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Araştırma Makalesi Research Article

Fractal Analyzes of Age-Friendly Transportation System: A Comparison of the İstanbul Kadıköy and Beşiktaş

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Abstract

There has been a notable rise in the elderly population and urbanization on a global scale. Urban design plays a crucial role in meeting the demands of the older population and promoting their social engagement and independence. The World Health Organization has published an eight-domain guide to age-friendly cities. Transportation is considered one of the primary concerns highlighted by the WHO. Accessible and reliable transportation helps older adults maintain independence and participate in various social and recreational activities. This research aims to investigate, evaluate, and compare the age-friendliness of urban transportation networks by assessing the complexity and extent of the transportation system using fractal geometry in two particular areas of Istanbul, namely Beşiktaş and Kadıköy. The box-counting analysis was conducted on both the Beşiktaş and Kadıköy public transportation networks in Istanbul, which are part of the age-friendly network, to assess their age-friendliness and efficiency. The findings of this study indicate that the public transportation system in Kadıköy exhibits a greater level of complexity and self-similarity compared to the system in Besiktas. The public transportation system in Kadikoy demonstrates a higher fractal dimension, suggesting a heightened level of connectivity and efficiency compared to the system in Beşiktaş. The findings of this study can be utilized in the context of public transportation to assess its efficacy by identifying its advantages and disadvantages. Consequently, the objective of this approach is to assist policymakers and planners in obtaining a comprehensive understanding of the advantages and disadvantages associated with the existing transportation infrastructure.

Keywords:

Age-Friendly Cities · Fractal Geometry · Box-Counting Method · Image processing · Türkiye · Spatial analysis

Yaş Dostu Toplu Ulaşım Sistemi'nin Fraktal Analizleri: İstanbul Kadıköy ve Beşiktaş'ın Karşılaştırması

Özet

Küresel ölçekte yaşlı nüfusta ve kentselleşmede dikkate değer bir artış görülmektedir. Kent tasarımı, yaşlı nüfusun taleplerini karşılamak ve sosyal katılımlarını ve bağımsızlıklarını teşvik etmek açısından önemli bir rol oynamaktadır. Dünya Sağlık Örgütü (WHO), yaş dostu şehirler için sekiz alanlı bir rehber yayınlamıştır. Ulaşım, Dünya Sağlık Örgütü tarafından vurgulanan başlıca ilgili alan olarak kabul edilmektedir. Erişilebilir ve güvenilir ulaşım, yaşlı yetişkinlerin bağımsızlıklarını sürdürmelerine ve çeşitli sosyal ve rekreasyonel etkinliklere katılmalarına yardımcı olur. Bu araştırma, İstanbul'un Beşiktaş ve Kadıköy bölgeleri olmak üzere iki belirli alanında, şehir ulaşım ağlarının ne kadar yaş dostu olduğunu incelemeyi, değerlendirmeyi ve karşılaştırmayı amaçlamaktadır. Fraktal geometri kullanarak ulaşım sisteminin karmaşıklık ve kapsamını değerlendirerek, Beşiktaş ve Kadıköy toplu taşıma ağları üzerinde kutu sayma analizi yapılmıştır. Bu çalışmanın bulguları, Kadıköy'deki toplu taşıma sisteminin Beşiktaş'taki sisteme kıyasla

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daha yüksek bir karmaşıklık ve özbenzerlik düzeyi sergilediğini göstermektedir. Kadıköy'deki toplu taşıma sistemi, Beşiktaş'taki sisteme kıyasla daha yüksek bir fraktal boyut sergileyerek, bağlantı ve verimlilik düzeyinde artış olduğunu göstermektedir. Bu çalışmanın bulguları, mevcut ulaşım altyapısı ile ilişkilendirilerek, toplu taşıma bağlamında etkinliğini değerlendirmek için kullanılabilir. Dolayısıyla, bu yaklaşımın amacı, politika yapıcılara ve planlamacılara, mevcut ulaşım altyapısıyla ilişkili avantajlar ve dezavantajlar konusunda kapsamlı bir anlayış sağlamaktır.

Anahtar Kelimeler:

Yaş Dostu Kentler ▪ Fraktal Geometri ▪ Kutu Sayma Yöntemi ▪ Görüntü Işleme ▪ Türkiye ▪ Uzaysal analiz

Introduction

The rapid and significant increase in the older population adds momentum and insistence to the age-friendly approach. With the population over 60 predicted to reach 22% by 2050, there will be a growing demand for age-friendly structures and services. Population aging and increasing urbanization are outcomes of successful human growth in the past century but also pose considerable future problems (WHO, 2007). The evolving desires of upcoming generations of older individuals to actively contribute to their surroundings will require a community that provides diverse choices (Fitzgerald & Caro, 2014). The World Health Organization (WHO) Global Network was formed in 2010 as a collaboration of global cities. It focuses on promoting active aging by focusing on both social and environmental factors that affect older communities. This is done using the eight areas outlined by the WHO (Fitzgerald & Caro, 2014).

The WHO's AFEE (The Age-Friendly Environments in Europe) framework includes transport and mobility as one of its domains to improve physical environments for older people. The focus is on accessible and affordable transportation options. As the elderly population increases, there is a need for age-friendly structures and services to support their welfare and productivity. The current topic needs more reliable quantitative research, which makes it challenging to comprehend the efficiency and effectiveness of transportation systems in urban areas. Therefore, this study aims to evaluate and compare the age-friendliness of urban transportation systems in two districts of Istanbul: Kadikoy and Besiktas. A fractal analysis method is used to achieve this. This study aims to determine the level of age-friendliness in the transportation systems being investigated to provide valuable insights to policymakers and planners. Fractal analysis is a valuable tool in assessing the complexity and efficiency of transportation systems, and it can contribute to creating age-friendly cities by promoting accessible and reliable transportation for older adults.

Fractal geometry is employed to evaluate the complexity and extent of the transportation system. By utilizing fractal analysis, this research aims to provide insights into the age-friendliness and efficiency of urban transportation networks. The objective is to assist policymakers and planners in obtaining a comprehensive understanding of the advantages and disadvantages associated with the existing transportation infrastructure.

Background

Age-Friendly Cities

Environmental gerontology has highlighted the importance of creating age-friendly communities. Studies show that the physical surroundings significantly affect the well-being of older adults. Urban settings have been found to impact the accessibility and autonomy of elderly inhabitants (Fitzgerald & Caro, 2014). Promoting supportive environments for older individuals by prominent international organizations such as the WHO and the United Nations has encouraged discussions about age-friendly communities. The term 'age-friendly city' was first introduced by the WHO in 2005 (Lui, Everingham, Warburton, Cuthill, & Bartlett, 2009). The project asked elderly individuals in focus groups to describe the advantages and obstacles they encountered in urban living areas. This gave elderly individuals a voice and resulted in the original WHO global guide and a checklist of characteristics that older people identified as essential within eight domains of an age-friendly city (WHO., 2007). This project aimed to create age-friendly urban environments, ensuring older adults' health and well-being (Lui et al., 2009).

Age-friendly cities facilitate active aging and community participation, empowering older adults to lead fulfilling lives while contributing to their communities (Fitzgerald & Caro, 2014).

Active aging benefits people of all ages in an age-friendly city. Enhanced infrastructure and safe communities improve mobility, independence, and security. Access to community assistance and health services reduces stress for the whole family (WHO., 2007).

An age-friendly community enables elderly residents to participate in community life through social contact and communal resources. This includes shopping, using parks and libraries, and participating in civic associations. An age-friendly community incorporates environmental and social components to provide abundant prospects for thriving in old life (Fitzgerald & Caro, 2014). The built environment encompasses various dimensions, including urban design, land use, and transportation networks (Ghanat Bari & Tekel, 2022). Improving living conditions for the elderly involves considering factors such as environment, social structures, engagement, well-being, and security. Research highlights that physical environment and residential arrangements can significantly impact their welfare. (Lui et al., 2009).

This intersection reinforces the claim that a community that is accommodating to people of all ages may be advantageous for all inhabitants, not just the elderly (Fitzgerald & Caro, 2014). Urban planning now focuses on creating inclusive strategies for the elderly through thoughtful neighborhood design, strategic location concepts, and healthcare considerations (Lui et al., 2009). The Outdoor surroundings, housing and transportation, social involvement, dignity, civic involvement and employment, communication and information, community support, and health services are all covered under the WHO AFC framework (WHO., 2007). Figure 1 depicts the structural arrangement of the Age-Friendly Environments in Europe project.

The primary aspect of age-friendly cities is the physical environment, which encompasses transportation and mobility, outdoor spaces, and housing. This guide aims to help cities adopt the viewpoint of older adults to identify areas that need development and find strategies to become more accommodating to their needs (WHO., 2007).

Importance of age-friendly transportation for older adults in urban areas

Growth projections indicate that a significant portion of Europe's population, around a quarter, will be aged 65 and above in the next thirty years. This demographic change presents challenges for society, particularly in developing effective strategies for healthy aging. WHO defines healthy aging as enhancing overall well-being in later stages of life. It is crucial to anticipate and provide solutions that cater to the specific needs of older adults, including their vulnerability to social isolation and injury. Transportation plays a vital role in enabling senior citizens to access urban mobility services and engage with the wider community, promoting active aging, participation, health outcomes, inclusion, and overall quality of life (WHO., 2007). Maintaining mobility is essential for the well-being and quality of life of elderly individuals, as it helps them retain independence, engage in social activities, and access necessary resources (Marsden et al., 2007; Tinella et al. 2023). Limited mobility and inadequate transportation options can lead to social isolation, reduced physical activity, and limited access to healthcare services (Michael et al., 2010). While driving is the main mode of transportation for most elderly individuals, func-

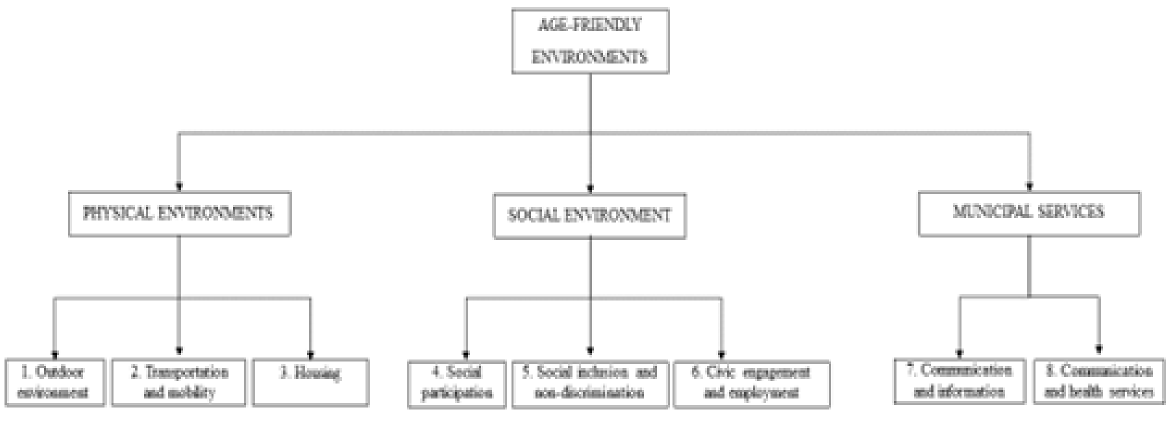

Figure 1. Age-friendly city domains (WHO., 2007)

tional limitations such as cognitive decline, visual impairment, and dementia can hinder their ability to drive safely (Bokolo, 2023). Studies have shown that older individuals often transition from driving to becoming vehicle passengers and eventually using public transportation (Golob & Hensher, 2007). A robust transport system should include safe and user-friendly public transport options for the elderly, as public transportation plays a pivotal role in enhancing their mobility, eliminating barriers, and promoting social inclusion (Islam, 2016; Musselwhite & Shergold, 2013).

In the previous studies done on this subject, several issues were raised:

In Saif et al.'s (2018) research, the available literature on public transport accessibility (PTA) has been reviewed, and the connection between (PTA) and different aspects of either transportation system, including mobility and sustainability or human life including employment rates, public health, social exclusion etc, have been investigated. It is highlighted that the performance of public transportation and its impact on other social aspects should be considered while planning public transport facilities. Accessible and affordable transportation is crucial for older adults to enhance their quality of life and maintain an active social life. However, there are challenges in ensuring equal access to transportation for all, particularly the elderly, and age discrimination can be a problem. The availability of public transportation is crucial for older individuals, and it is essential to provide dependable transportation services to enhance their quality of life. The rapidly increasing aging population has significant social and economic consequences, and the needs of elderly individuals vary based on various factors such as lifestyle, socio-demographic characteristics, and cognitive and mobility functioning. The lack of adequate transportation system standards hinders the mobility of senior citizens and restricts their participation in social events. Assessing current transportation systems for compliance with effective and elder-friendly standards is necessary, focusing on affordability, accessibility, and safety.

Public transport is an essential component of most people's lives. This specific group of population growth will require special attention to accessibility and mobility issues in combination with the transport system, which undoubtedly can play a key role in support (Fatima & Moridpour, 2019). Fatima and Moridpour (2019) in their research identify the travel patterns and modes for elderly commuters in greater Melbourne, Australia. Using VISTA (Victorian Integrated Survey of Travel and Activity) 2012, travel patterns were analyzed using the statistical software SPSS. The study proposes strategies to improve public transport system use to promote aging in place. Promoting secure and easily accessible public transit systems is crucial for enhancing urban transportation, and effective policies are needed to achieve this goal. However, there is a lack of information and research on the mobility needs of older adults, and comprehensive support services are required to ensure sustainable mobility and social participation. Accessibility refers to the ability of seniors to easily access services that meet their mobility needs, utilizing nearby amenities and resources. Increasing the number of cars, routes, stations, and stops in areas frequently visited by the elderly can enhance accessibility.

Klicnik and Dogra's (2019) study aims to identify and understand the constraints to active transportation that older adults experience to inform the development of viable solutions. Focus group interviews were conducted with community-dwelling older adults (n = 52) living in the City of Oshawa in Ontario, Canada. Active transportation is an accessible and affordable mode of physical activity that facilitates active aging. This is an important consideration as cities work towards becoming age-friendly. It was clear from our data that urban design and the policies and practices of municipalities are key influencers of engagement in active transportation among older adults. Thus, an age-friendly and accessibility lens needs to be applied to all working committees in municipalities.

Metropolitan areas face challenges in ensuring secure transportation for elderly individuals and those with disabilities, as transportation infrastructures are complex and interconnected. The integration of various means of public transportation, particularly the first and last segments of the trip, is crucial for elderly individuals. The objective of the study is to assess the extent of accessibility to public transportation using fractal analysis to evaluate its coverage.

Previous research has emphasized the importance of developing cities that accommodate older adults and reduce their challenges when using public transportation. However, there needs to be more quantitative studies that allow us to evaluate and analyze the current transportation system from the lens of municipal practices, policies, and urban design. Fractal geometries have characteristics of self-similarity and scale invariance, which can provide valuable insights into the coverage and accessibility of transportation networks by referring to urban design. Using fractal geometry allows us to examine the expansion of the current comprehensive network and identify areas that can be improved. The purpose of this research is to assess the comprehensiveness and convenience of transportation infrastructure using the principles of fractal geometry and deliver measurable results from an urban design project (even before it is applied to the city).

Fractal analysis

The word “fractal” has its roots in the Latin term “fractus,” which means “broken or fractured.” This concept was introduced by Benoit Mandelbrot (Dasari & Gupta, 2020).

Fractals are complex, self-replicating geometric forms characterized by a recurrent pattern that spans several scales. Fractals are used in urban studies to analyze the configuration of cities, specifically the allocation of land use and the progression of growth. Fractal dimensions often fall within the range of 1 to 2, where higher values suggest a consistent spatial arrangement and lower ones suggest a fragmented one. Research in this field has been carried out by Michael Batty (1994), Benguigui, Czamanski, Marinov, & Portugali (2000), Wang, Luo, & Luo (2017), Chen & Wang (2013), Frankhauser (2015), Lagarias (2008), Terzi & Kaya (2011), Thomas, Frankhauser, & Biernacki (2008).

Fractal theory was introduced during an analysis of Britain’s coastline. It has since been applied to various fields, including urban morphology. The fractal dimension is a mathematical concept that measures an object’s roughness across different sizes, allowing us to analyze spatial patterns. A higher fractal dimension indicates greater efficiency in space-filling (Sreelekha et al., 2016). Fractality is linked with how an object or a set of objects fills space. If we imagine space as a flat plane and objects as within that plane, a line would have only one dimension, while a surface would have two. Unlike simple lines or surfaces, Fractals do not take up space similarly. Instead, their fractal dimension falls between 1 and 2, depending on how alike they are to themselves at different measurement scales (Abid & Tortum, 2021). This self-similarity reflects the universal law of urban spatial form, leading to research on the fractal dimensions of cities and their road networks (Wang et al., 2017). Fractal dimensions are used to quantitatively evaluate urban road networks’ distribution density, network complexity, coverage, connectivity, and access depth. Using fractal theory can facilitate more comprehensive and in-depth quantitative research on specific problems, leading to richer, systematic conclusions (Deng en at., 2023). The study of urban morphology involves examining the organization of constructed areas and other architectural features of the city, including transportation networks, through fractals. The fractal dimension, denoted by D, measures the spatial arrangement of developed areas. As patterns become more evenly distributed, fractal dimension values increase, whereas lower values are observed when development patterns are linear, contrasting, or fragmented. The fractal dimension is a metric used to quantify various aspects of the complexity of urban development patterns, intending to capture specific attributes (Lagarias & Prastacos, 2020, 2021). A transportation system with a higher fractal dimension indicates that the transport network has increased interconnectedness and covers a larger area of central district zones (Abid & Tortum, 2021).

Fractal theory has expanded into numerous fields, including geometry, complex systems, geography, and urban morphology. Urban areas are considered complex hierarchical systems, and their fractal characteristics are particularly fascinating for defining city limits and designing urban layouts. Therefore, it is critical to incorporate fractal theory into urban planning and development research (Wang et al., 2017). As a result, incorporating fractal theory into urban planning and development research has become essential.

Fractal dimension and density are related, with a larger fractal dimension indicating a higher density due to more iterations and complete occupation of the assigned area (Jahanmiri & Parker, 2022). The fractal characteristics of urban forms and road networks can provide valuable information for urban planning (Wang et al., 2017). In a way, the fractal dimension reflects the spatial pattern of a transport network filling urban space (Sreelekha et al., 2016).

Aim

This study suggests employing fractal analysis to assess urban transportation systems in two districts of Istanbul to aid policymakers in developing and enhancing transportation systems.

Method

Fractal dimension can be determined using several methods, such as the cell count, box counting, and mass-radius methods. City subsystems, including the transportation system, exhibit fractal properties. The box-counting method has been extensively utilized to determine the fractal dimension of transportation networks, as evidenced by numerous studies (Benguigui et al., 2000; Kim et al., 2022; Shen, 2002; (Sreelekha et al., 2017; (Sreelekha et al., 2016; Muñoz et al., 2018; Santos & Santos, 2018). Box fractal dimension (D) is a measure used to quantify the spatial pattern of a road network (Sreelekha et al., 2016). The box-counting method was selected for calculating the fractal dimension due to its simplicity and effectiveness in capturing complex patterns' self-similarity and spatial characteristics. The box-counting method overlaps a grid of cells onto an object and counts the number of occupied cells. This is done using grids of varying cell sizes. The box dimension is calculated by plotting the logarithm of the number of occupied cells (N) against the logarithm of the inverse of the cell size. The slope of the resulting line corresponds to the box dimension (Abid et al., 2021).

Case Study

This research aims to assess the age-friendliness of two areas in Istanbul, Turkey. These areas, Kadıköy and Beşiktaş, were both added to the World Health Organization's Global Network for Age-Friendly Cities and Communities in 2016 and 2019, respectively
('Besiktas Municipality - Age-Friendly World', 2019;'Kadıköy - Age-Friendly World', 2016)
(https://extranet.who.int/agefriendlyworld/afp/kadikoy-municipalitys-social center/) (https://extranet.who.int/agefriendlyworld/network/besiktas).

Data Analysis and Result

OpenStreetMap (OSM) was chosen as the resource for urban transportation network maps in this study due to its comprehensive and freely available data. OSM provides a range of data from many world regions, making it a valuable tool for analyzing transportation systems in different cities. Similarly, data from the Kadikoy and Besiktas districts was merged and stored using the Quantum Geographic Information System (QGIS). QGIS is a widely used spatial data analysis and visualization software that allows researchers to efficiently manipulate and analyze geographical data. The transportation map of the areas, which includes train, bus, and subway routes, has been exported and evaluated using the box-counting method. The Political Map of Turkey from the General Directorate of Mapping, Ministry of National Defense, was chosen to establish the boundaries of Istanbul neighborhoods due to its authoritative and reliable nature. The images used in this study had the exact dimensions (4661x2344 pixels) and resolution (360 dpi) to ensure the accuracy of the analysis. Consistent dimensions and resolution are essential for preventing distortion or misinterpretation of the data. If the images had different dimensions or resolutions, it could lead to inconsistencies in scale and clarity, which may affect the accuracy of the analysis. The working space of QGIS is depicted in Figure 4.

The proposed approach involves dividing the transportation pattern into a grid including several dimensions and then capturing the number of boxes encompassing relevant data at each iteration. By iteratively applying this methodology at various iterations and modifying the dimensions of the grids, we can obtain a quantitative value for the fractal dimension, which characterizes the level of spatial occupation and complexity of the transportation infrastructure. The analysis comprised four distinct steps, wherein the transportation pattern was systematically divided into grids of decreasing sizes. At each iteration, the dimensions of the grids were halved, leading to reduced grid sizes and facilitating a more comprehensive examination of the transportation system.

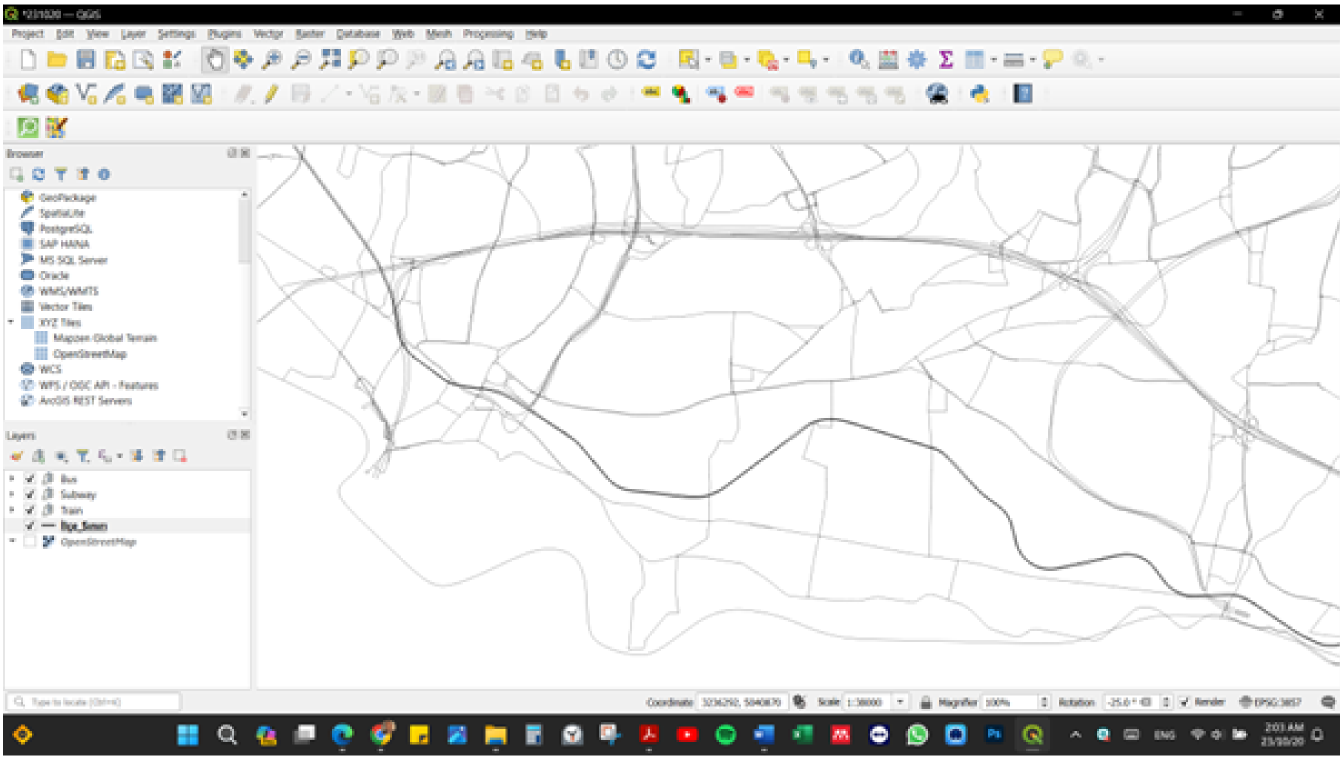

Figure 2. Qgis downloaded bus, train, subway, and district layers of İstanbul

Methodological Factors

It is observed that the box-counting methodology is influenced by five interconnected factors that significantly impact the accuracy of the results. These factors include the attributes of the field, such as the proportion of background and white space; the characteristics of the image, such as bit depth and line width; the disposition of the grid, including the placement and orientation of subsequent grids, the scaling coefficient, which represents the ratio between successive grids, and the statistical divergence, which involves error management and limits (Ostwald, 2013). Therefore, In our case study, we set the study by considering these factors.

The box-counting technique was applied to the Kadıköy urban transportation map with a grid length of 293 to 293 pixels, 146.5 to 146.5 pixels, 73.25 to 73.25 pixels, and 37 to 37 pixels. Additionally, the map was scaled down by 0, 2, 4, and 8 factors. The first and last steps are presented in Figures 5 and 6.

Moreover, the box-counting technique was also applied to the Beşiktaş urban transportation map, with a grid length of 293 to 293 pixels, 146.5 to 146.5 pixels, 73.25 to 73.25 pixels, and 37 to 37 pixels. Additionally, the map was scaled down by 0, 2, 4, and 8 factors. The first and last steps are presented in Figures 7 and 8.

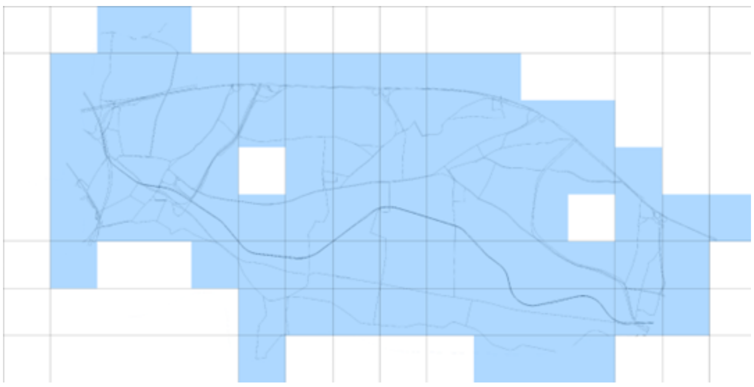

Figure 3. Box-counting grid system applied to Kadıköy urban transportation map with a grid length of 293 to 293 (pixels) with the scaled-down factor of 0

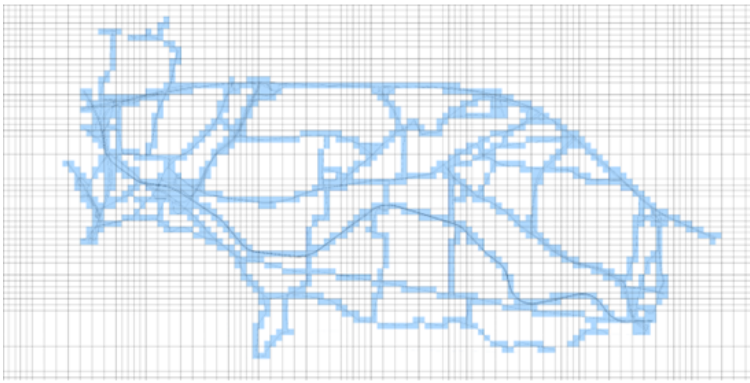

Figure 4. Box-counting grid system applied to Kadıköy urban transportation map with the grid length of 37 to 37 (pixels) with the scaled-down of 8

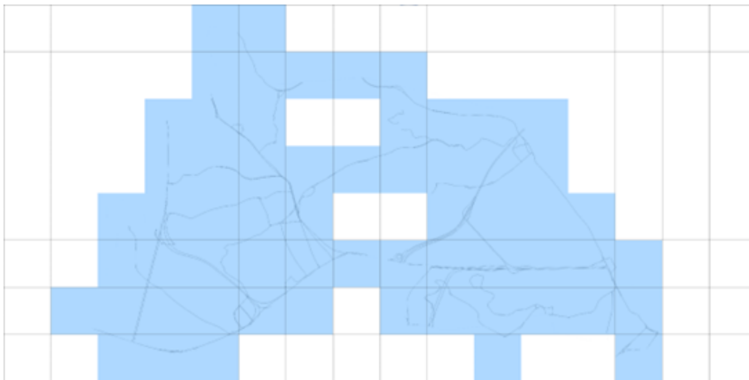

Figure 5. Box-counting grid system applied to the Beşiktaş urban transportation map with a grid length of 293 to 293 (pixels) with a scaled-down factor of 0

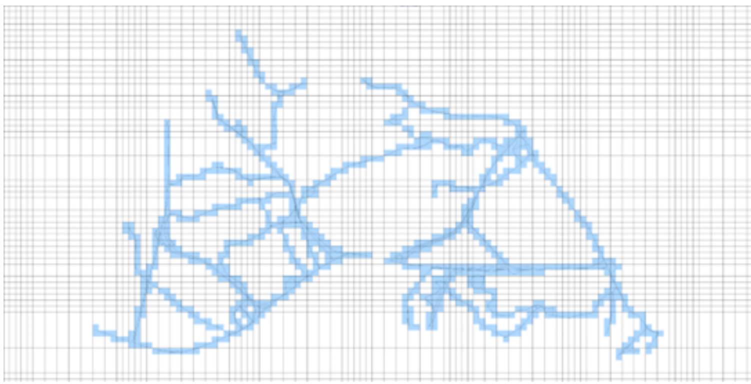

Figure 6. Box-counting grid system applied to the Beşiktaş urban transportation map with a grid length of 37 to 37 (pixels) with the scaled-down of 8

Results

Quantification of the information that is included in boxes at each level is part of the process of collecting data. The logarithmic values of the scaled factor and the number of boxes are then computed and entered in Tables 2 and 3, respectively. The scaled-down factor represents the division proportion at each stage of the box-counting analysis. The logarithmic outcome of the scaled-down factor value is called Log (S). On the other hand, the number of boxes in each analysis stage containing information is denoted by (N). The logarithmic value of the number of boxes is recorded as Log(N).

Logarithmic values of (S) are plotted along the y-axis of a log-log plot, while logarithmic values of (N) are plotted along the x-axis of the same plot. This plot is created using the findings that

Scaled-down factor (S)	0	2	4	8
Log (S)	0	0.301029996	0.602059991	0.903089987
Number of boxes (N)	61	160	381	824
Log (N)	1.785329835	2.204119983	2.580924976	2.915927212

Table 2. Parameters for the box-counting analysis for the Beşiktaş public transportation system

Scaled-down factor (S)	0	2	4	8
Log (S)	0	0.301029996	0.602059991	0.903089987
Number of boxes (N)	76	222	560	1255
Log (N)	1.880813592	2.346352974	2.748188027	3.098643726

Table 3. Parameters for the box-counting analysis for the Kadıköy public transportation system

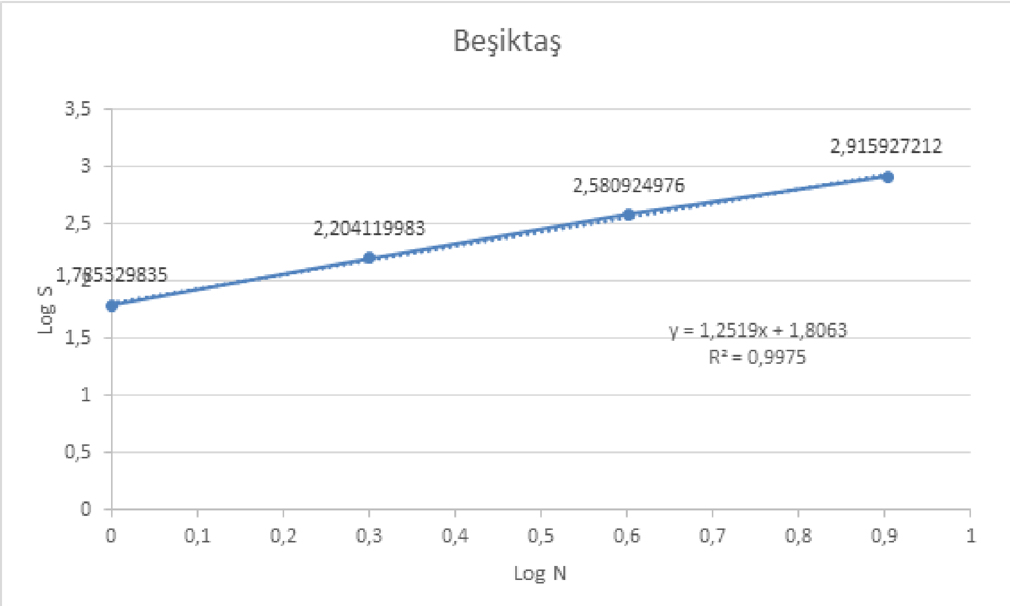

Figure 7. Log-Log chart illustrated for the Beşiktaş districts according to the box-counting analyses outcomes

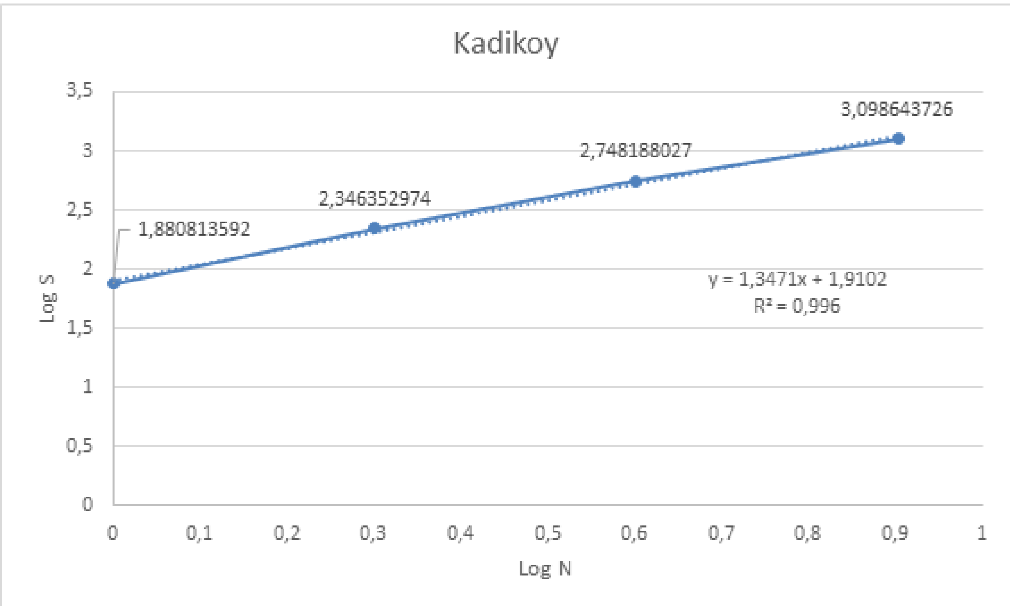

Figure 8. Log-Log chart illustrated for the Kadikoy districts according to the box-counting analyses outcomes

were acquired. Calculating the mean slope of the resulting line on the log-log graph is how the fractal dimension is achieved. Figures 9 and 10 present the graph for the Beşiktaş and Kadıköy, respectively.

Based on comprehensive evaluations, it has been determined that the fractal dimension of the public transportation system in Kadikoy is computed to be 1.34. In contrast, the fractal dimension of the transportation system in Besiktas is seen to be 1.25.

Discussions

The lack of appropriate and dependable metrics that accurately capture the complex interplay between aging and the environment poses a significant challenge in developing age-friendly communities. To make progress, it is essential to adopt more rigorous assessment methodologies and tools that can effectively measure, enhance, and validate theories, as well as enable efficient planning, execution, and evaluation of the impact of AFC initiatives on individuals and communities (Kim et al., 2022). Spatial analysis approaches currently in use are not capable of providing a comprehensive evaluation of the complex subsystems that make up a city, such as population dynamics, land use, and transportation networks, at different scales. Fractal analysis, on the other hand, can do so, as it can assess a system from a macro to a micro level due to the fractal characteristics of the transportation network and other subsystems in a city, such as irregularity, scale invariance, and self-similarity. Therefore, fractal analysis can be an effective tool for gathering and presenting information in a city (Dasari & Gupta, 2020). A way to measure the complexity of a pattern is by using the fractal dimension.

This study aims to analyze and evaluate the transportation networks in two age-friendly areas of Istanbul regarding their extent, accessibility, and suitability. Insights are being provided to policymakers and planners to improve and enhance transportation networks. The assessment of public transit networks' coverage and inclusiveness is conducted using fractal geometry. The fractal dimension was calculated for the public transportation systems in Kadikoy and Besiktas. The results show that Kadikoy has a higher fractal dimension of 1.34, indicating a more complex and efficient transportation system when compared to Besiktas, where the fractal dimension is 1.25. The study indicates that the transportation system within Kadikoy has a more fractal dimension, which can contribute to a more inclusive and accessible transportation system for people of all ages. Therefore, an age-friendly transportation system needs to promote greater inclusivity. This research can help improve transportation infrastructure and promote inclusivity in metropolitan areas, benefiting all residents, especially seniors.

Limitation and implication

Fractal studies aim to establish a connection between a city's function and urban organization and its fractal measurement. Shen's (2002) research investigates how the extent of urban development, in terms of built-up and urbanized areas, correlates with the fractal assessment of urban shape. Batty and Longley (1994) suggest conducting further research to investigate the correlation between urban size, fractal dimension, dynamic density, and developing structure. According to the findings of previous studies, it is recommended that future research on fractals in cities and urban subsystems should concentrate on establishing meaningful links between the measurement of a city or its subsystem using fractal analysis and its functioning and development dynamics. It is crucial to carry out this study to reveal the significant relationship between fractal geometry and policymaking and planning in the real world (Dasari & Gupta, 2020). There are various methods to determine the fractal dimension, such as cell count, box counting, and mass-radius approaches. The transportation system, along with other subsystems in the city, has fractal characteristics. Fractal analysis is useful in evaluating features like irregularity, scale invariance, and self-similarity. By analyzing the fractal dimension of the transportation system, valuable insights can be gained into its spatial characteristics, including the distribution of space, extent, and interconnections.

Our research has the potential for expansion and improvement in future studies, building upon the foundation we have laid. It is essential to acknowledge the limitations of our research to comprehend its implications fully. Our study focused on only two neighborhoods in Istanbul that were approved as age-friendly by the WHO. Future research can be conducted with a broader case study to examine the feasibility and effectiveness of implementing age-friendly policies in various cities across the globe. Furthermore, in this study, we utilized public transportation data from OpenStreetMap, an open data source, but having access to more comprehensive data can improve future research studies.

Conclusions

The conclusion that can be drawn from the significance and contribution of this study is as follows:

1. Assessing Age-Friendliness: The study aims to assess and evaluate the age-friendliness of urban transportation systems in two districts of Istanbul, Kadikoy and Besiktas. Using a fractal analysis method, the study provides a quantitative measure of the age-friendliness of these transportation systems. This assessment is crucial for policymakers and planners to understand the strengths and weaknesses of the existing transportation infrastructure and make informed decisions to enhance its age-friendliness.

2. Efficient Methodology: The study offers an efficient method for calculating the coverage of complex transportation networks in urban areas from an age-friendly city vision. By using fractal analysis, which captures the complexity and connectivity of transportation networks, the study provides a comprehensive and holistic approach to evaluating the age-friendliness of transportation systems. This methodology can be applied to other cities and regions to assess and enhance their transportation systems.

3. Policy and Planning Guidance: The study's results can assist policymakers and planners in designing and enhancing sufficient transportation systems. By identifying areas of improvement and providing insights into age-friendly features and amenities, the study can guide the development of transportation infrastructure that meets the unique needs and circumstances of older individuals. This can create more inclusive and accessible cities for all residents, including older adults.

Overall, the study's significance lies in its contribution to the age-friendly movement by providing a quantitative assessment of the age-friendliness of urban transportation systems. It offers an efficient methodology and valuable insights for policymakers and planners to enhance transportation infrastructure and services to support the well-being and mobility of older individuals in urban areas.

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