presents a distinct historical trajectory. 19th Century reconstruction efforts, particularly following major fires, introduced new street geometries and spatial interventions (Çelik, 1996). Architect Luigi Storari's implementation of rhomboid junction forms, beginning in 1854, played a critical role in shaping certain neighborhoods, producing widened nodes that function as small urban squares within the street network. Such nodes are significant elements for understanding the spatial rhythm of matrix routes, as they create character zones, influence plot arrangements, and often concentrate building height variations – an aspect emphasized by urban space theorists concerned with node behavior and spatial intensity (Bentley *et al.*, 1985; Carmona *et al.*, 2003; Gehl, 2011).

Despite increasing attention to the three-dimensional structures of cities, the influence of matrix routes on vertical urban character remains insufficiently investigated. Urban form commonly develops around a primary structure of routes, yet how these routes – together with their architecturally and morphologically distinct nodes – shape the three-dimensional landscape has not been fully explored. Do nodes along matrix routes function as focal points of vertical differentiation? How do height variations correspond to parceling histories, zoning regulations, and spatial typologies?

To address these questions, this study focuses on Karakolhane Street, a central matrix route in the formation of the Yeldeğirmeni district in Kadıköy, Istanbul. The evolution of this route can be traced through historical maps, while its distinctive rhomboid nodes – originating from Storari's post-fire interventions – provide key character zones for examining plot transformations, building heights, and three-dimensional urban relationships. By analyzing these elements together, the study aims to reveal how matrix routes and their nodes contribute to the vertical articulation of urban form.

METHODOLOGY

Caniggia and Maffei (2001) highlight the foundational role of matrix routes in the emergence and evolution of urban form. These primary paths typically precede building activity and structure the development of the surrounding fabric, yet they cannot be understood independently of their contextual relationships. Strappa (2018) similarly argues that the urban plan is produced through the interaction of routes and textures, and that reading the system of routes is essential for interpreting the morphological structure of the city.

Drawing upon this theoretical framework, the present study examines the role of the matrix route, its nodes, and its poles in shaping the three-dimensional urban landscape of the Yeldeğirmeni district in Kadıköy. Karakolhane Street was selected as the primary case study due to its historical role as a generative path and its distinctive spatial characteristics. Functioning as the main matrix route of the neighborhood, the street organizes the surrounding urban fabric through its continuity, alignment, and morphological depth. Critically, it incorporates several rhomboid-shaped nodes, introduced during architect Luigi Storari's post-fire reconstruction interventions beginning in 1854 (Çelik, 1996). These widened junctions behave as micro-squares within the linear route system, forming character zones that influence plot formation, building typologies, and vertical articulation. Their spatial distinctiveness and concentration of activities make them central to analyzing two- and three-dimensional morphological transformations.

Accordingly, the research seeks to answer the following questions:

- How has the development of the matrix route influenced the urban structure and plot configuration within the study area?
- How does the matrix route affect building heights? In which segments do height variations become

pronounced, and do rhomboid nodes function as focal points for vertical differentiation?

- How have changes in zoning regulations over time shaped height patterns and vertical development along the matrix route?

To address these questions, the analysis proceeds through several complementary dimensions:

- the street structure of Karakolhane Street and the identification of character-defining nodes,
- plot subdivision processes and their effects on urban blocks,
- vertical changes resulting from successive zoning regulations, and
- height differences observed at polar and rhomboid nodes, and their implications for the three-dimensional urban landscape.

To supplement the morphological reading and provide a quantifiable basis for evaluating the built environment, the study incorporates the Spacemate method developed by Berghauser Pont and Haupt (2021). This analytical framework assesses urban form using four parameters: the floor space index (FSI - intensity) (floor area/ground area), ground space index (GSI - coverage) (built up area/ ground area), building height (L), and open space ratio (OSR - spaciousness) (non-built ground area/floor area). Together, these indicators enable a systematic examination of density in both two and three dimensions. Within the context of Karakolhane Street, Spacemate serves as a complementary tool for understanding how the matrix route and its rhomboid nodes structure volumetric intensity. By measuring variations in plot occupation, building coverage, and average storey height, the method helps identify local concentrations of built form and clarifies vertical transitions along the route. This quantitative layer reinforces the interpretation of street sections and silhouettes, enabling a deeper reading of the urban landscape and its sustainability implications.

In the analysis of nodes, the one with the beveled corners – Node A – was selected to understand the importance of them for the matrix routes. Node A – located at the intersection of Karakolhane Street and İskele Street – was selected because it represents the most spatially and morphologically distinctive point along the matrix route. Unlike ordinary right-angled junctions, Node A exhibits the rhomboid, beveled geometry introduced through Storari's 19th century post-fire interventions, creating a micro-square condition that expands both movement and visibility. Historical maps (Goad, 1906; Pervititch, 1937) consistently show that this junction attracted larger plots, amalgamations, and taller buildings earlier than other parts of the neighborhood. As a result, Node A functions as a focal point of three-dimensional specialization, where shifts in height, massing, and density are most pronounced. These characteristics make it the ideal micro-area for understanding how the matrix route generates vertical transformation and the structuring of hierarchies in the Yeldeğirmeni urban fabric.

To document morphological and vertical transformations, the study draws upon historical maps, archival records, textual sources, illustrations, and photographs. Historical maps constitute the primary dataset, as they reveal shifts in street alignments, block structures, and building footprints from the 18th century onward. Particularly significant are the fire insurance plans prepared by Goad (1906) and Pervititch (1937), which offer detailed representations of the built environment during the late nineteenth and early 20th centuries. These sources make it possible to trace the evolution of the matrix route, identify the emergence of rhomboid nodes, and analyze plot-level changes.

Plot patterns and building configurations were examined through comparative layer analysis, allowing the study to track changes in the façade alignment, building depth, and height regulations across different periods. Street sections and silhouettes were employed to identify vertical discontinuities along the route, with special emphasis on the spatial behavior of nodes. By combining morphological theory, cartographic evidence, zoning analysis, and Spacemate-based density assessment, the methodology provides a comprehensive framework for understanding the three-dimensional articulation of Karakolhane Street.

BEGINNING OF THE CITY: THE MATRIX ROUTE

The urban organism is formed by the combination of the city's street layout and structures. The concept that governs this aggregation is the urban fabric, which provides order to the urban system through streets and buildings. Streets typically develop around pre-existing routes; the initial path that structures urban formation often precedes built development and establishes the basic framework for subsequent growth. In some cases, these formative routes originate from deliberate design interventions (Strappa, 2018), while in other cases they emerge from repeated movement between significant destinations. Such original paths – referred to as matrix routes – connect two poles of particular importance, as exemplified by the Via del Corso in Rome.

Along these matrix routes, the presence of continuous side walls ensures the alignment and juxtaposition of building façades, thereby fostering the aggregation processes that generate the urban fabric (Caniggia and Maffei, 2001). The modular rhythm of building façades contributes to the structural modularity of the block, establishing morphological continuity among similar building types across different periods of development. Typically, this aggregate module takes the form of a continuous rectangular pattern, with the shorter side running parallel to the matrix route and the longer sides oriented perpendicularly, although variations do occur (Caniggia and Maffei, 2001). Secondary routes, often positioned two plot depths away from the main street, are usually arranged perpendicular to the matrix route, and their intersections create nodes that structure the fabric (Strappa, 2018).

Maretto (2018) identifies routes, nodes, and textures as the three primary components of urban structure. From the perspective of spatial hierarchy, he argues that routes exert a stronger influence on the organization of urban life than other elements. Strappa (2018) similarly views routes as the principal analytical device for understanding urban form and territorial organization. The degree of specialization that urban elements acquire – whether at the level of buildings or nodes – depends on the hierarchical status of the route to which they belong. Routes determine the gradation of nodality and the prominence of urban poles (Maretto, 2018). Highly specialized buildings typically occupy the matrix route that links the city's principal poles. Moving outward from the matrix route, building functions gradually shift toward predominantly residential uses as the route loses nodal intensity. A comparable pattern can be observed in building height, which tends to increase near nodes and diminish along anti-nodal segments (Maretto, 2018).

Like matrix routes, nodes are essential for understanding the evolving character of the city during the construction process. A node may be defined as the point at which two continuities intersect, where one continuity branches into another, or where a discontinuity disrupts a linear sequence. In this sense, nodes represent the structural connections among the components of the urban organism. These connections may take the form of axes, intersections, or enclosed spatial configurations, and they often emerge through the individualization of routes and textures (Strappa, 1998). In certain cases, the initial or terminal nodes of matrix routes acquire a heightened significance, functioning as poles – points of intensified urban meaning and activity.

Lynch (1960) describes nodes as junctions or strategic points where particular characteristics accumulate. While he does not assign special importance to ordinary intersections, he emphasizes that nodes gain significance when they exhibit polar qualities, contributing strongly to the imageability of the city. Thus, major squares, elongated linear spaces, and even entire districts may function as poles within the urban structure. As places of convergence and concentration, the impact of nodes becomes particularly pronounced when they possess a distinct spatial form.

CONTEXT

Karakolhane Street in the Yeldeğirmeni neighborhood of Kadıköy represents a characteristic example of the historical evolution of a matrix route within 19th century Istanbul. Extending from the center of Kadıköy toward the northern parts of Yeldeğirmeni, the street gradually emerged as a principal structural axis, shaping and connecting the spatial organization of both areas. As part of the broader development of Istanbul's residential quarters during this period, Karakolhane Street is distinguished by several prominent junctions that reveal its morphological significance within the urban fabric.

Morphological development of Yeldeğirmeni

Yeldeğirmeni constitutes one of the key focal zones of Kadıköy, marked by its accessibility to transportation, cultural amenities, commercial services, and educational institutions. Owing to its strategic location, the district has sustained its vitality and continued to benefit from urban regeneration initiatives. Its connectivity – linking the Anatolian and European sides by sea, land, and rail – reinforces its role as a major urban node within Istanbul.

The name "Yeldeğirmeni" derives from the four windmills constructed during the late 18th century by Hafız İbrahim Ağa, chief architect under Sultan Abdülhamid I (1774–1789) (Giz, 1988). These windmills were established to meet the flour needs of the army, the palace, and the local population (Akbulut, 1994). The district occupies part of the former Haydarpaşa Meadow, an area that served multiple functions following the conquest of Istanbul, including military training, seasonal recreation, and various social activities (Türker, 2008).

The earliest permanent settlements in the area appeared between the 15th and 16th centuries in the form of garden houses. The construction of the Osman Ağa Mosque in 1612 intensified development in the parts of Yeldeğirmeni closest to the Kadıköy center (Türker, 2008). During the reign of Selim III (1789–1807), the number of houses increased and the first traces of a recognizable street network emerged (Barkul, 1993a; 1993b). Helmuth von Moltke's map (1852) indicates that the settlement expanded parallel to the shoreline along the slopes of Yeldeğirmeni.

The Tanzimat era had significant implications for Istanbul's urban fabric. The extension of certain social and urban privileges to minority communities shaped the morphology of districts such as Galata, Pera, Harbiye, Moda, Üsküdar, and Kadıköy, including Yeldeğirmeni (Eyüboğlu, 1991; Çiçek, 2015). The establishment of Kadıköy's first post office in 1845 on İzzettin Street indicates that the district was already undergoing organized urban development (Şimşek, 1987). The later introduction of the tram system further accelerated movement and migration, leading to increased settlement during the second half of the 19th century.

By this period, two and three-storey buildings – constructed in accordance with contemporary regulations – began to integrate with and reshape the traditional fabric of Yeldeğirmeni. The arrival of Greek, Armenian, and Jewish communities contributed to demographic growth and expanded building activity, prompting the construction of some of the earliest apartment buildings on the sea-facing slopes in the early 18th century (Şahin, 2013). The construction of the Haydarpaşa Railway Station further transformed the district, attracting German and Italian engineers, whose settlement in the area added to its cultural and social diversity.

At the beginning of the 20th century, the district began to assume its present-day urban form (Şendur, 2010). The Goad (1906) map shows that the previously organic urban fabric had transitioned into a grid pattern, producing more regularized streets and geometric blocks (Figure 1). In 1947, the infilling of Kadıköy Bay enabled the creation of a coastal road connecting Kadıköy and Üsküdar, reinforcing the district's accessibility. Although the intensive urbanization of the 1980s did not result in substantial changes to the overall plan structure, it led to the demolition of many historical low-rise buildings and their replacement with 5–6-storey apartment blocks, altering the district's architectural character at the building scale. By the 1990s, most vacant plots had disappeared, marking the district's full transition into a mature urban neighborhood.

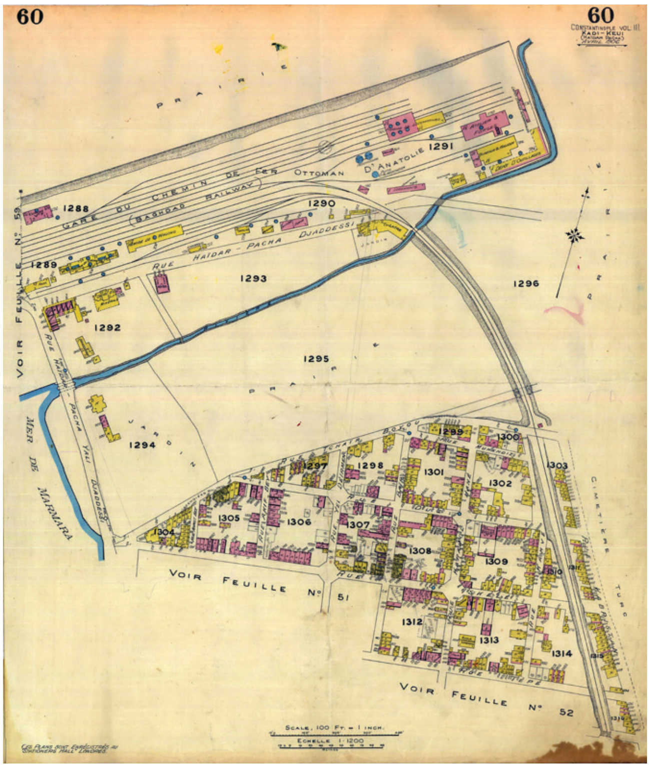

Figure 1. Plan d'assurance de Constantinople: Kadıköy (Source: Goad, 1906)

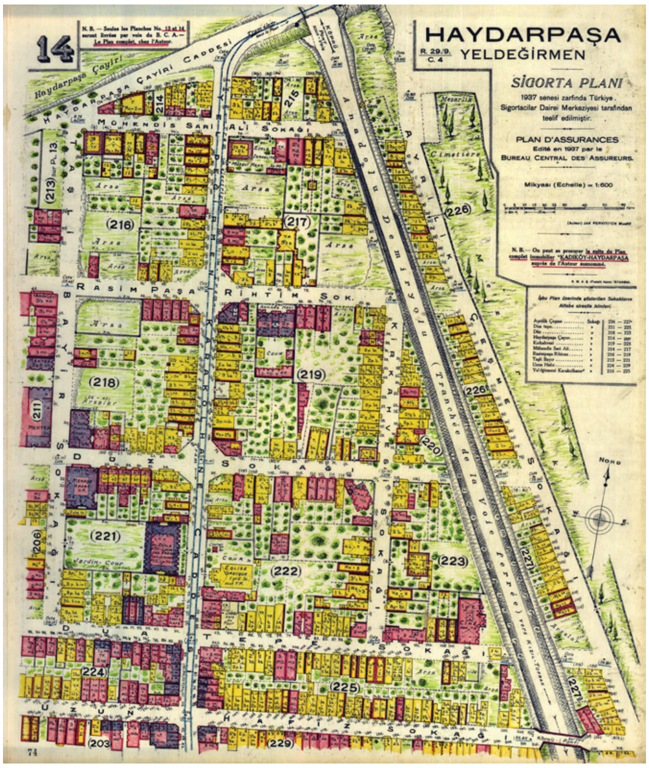

Figure 2. Sigorta Planı. Haydarpaşa. Yeldeğirmen. No: 14 (Source: Pervititch, 1937)

Impact of town planning rules

Although no major planning interventions affected Yeldeğirmeni during the Pre-Tanzimat period, the regulations, zoning laws, and planning frameworks introduced during the Tanzimat era, and later in the Republican period, had a profound influence on the district's morphological development. In particular, zoning plans shaped the neighborhood's density, functional organization, and physical growth. Prior to the Tanzimat reforms, comprehensive spatial planning was not practiced in the Ottoman Empire; regulatory measures emerged mainly in response to the frequent and destructive fires that plagued Istanbul.

The 18th century marked the first attempts to introduce more systematic regulatory measures. Following the devastating Cibali fire, dense and contiguous construction were prohibited and it was required that workplaces be built of masonry. Additional regulations during this period mandated the use of masonry construction and limited buildings to two storeys (Sakaoğlu, 1994). In 1725, another ordinance established differentiated height limits: Muslim houses were restricted to 12 zira (approximately 9 m), while non-Muslim houses were limited to 9 zira (approximately 6.75 m) (Ergin, 1995; Günergün, 1998). Despite these attempts, a holistic approach to urban replanning did not emerge before the 19th century, and reconstruction in fire-damaged areas generally adhered to existing spatial patterns (Çelik, 1996).

The most substantial transformations in spatial regulation and urban planning occurred between the Tanzimat period and the establishment of the Republic. Rapid population growth, increasing density, and repeated fires made legal regulation imperative. Systematic codification began with the Ebniye Declaration (Divan-ı Hümayun, 1848), the first zoning ordinance applicable to Istanbul. A revised version followed in 1849 (Divan-ı Hümayun no. 2, 1849), but these early regulations proved insufficient to guide urban development, prompting the enactment of the Regulation on Streets and Buildings (Devlet-i ʿAlīyye-i ʿOsmānīyye, 1864) . The most comprehensive of these, the Ebniye Law (Devlet-i ʿAlīyye-i ʿOsmānīyye, 1882), established detailed rules governing street widths, building heights, and construction materials.

The 1848 regulation classified roads into three categories – major (7.5 m), ordinary (6 m), and minor (4.5 m) – and prohibited architectural projections over the street. It also introduced limits on building height: 13.5 m for wooden structures and 16.5 m for masonry buildings. The accompanying Ebniye Declaration (Divan-ı Hümayun, 1848) modified these heights to 10.5 m and 15 m respectively. The 1849 regulation (Divan-ı Hümayun no. 2, 1849) further refined these limits, setting the height of wooden buildings at 14 zira (≈10.5 m) and masonry buildings at 20 zira (≈15 m), while prohibiting wooden construction between masonry structures. The 1864 regulation classified streets into four categories and required that redevelopment in fire-damaged zones follow rectilinear plot arrangements. The Ebniye Law (Devlet-i ʿAlīyye-i ʿOsmānīyye, 1882) expanded these classes to five, ranging from 6 to 15 m, and established new height limits based on street width: 18 m for masonry and 12 m for wooden buildings on streets 6–7.5 m wide, and 21 m and 13.5 m respectively on streets 9–11.25 m wide. This law remained in force until the Municipal Building and Roads Law (No. 2290) of 1933 (Türkiye Büyük Millet Meclisi, 1933) was enacted (Denel, 1982).

During the early Republican period, the Ebniye Law (Devlet-i ʿAlīyye-i ʿOsmānīyye, 1882) continued to be applied with amendments until Municipal Building and Roads Law No. 2290 (Türkiye Büyük Millet Meclisi, 1933) came into effect in 1933. This legislation, the first zoning law of the Republic of Türkiye, mandated right-angled block corners and specified block dimensions of 50–80 m in width and 150–200 m in length. It also required streets to be no narrower than 9.5 m, with 4.5 m allocated for sidewalks (Ersoy, 2017). In 1957, Law No. 6785 (Türkiye Büyük Millet Meclisi, 1957) replaced the 1933 law, and in 1985, Law No. 3194 (Türkiye Büyük Millet Meclisi, 1985) became the principal zoning legislation.

Several planning decisions directly affected Yeldeğirmeni during the late 20th century. The Kadıköy Rasimpaşa Neighborhood Zoning Plan of 1971 (İstanbul Belediyesi, 1971) established a maximum height of 18.50 m for plots facing Rıhtım Street and 15.50 m for interior plots, with additional requirements for plots adjacent to historical monuments. The 1/5000 Kadıköy Centre Master Plan, approved in 1994 (İstanbul Büyükşehir Belediyesi, 1994), designated plots along Kadıköy–Haydarpaşa Rıhtım Street as commercial areas, retaining the 18.50 m height limit, while maintaining the 15.50 m limit for interior blocks. This framework was further detailed in the 1998 Rasimpaşa Conservation Zoning Plan (1/1000 scale) (İstanbul Büyükşehir Belediyesi, 1998), which reaffirmed the commercial designation of Rıhtım-facing plots and set height limits in accordance with the street silhouette for historical buildings and their surroundings. Since then, Yeldeğirmeni has not undergone any major zoning changes, apart from regulations associated with railway-related planning interventions within the district's boundaries.

MORPHOLOGICAL STRUCTURE OF KARAKOLHANE STREET

Jacques Pervititch's insurance plans from the 1930s provide one of the most detailed visual records of the structural configuration of Karakolhane Street (Pervititch, 1937). The evolution of the street can be traced through a sequence of historical maps – from those of Kauffer in 1786 (Kauffer, 1786) to contemporary cartographic sources. While early maps offer only limited information on the district's development, they nonetheless reveal key morphological foundations. Plan de la ville de Constantinople (Kauffer, 1786), for instance, illustrates the basic formation of streets and avenues in the center of Kadıköy. At this stage, Halitağa Street appears as the initial element from which Karakolhane Street would later emerge, though it initially extended only as far as Taşköprü Lane. The 1815 map by Kauffer and Lechevalier shows a similar situation (Kauffer and Lechevalier, 1815).

A more developed pattern begins to appear in Helmuth von Moltke's map (1852), which shows coastal construction parallel to the shoreline and depicts Halitağa Street connecting to Acıbadem via Taşköprü Street. However, the existence of Karakolhane Street is not yet evident. Engineer Hübner's map (1876) marks the first clear indication of a branch extending from Halitağa Street into Yeldeğirmeni, accompanied by increasing construction activity toward the northern parts of the neighborhood. Substantial progress is documented in Plan de Constantinople (Stolpe, 1882), where a street branching from Halitağa Street is shown connecting to Ayrılık Çeşmesi, suggesting that the foundational alignment for Karakolhane Street had by then been established.

In the early 20th century, Goad Pasha's fire insurance plans further illuminate the urban layout of Yeldeğirmeni (Goad, 1906) (Figure 1). These maps demonstrate the application of grid planning principles – likely shaped by experiences of earlier fires – resulting in a more regularized urban form. The plans clearly indicate that Karakolhane Street functioned as a matrix route: construction density along the street was markedly higher than along the Rıhtım, and the built-up area expanded northward in response to the development of Haydarpaşa Station. The presence of institutional buildings, including a school and a church, reinforces the route's role as a structurally and socially significant axis.

Pervititch's insurance maps for Kadıköy, prepared in 1937, depict a continued rise in construction intensity along Karakolhane Street (Pervititch, 1937) (Figure 2). The introduction of the tram line further enhanced the street's importance, strengthening its function as a main route. This transportation improvement not only facilitated movement but also contributed to the street's growing attractiveness for commercial uses, solidifying its status as a central spine within the district's urban fabric.

Nodes of Karakolhane Street

Karakolhane Street incorporates several significant nodes of varying scales, one of which is a square-like junction with beveled corners located in the northern section of the route. This junction functions as a key point along the matrix route, offering an advantageous position from which to observe morphological changes in both two and three dimensions. It is embedded within an urban fabric characterized by notable buildings and distinct spatial configurations. Within this context, the primary spatial system components include the urban block, open space, and the development of plot and building textures. The physical components of the urban fabric – such as building depth, the relationship between buildings and the street, and building height – play a crucial role in shaping the character of the area. Morphological transformations in floor-area density, surface area, and façade composition are documented across major periods of the city's development, with street sections and silhouettes serving as essential analytical tools.

Analysis of the three-dimensional structure of the node

The analysis is grounded in a comparative examination of the physical characteristics, historical and spatial development, planning decisions, and morphological structure of the neighborhood. This evaluation uses the Goad maps (1906), the Pervititch insurance plans (1937), and current maps (İstanbul Büyükşehir Belediyesi, 2023) that document spatial changes within the four selected urban blocks.

Street–urban block geometry

Following major fires in Istanbul, new planning approaches were introduced, leading to the adoption of more regularized grid patterns in many neighborhoods. In Yeldeğirmeni, the grid texture evident on Goad's 1906 map has remained largely unchanged. The street–block structure reflects this regularity, with Karakolhane Street functioning as the matrix route that organizes the surrounding fabric. At the intersection of this route with İskele Street – aligned perpendicularly – a square-like junction with beveled corners forms a significant nodal point positioned at the center of the grid (Figure 3). This spatial configuration reinforces the hierarchy of the route and underscores the node's importance in structuring circulation and morphological transitions.

Plot–building fabric

19th century Ottoman modernization and the fragmentation of large households produced a growing demand for smaller dwellings, which, together with rapid population growth and evolving land-ownership laws, shaped Istanbul's denser residential morphology. As a result, new housing types emerged on narrow, elongated plots, a pattern driven by both the need to maximize limited urban land and the subdivision of former large estates (Yücel, 2019). In Yeldeğirmeni, this resulted in attached row houses situated on plots extending from the street to rear gardens or courtyards, forming the characteristic fabric of the neighborhood. The Goad map (1906), the Pervititch plans (1937), and current cadastral data all show that this courtyard-based arrangement largely persisted, even as overall density increased. Corner buildings and enlarged plots at nodal points stand out, reflecting functional specialization along key routes.

The Goad map shows that subdivision processes were still underway in the early 20th century (Goad, 1906). By contrast, the Pervititch maps document that subdivision had been completed, although plot numbers had not yet been fully assigned. Contemporary maps now clearly delineate all plot boundaries and numbers (Pervititch, 1937) (Figure 3). A comparison between the 1937 Pervititch map and current mapping reveals an increase in the number of plots within the four urban blocks studied – from 111 to 129. This increase suggests a simultaneous process of fragmentation and selective amalgamation.

Plot amalgamations have produced noticeable changes in the dimensions of new building masses. Along Karakolhane Street – the neighborhood's primary commercial axis – demand for additional space has been the main driver of such amalgamations. For example, some of the plots have been consolidated to accommodate larger building

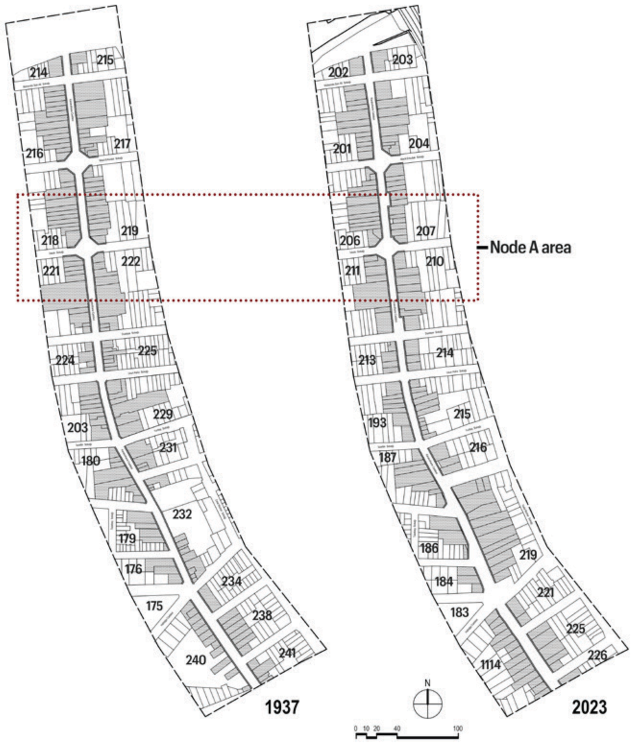

Figure 3. Karakolhane street matrix route and pertinent strip 1937-2023 and Node A area (Source: Authors, 2025)

footprints. Historical continuity is also apparent: buildings situated on the corner of blocks 1309 and 1312 have maintained their spatial relationship with the junction from the Goad map to the present. In contrast, corner buildings on blocks 1308 and 1313 have undergone significant change, and only recently have their footprints realigned with the square (Figure 4). The larger building plots facing the nodal square differ markedly from the finer-grained historical residentials. Their expanded floor areas introduce building masses of greater scale, resulting in increased variation in the three-dimensional morphology of the neighborhood, and contributing to a more heterogeneous urban landscape.

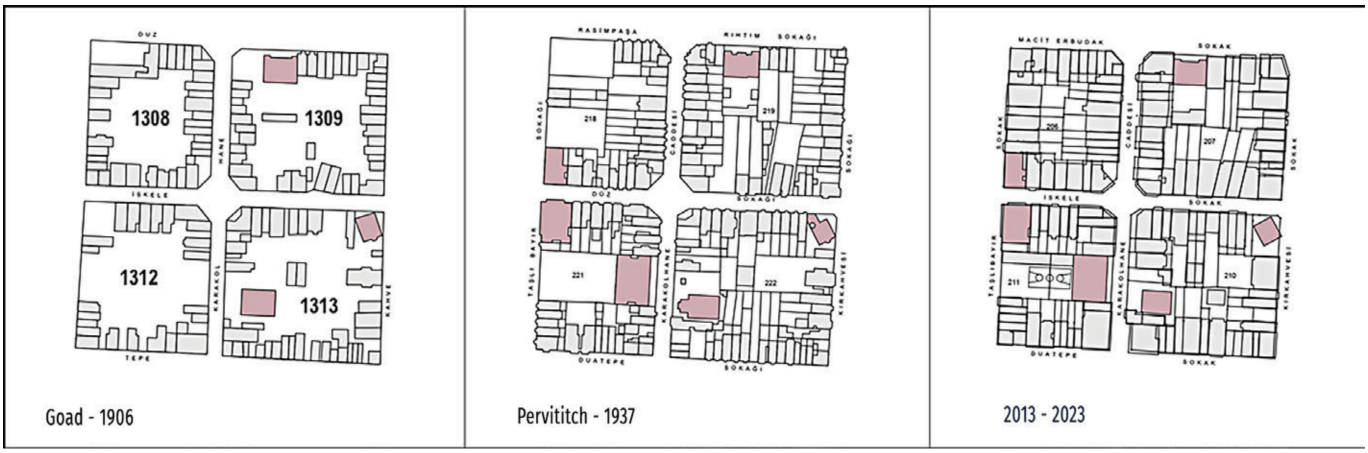

Figure 4. Morphology of the Node A related with urban blocks 1308, 1309, 1312, 1313 (Source: Authors, 2025)

Three dimensional structure: density and building height

The Spacemate framework, developed by Berghauser Pont and Haupt (2021), conceptualizes compactness through the relationship between built-up area and total urban block area. The Goad (1906), Pervititch (1937), and current (İstanbul Büyükşehir Belediyesi, 2023) maps demonstrate a consistent increase in the proportion of built-up surfaces within the four examined blocks, accompanied by a corresponding decline in open space (Table 1). This trend reflects a gradual intensification of the neighborhood's spatial fabric.

Table 1. Open space ratio of urban blocks 1308, 1309, 1312, 1313

	Urban Block No.	1906	1937	2023
Pressure on Non-built Space - Spaciousness (Open Space Ratio-OSR)	1308/218/206	0.51	0.59	0.09
	1309/219/207	0.65	0.67	0.12
	1313/222/210	0.65	0.58	0.17
	1312/221/211	0.78	0.27	0.11
	Average	0.65	0.5	0.12

Changes in the area's three-dimensional structure – particularly building height – are also observable across the same temporal sequence (Figure 5). Significant formal transformation has occurred as a result of vertical expansion. In the Goad map (1906), the average building height within the four blocks ranges from two to three storeys. By the time of the Pervititch plans (1937), the average height had risen to three storeys, despite the presence of several taller structures such as the five-storey Ankara Apartment, the six-storey Celal Muhtar Apartment, and the four-storey St. Louis Primary School. In the current map (İstanbul Büyükşehir Belediyesi, 2023), building heights have increased substantially, with most structures reaching four to five storeys and high-rise buildings occupying all corner parcels – indicating a strong upward shift driven by growing spatial demand.

Figure 5. Karakolhane street building height-third dimension 1937-2023 and Node A area (Source: Authors, 2025)

Density values derived from the Spacemate parameters confirm this vertical intensification. Increases in the ratio of total building floor area to urban block area (Table 2) indicate a marked rise in three-dimensional density, surpassing the horizontal compactness already evident in the earlier maps. The comparison of floor area and building height therefore reveals a pattern of uncontrolled vertical growth that has reshaped both the massing and the silhouette of the neighborhood.

Table 2. Density change in urban block 206, 207, 210, 21

	Urban Block No.	1906	1937	2023
Intensity (Floor Space Index-FSI)	1308/218/206	1.11	1.08	3.38
	1309/219/207	0.94	0.91	3.03
	1313/222/210	0.92	0.98	2.54
	1312/221/211	0.87	1.67	3.06
	Average	0.95	1.16	2.89

Three dimensional structure: street sections

The A–A section serves as a key analytical tool for understanding the three-dimensional structure of the neighborhood. This section is centered on Karakolhane Street – the district's matrix route – and extends across Taşlıbayır and Kırkahvesi streets (Figure 6). A comparative reading of the street sections derived from the Goad (1906), Pervititch (1937), and current maps (İstanbul Büyükşehir Belediyesi, 2023) reveals notable transformations. In the Goad map, buildings along the section range from two to three storeys, with expansive courtyards separating the blocks. The zoning regulation closest in time to the Goad map (1906), the Ebniye Law (Devlet-i ʿAlīyye-i ʿOsmānīyye, 1882), prescribed maximum building heights of 12–18 m along streets such as Karakolhane Caddesi and İskele Sokak, both of which have widths of approximately 10 m. Although the precise heights of the buildings depicted on the Goad map are not documented, their two and three-storey profiles appear consistent with these regulatory limits.

The Pervititch map illustrates a gradual increase in building heights and a reduction of open spaces, as plot consolidations and infill development introduced new structures into previously vacant courtyards (Pervititch, 1937). The map also indicates general compliance with the building envelopes established under the Ebniye Law (Devlet-i ʿAlīyye-i ʿOsmānīyye, 1882). The subsequent Municipal Building and Roads Law No. 2290 (Türkiye Büyük Millet Meclisi, 1933) required that sidewalks measure at least 4.5 m in width; however, the absence of detailed sidewalk representation in the Pervititch plans limits a full assessment of compliance at that time.

Later zoning plans from Istanbul Metropolitan Municipality (İstanbul Belediyesi, 1971; İstanbul Büyükşehir Belediyesi, 1994; 1998) established a uniform maximum building height of 15.5 m for most of the district. The current map confirms that buildings along the A–A section have largely reached this height limit, demonstrating a progressive vertical intensification consistent with successive regulatory frameworks.

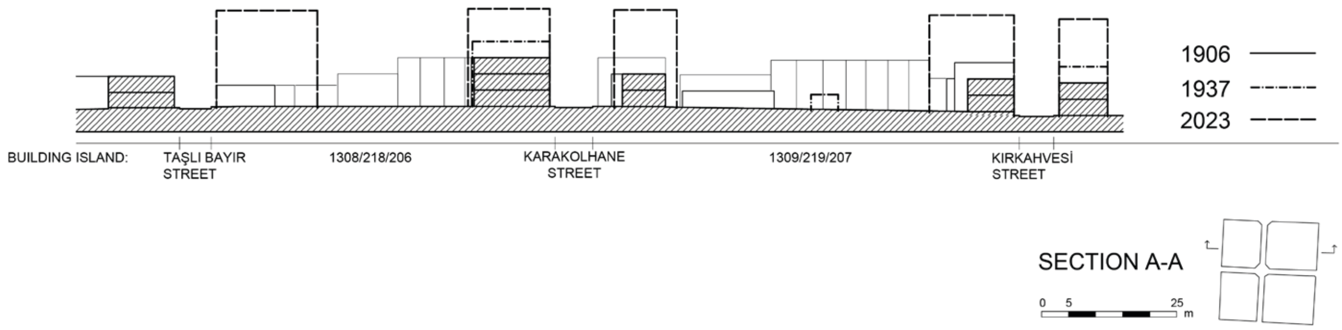

Figure 6. Change of heights, section A-A, Karakolhane Street
(Source: Authors, 2025)

DISCUSSION

The findings reveal that the three-dimensional transformation of Yeldeğirmeni is strongly organized by the enduring influence of Karakolhane Street as the district's matrix route. While the street's alignment and role have remained stable since the 19th century, its vertical profile has undergone substantial intensification. Buildings that averaged 2–3 storeys in the Goad period have progressively risen to 4–5 storeys in the present, reaching the 15.5 m height limit established by late 20th century zoning plans (İstanbul Büyükşehir Belediyesi, 1998). This vertical shift confirms that the matrix route functions not only as a generator of horizontal fabric but also as a catalyst for height concentration.

The rhomboid-shaped nodes along Karakolhane Street play a decisive role in shaping these height alterations. Their expanded geometry supports higher functional intensity, and consequently, buildings facing these nodes exhibit consistently greater heights and larger massing than those located along interior streets. This aligns with theoretical claims that nodes act as spatial attractors, where architectural specialization and volumetric differentiation become most pronounced (Strappa, 2018; Lynch, 1960). The dominance of high-rise corner structures in these zones reinforces their role as vertical landmarks within the district.

Plot dynamics further amplify three-dimensional variation. Increases in plot fragmentation have enabled more infill construction, while targeted amalgamations – especially along the matrix route – have produced larger building footprints capable of supporting higher structures. The application of the Spacemate method confirms this: rising FSI and GSI values, along with reductions in OSR, indicate a steady transition from low-rise, courtyard-based morphology toward a denser, vertically defined urban form.

Zoning regulations have simultaneously constrained and stimulated vertical growth. While earlier laws – e.g., the Ebniye Law (Devlet-i ʿAlīyye-i ʿOsmānīyye, 1882) – imposed material-based height limits, later current plans (İstanbul Büyükşehir Belediyesi, 2023) formalized a consistent maximum height regime. The current morphology demonstrates that these limits have been fully reached, particularly along Karakolhane Street and its nodes, where market pressures align with regulatory allowances to produce a uniform mid-rise profile.

Overall, the study shows that 3D height alteration is the central driver of Yeldeğirmeni's contemporary morphological transformation. The persistence of historical street geometry contrasts with rapid vertical expansion, producing a landscape where identity is increasingly shaped by building height, nodal intensification, and the cumulative effects of regulatory frameworks. The challenge for future planning lies in managing this verticality while preserving the spatial coherence generated by the matrix route and its characteristic nodes.

CONCLUSIONS

Routes occupy a central role in shaping urban form, as numerous scholars in urban morphology have emphasized. The urban fabric emerges in relation to them, and spatial hierarchies are structured through their alignment, continuity, and connectivity. Among these, the matrix route stands out as the most formative element, functioning as the structural backbone of a settlement. Throughout history, the configuration of routes has developed in response to topography, environmental constraints, and socio-economic dynamics. While natural conditions often promote linear or multidirectional patterns, deliberate human intervention can impose new geometries onto the landscape, producing routes that redefine the urban order. The orientation and hierarchy of routes are therefore closely tied to their nodal points, which gain significance through a combination of physical position, accessibility, and social function.

Karakolhane Street in Yeldeğirmeni illustrates this process with remarkable clarity. As construction expanded from the center of Kadıköy, different routes emerged toward key destinations on the Anatolian side and toward the north and west. Karakolhane Street, positioned close to the district's commercial and transport core, benefited from these conditions and became a major structural corridor. The route bears the imprint of Ottoman modernization, functioning as a *cardo-like* axis within a grid system, hosting the rhomboid nodes attributed to Italian engineer Luigi Storari's post-fire planning interventions. These nodes, with their distinctive geometric form, served as spatial attractors that shaped both the ground plan and the vertical profile of the district.

The development trajectory of Karakolhane Street demonstrates how a matrix route not only organizes horizontal morphology but also drives three-dimensional intensification. Over time, plots facing the route accommodated taller buildings, reflecting commercial demand and the functional specialization of nodal points. Diagonal buildings at the square corners differentiated themselves through both architectural expression and height, reinforcing the route's prominence in the urban landscape. Yet, as population pressures increased and zoning regulations shifted, these height distinctions gradually diminished. The mid-rise homogenization of recent decades has altered the skyline, weakening the once-pronounced vertical hierarchy that defined Yeldeğirmeni's character. Today, the most visible remnant of the matrix route's historic role is the street's width, which remains greater than the narrower building routes that intersect it.

This pattern echoes a broader challenge identified by Whitehand (2007) – while historical routes often survive within modern urban fabrics, their morphological significance is seldom fully appreciated in planning practice. Urban landscapes are frequently managed through the protection of individual monuments or designated conservation areas, rather than through a holistic understanding of the interconnected systems that give cities their form. The matrix route, however, is not an isolated relic but a primary structuring axis that carries the spatial memory of the city and informs its three-dimensional evolution. Treating it merely as a circulation line overlooks its deeper function as a generator of urban identity.

Understanding the matrix route therefore requires a comprehensive analysis of its vertical dimension – its height logic, nodal intensities, and the ways in which building massing responds to its hierarchy. This study shows that such an approach provides critical insights for managing historic urban landscapes, particularly those undergoing rapid transformation. The preservation and thoughtful adaptation of matrix routes and their nodes can offer a powerful framework for sustaining urban character while accommodating contemporary needs. In this sense, the matrix route is not only a historic artifact but a strategic guide for future urban development, offering a structural and morphological continuity that can anchor the evolving three-dimensional city.

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