Impact of Urban Form on Movement Densities: The Case of Street Networks in AlKarkh, Baghdad, Iraq

Saif Albabely[1] & Dhirgham Alobaydi[2]
Department of Architecture Engineering, College of Engineering,
University of Baghdad, Baghdad, Iraq.
saifullah.Mansour2004D@coeng.uobaghdad.edu.iq
dalobaydi@uobaghdad.edu.iq , dalobaydi@gmail.com

Abstract

This paper investigates the correlation between the arrangement of street networks and the density of movement in historic urban cores, with a focus on the AlKarkh area in Baghdad, Iraq. The objective of this study is to understand the impact of urban spatial configuration on movement densities.

The research employed various methods within a case study approach and involved site observations, and space syntax analysis. 'Integration' and 'Choice', the two key measures of space syntax analysis were utilized to identify the most integrated streets and accessible paths with significant depth values, as well as less integrated streets and inaccessible paths with low values. This analysis aims to comprehend how the spatial arrangement of the street network influences the movement patterns of both pedestrians and vehicles in the area.

The findings reveal that the spatial configuration of the street network plays a vital role in shaping the distribution of movement densities. The correlations demonstrate that increased radii values in the movement process lead to higher integration values and expanded areas within the entire network system. The study concludes that AlKarkh's main streets, notably Haifa Street and key intersections, act as dynamic urban arteries, fostering diverse interactions and activities, optimizing pedestrian and vehicular mobility, and driving vibrant movement densities, enhancing the representation of movement patterns in sustainable and livable historic cores. The study's recommendations for urban designers and policymakers, along with future research directions, are important for optimizing movement patterns and fostering vibrant, sustainable, and livable historic cores like AlKarkh.

Keywords: Streets, Urban form, Integration, Choice, Syntactic properties, and AlKarkh.

Introduction

Urban environments are complex systems, comprising interconnected networks of streets that serve as the arteries of movement for both pedestrians and vehicles. Spatial configurations of street networks within historical urban cores play a crucial role in shaping the distribution and intensity of movement densities (Hillier and Hanson, 1989; Hillier 2007). Understanding the relationship between urban form and movement patterns is essential for effective urban planning and design, particularly in densely populated areas where efficient movement is vital (Kostof, 1991; Montgomery,1998).

According to Hillier and Vaughan, (2007), Space syntax plays a crucial role in analyzing the impact of spatial configuration on movement density in the built environment. As Hillier, (2005) points out, space syntax techniques can produce insights into the patterns and distribution of movement, shedding light on the relationship between spatial layout and human mobility. It enables a comprehensive understanding of how the arrangement of spaces and their connectivity influence movement patterns and density (Hillier,2008).

Space syntax provides a valuable framework for studying movement density within the built environment (Hillier,2005; Hillier,2014). Analysis of spatial configuration can identify areas that attract higher levels of movement and those that experience lower levels of activity. Van Nes and Yamu (2021) show that space syntax enables the identification of spatial configurations that facilitate or hinder movement density through the examination of connectivity and accessibility of different spaces. This knowledge can inform urban planners and designers in creating more efficient and accessible environments that promote higher levels of movement and activities.

Moreover, space syntax analysis enables the exploration of the relationship between spatial configuration and movement distribution. Hillier (2008) further points out that it can uncover patterns and variations in movement density by examining how movement is distributed across different areas of the built environment. This understanding can inform decisions regarding the placement of amenities, transportation infrastructure, and public spaces to ensure an equitable distribution of movement opportunities and facilitate social interactions. Thus, space syntax contributes to the creation of more inclusive and livable built environments by enabling the consideration of the impact of spatial configuration on movement distribution (Hillier,2007).

Space syntax analysis thus plays a significant role in describing the impact of spatial configuration on movement density in the built environment. It provides insights into the patterns and distribution of movement, facilitating a better understanding of how spatial layouts influence human mobility (Van Nes and Yamu,2021; Pont and Marcus,2015). Indeed, space syntax techniques, help urban planners to make informed decisions to create more efficient, accessible, and inclusive environments that promote higher levels of movement and enhance the overall quality of urban life.

Review of Literature

There is extensive literature that have employed the space syntax approach, measures and techniques to examine the role of spatial configuration of the built environments in relation to urban forms and structures. Griffiths (2012) has highlighted the importance of integrating space syntax in historical urban research to explore the relationship between urbanism and social activities. He shows that by incorporating spatial history and historical contexts, researchers can address current urban challenges and gain insights for future urban design. Griffiths et al. (2013) have also examined historical changes in main streets in London suburbs, emphasizing the significance of mixed activities and community engagement for sustaining vibrant city centers. Similarly, Badach et al. (2018) have analyzed the influence of urban movements and non-governmental organizations

on spatial development and local urban planning processes in Poland, emphasizing sustainable development and participatory planning.

On the other hand, Soltani et al. (2019) have highlighted the significance of analysis programs and spatial syntax tools in accurately measuring socio-spatial aspects of the built environment. Matejcek and Pribyl (2020) have elaborated on this when they introduced space syntax as a versatile tool in city planning, enabling the analysis of spatial configuration and its impact on human behavior. Jin et al. (2022) have also investigated Guangzhou's historical district, emphasizing the need for improved accessibility and the consideration of socio-economic factors in preserving and distributing historical buildings. Asami et al. (2003) extends this by introducing the incorporation of the third dimension in space syntax analysis, specifically applied to historical Istanbul. They provide valuable insights into the spatial dynamics and accessibility of the city, while contributing to a better understanding of its historical development and urban design by considering vertical connectivity in addition to horizontal spatial configuration.

In the realm of urban development, Alobaydi and Rashid (2017) have examined the impact of European colonial powers on Baghdad's urban cores, advocating for the integration of modern planning approaches with the existing urban fabric. Al-Saaidy and Alobaydi (2020, 2021) have investigated the effects of morphological changes on traffic performance and the connection between road network features and population density in Iraq, providing insights for transportation planning and the preservation of cultural and historical identity. Al-Hinkawi et al. (2021) have examined the impact of urban growth on street networks and land use in historical city centers, highlighting the importance of understanding spatial organization and integrating new development processes with traditional urban fabric. Furthermore, a series of studies have studied into the analysis of spatial configuration using morphological approaches. Notably, Mohammed and Alobaydi (2020a, 2020b), Alobaydi et al. (2020), Karimi (2018) explored the subject in relation to residential areas; in relation land use distribution (Farhan et al., 2022; Alsaffar and Alobaydi, 2023; Al Hashimi and Alobaydi, 2023); in relation to the growth and residential clusters (Aziz et al. 2020; Al Sayed et al., 2022); in relation to street properties (Kaplan and Omer, 2022; Serra et al. , 2015). These research efforts contribute valuable insights into understanding the interplay between spatial layout and urban development.

These studies enhance our understanding of urban dynamics and underscore the importance of incorporating sustainable practices, engaging the communities, and integrating historical and cultural elements into urban planning and development. However, further research and investigations are needed to deepen our knowledge in the field of urban design and gain a better understanding of the existing built environment. This ongoing exploration will contribute to more informed decision-making and improved approaches to shaping our cities.

The Research

This paper is divided into three main parts. First, it introduced the utilization of the space syntax approach to comprehend the built environment, both in relation to other urban features and independently. The second part outlines the methods, measures, and techniques employed, categorizing them according to the research analysis process. Finally, the paper presents, discusses, and compares the findings based on the measured outcomes.

The aim of this research is to investigate the impact of spatial configurations within street networks on movement densities in historic urban cores, with a specific focus on the AlKarkh area in Baghdad, Iraq. AlKarkh has been selected for study purposes because it stands out as an engaging case study due to its status as one of the oldest historic cores in the region, its diverse heritage buildings and urban fabrics, its cultural richness, and the presence of traditional souqs that offer a glimpse into the area's vibrant past and present. As a subject of study, AlKarkh presents a wealth

of knowledge about the human heritage and history of Baghdad, making it a compelling and relevant area for further research and preservation efforts. In order to meet this aim, a set of objectives which are:

- To analyze the spatial arrangement and connectivity of street networks in AlKarkh using Space Syntax analysis and identify highly integrated streets and key intersections.
- To examine the movement densities of pedestrians and vehicles in the study area through site observations and traffic data collection during peak hours.
- To provide valuable recommendations for urban designers and policymakers, based on the research findings, to enhance the spatial network and create sustainable and livable historic cores that optimize pedestrian and vehicular mobility.

Research Methodology

This study utilizes various research approaches to examine the subject matter. The approaches encompass analyzing a case study, making site observations, conducting space syntax analysis, and performing statistical analyses. By integrating these approaches, a thorough and reliable methodology has been devised to steer the research process.

The researcher collected basic data, such as maps, photos, and reports of the study areas, from relevant sources (Al-Ashab,1974; Fethi, 1978; Pieri, 2008; Pyla, 2008; Al-Saffar, 2018; Alobaydi, 2017), including the Department of Research and Studies in the Municipality of Baghdad. However, to ensure up-to-date information, the data was supplemented and updated through on-site visits, observations, and surveys conducted by the researcher.

Space Syntax (Measures and Techniques)

Space Syntax analysis is a valuable methodology that provides insights into the dynamics of movement and flow in urban environments. It focuses on understanding how people and vehicles interact within cities, contributing to our understanding of how urban areas function (Penn, 2003). By analyzing the spatial arrangement and connectivity of streets, the Space Syntax approach offers valuable insights into how street layouts influence movement patterns (Steadman, 2004). This analysis examines the syntax properties of street networks, identifying integrated or segregated streets and their relationship with crowded movements and surrounding activities (Hillier, 2002; Hillier and Hanson, 1984). Consequently, the Space Syntax approach enhances our understanding of how different urban environments impact vehicle movements and their connections to social and economic activities

The axial map is a vital component of the Space Syntax approach, providing a visual representation of how streets are organized in urban networks. These maps enable the analysis of street connectivity, integration, and segregation, shedding light on how people navigate through urban spaces (Penn, 2003). To study specific areas within the built environment, axial maps are transformed into dynamic depictions of streets, intersections, and nodes using AUTOCAD 2022 (Hillier, 1984). The drawing process focuses on maximizing the length of axial lines while minimizing their quantity, while ensuring uninterrupted connections between key points. Furthermore, the functionality of street networks is examined using DepthmapX, a performance analysis tool (Lerman and Omer, 2014). By establishing spatial relationships among streets, intersections, nodes, dead-ends, and open spaces, DepthmapX generates a structured map that enhances our understanding of how the road network operates, its activities, accessibility, density, and social performance.

Angular segment analysis is a significant aspect of Space Syntax, focusing on individuals' cognitive behavior during navigation. It considers the preference for paths with minimal angular changes (Turner, 2001; Turner, 2007). By examining overlapping trips through each segment, valuable insights into frequently used paths are gained (Turner, 2000; Kolovou et al., 2017). Dividing intersecting lines into parts and creating an angular segment map allows for accurate analysis and advanced understanding of global and local integration (Turner, 2007; Shatu et al., 2019).

Integration is a crucial measure in Space Syntax analysis, determining the relative depth of a spatial system from any point within it. It assigns values to axial lines based on their connectivity to other lines, indicating their integration or separation. High integration is represented by red-colored lines, indicating better connections, while blue-colored lines represent lower integration Hillier, 2007; Hillier 2008; Alobaydi and Rashid, 2015). Global integration assesses how well-integrated a street axis is with all other streets in a system, while local integration focuses on the integration values within a localized area. Choice measures in Space Syntax analysis provide valuable insights into the potential for movement and accessibility within a street network. Global choice evaluates overall movement and accessibility on a larger scale, assessing the shortest distances and network efficiency. Local choice focuses on specific areas within a network, such as markets or shopping centers, measuring movement potential and accessibility within localized regions (Rashid and Alobaydi, 2015). This analysis helps understand the ease of reaching destinations within a limited number of steps. These measures play a crucial role in urban design and planning.

Given that this research examines the case study of AlKarkh area, it is crucial to provide a comprehensive description of the urban form of this historic core.

The Case Study (AlKarkh)

Urban Form

The historic core of AlKarkh, as a significant part of Old Baghdad and its heritage, represents an essential piece of Iraq's cultural heritage (Al-Ashab,1974), as seen in the Fig. 1. The study of this area could provide a valuable opportunity to gain insight into the urban development of Baghdad throughout history (Fethi, 1978).

The study area presents a complex blend of the traditional, irregular organic urban fabric and grid urban fabric formed over time in response to urban growth processes and the general needs of the region. The historic center of the area has been divided into parts by road networks that have penetrated the old urban fabric, thereby affecting the spatial organization characteristics that characterize the old fabric. Over-population and density of housing have further contributed to the deterioration of the old fabric, making it an unsuitable environment for housing due to the weakness of services and their inability to meet the housing requirements (Al-Saffar, 2018) (Fig. 2).

Moreover, the area has been subject to the policies of modern constructions, represented by multi-story residential buildings that have negatively impacted the internal environment of the old residential area, causing it to lose its privacy and become visually isolated from its surroundings (Alobaydi, 2017). The change in land use, including the presence of industrial and craft activities within the old residential area, has also significantly altered the socio-economic dynamics of the community, giving rise to new challenges in sustaining livelihoods and preserving traditional occupations and souqs. Concentrated industrial uses in one area has weakened the infrastructure and has made it difficult to access quiet residential areas from areas with heavy and noisy use. In addition, the region's movement system is highly complex, especially in the main and internal streets, leading to frequent traffic congestion and difficulties in access.

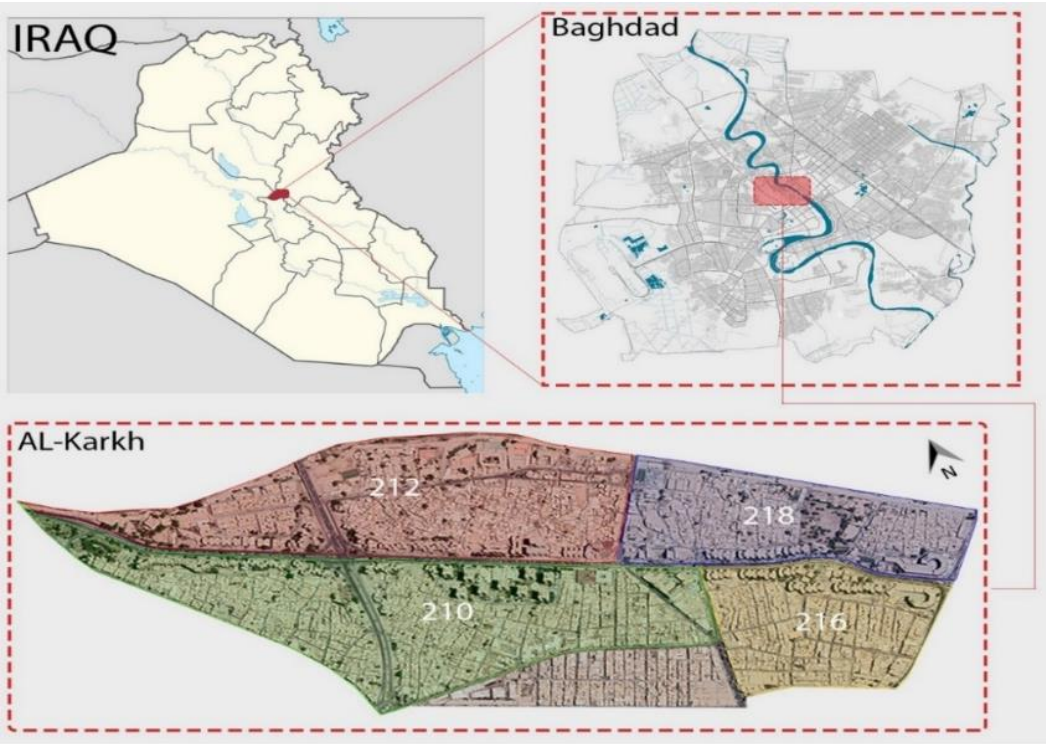

Fig. 1: The location of AlKarkh area, Baghdad and Iraq - the main four neighborhood boundaries.

Source: Authors.

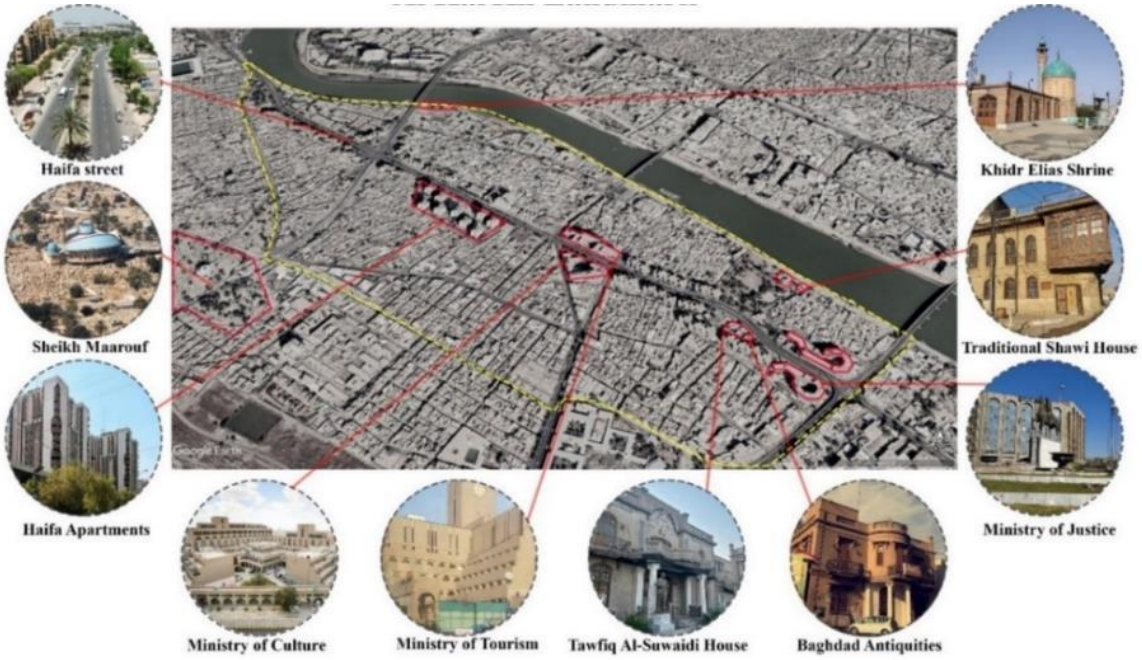

Fig. 2: Landmarks founded in the case study of AlKarkh Landmark.
Source: Authors

Site Observations

To gain insights into the street networks, site observations were conducted in the study area, encompassing both vehicular and pedestrian traffic. Four specific locations, including main streets and intersections recognized based on the resulted maps of the DepthmapX analysis, were identified for the traffic observations. These observations facilitated the identification of movement patterns, calculating the vehicular and pedestrian data, describing the movement densities within the study area. The observations were carried out during peak hours from Sunday to Thursday, spanning a 10-hour period from 8 am to 6 pm, with samples taken every 15 minutes. Filming was utilized to directly measure movement densities, capturing data such as start time, vehicle types and quantities, pedestrian counts, date, and survey location. The analysis of site observations focused on presenting the results of traffic record data analysis, describing peak locations and times for movement density of both people and vehicles, as well as identifying congestion factors based on the collected data and information (Table 1).

Table 1: Movement density data for pedestrian and vehicles in stations.
Source: Author by site observation

Movement density	Station 1	Station 2	Station 3	Station 4
Pedestrian	913	834	743	1255
Vehicles	7743	50251	30795	18353

In the AlKarkh core study area, a comprehensive site observation survey was conducted to analyze transportation service requirements and the road network. The four stations were used to collect data on traffic density and movement during peak times on official working days in June and July 2022. The survey also gathered information on land use and street patterns to provide a comprehensive understanding of the current transportation system in the area. (Fig. 3).

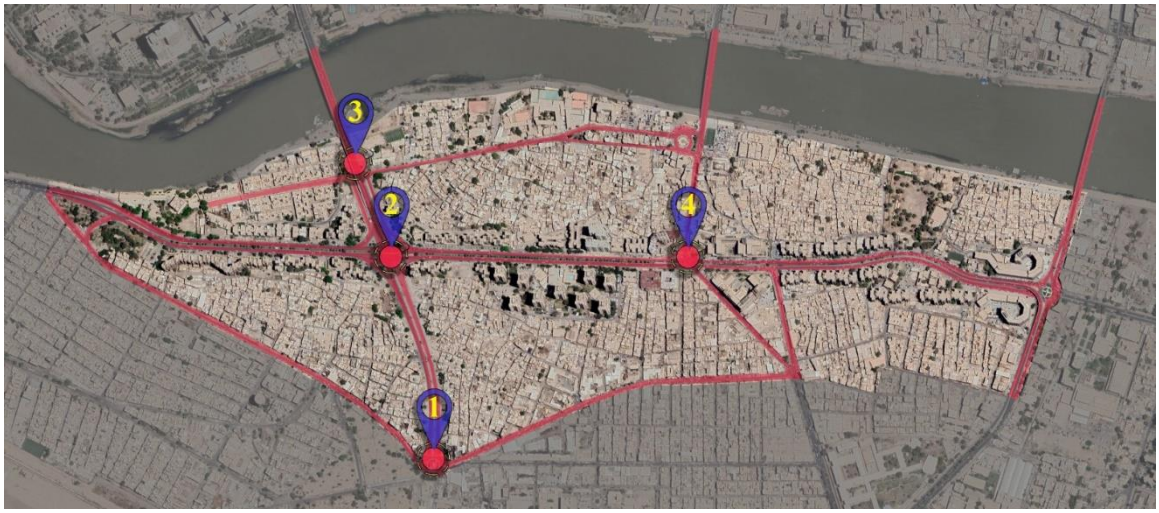

Fig. 3: The four stations used for observations selected in the main intersections of AlKarkh Core.
Source: Authors

The collected traffic data, including information on vehicles and pedestrians, will be highly valuable for understanding their relationship with the integrated streets identified through the colored maps generated using integration and choice measurements from DepthmapX. By analyzing the integration values and choice measures, we can gain insights into how the observed traffic interacts with the street network's connectivity and accessibility. This analysis will allow us to evaluate the efficiency of movement and identify any potential patterns or correlations between traffic flow and the integrated streets. Ultimately, integrating the traffic data with the colored maps will provide a comprehensive understanding of the spatial dynamics and functioning of the transportation system in the study area.

Research steps

- Data collection was set up to ensure relevance and utility. Specific criteria were established as follows
    - Essential urban elements such as streets, vehicular traffic density data, pedestrian roads, and land use data were included.
    - Data quality was prioritized, aiming for globally recognized scales, even if not meeting international standards. This facilitated the creation of a foundational map for the Space Syntax analytical program.
- Data digitalization was conducted to create the necessary basic maps for the element analysis program, the following steps were taken for data digitization:
    - Visited the Municipality of Baghdad to obtain GIS maps and maps of the study area, including previous projects related to AlKarkh core development. This provided crucial data on land uses and traffic density for analysis.
    - Visited the AlKarkh municipality to acquire maps of the province and main streets. Population information was also gathered to enhance the accuracy of the area's representation.
    - Conducted sequential visits to the study area to calculate traffic densities for vehicles and pedestrians, collecting data on traffic flow and observing pedestrian activity.
    - Created a current state plan of the study area using AUTOCAD 2022 software, ensuring accuracy and completeness by referencing a Google map image.
- Data analyses were conducted as the following steps were taken:
    - Drew a current state plan of the study area using AUTOCAD 2022 software, referencing a Google Maps image for accuracy.
    - Exported the map file from AUTOCAD (DWG) to (DXF) format.
    - Imported the (DXF) format file into UCL DepthmapX software by selecting "Map," then "Import File," and choosing the (DXF) format file.
    - Utilized the Axial Map indicator in DepthmapX software to generate the axial line map.
    - Applied the Graph Analysis tool to input a radius value (Rn), such as R3, and executed the convex hull graph analysis.
    - Used the Integration Indicator in the axial line map to calculate the integration value.

- Generated the Angular Segment Analysis graph by selecting "Tools," then "Segment," and running the analysis with radius values of 200, 400, 600, and so on to measure choice.

Findings and Discussions

The global integration map reveals the spatial arrangement of the AlKarkh core, highlighting the concentration of main streets within the urban center. Notably, Haifa Street stands out as a vital artery in the historic area, exhibiting high integration values. Key intersections, such as Al-Tala'i Square with the Bab Al-Mudham Bridge and the road connecting Al-Shuhada Square with the Bab Al-Mudham Bridge Square, form a ring road that encircles significant urban events. These areas attract diverse individuals, including residents, visitors, and passers-by, resulting in elevated movement densities. Analyzing the global integration map, which is a comprehensive representation of the interconnectedness and relationships between all the lines within the entire street network on a global scale, allows the researchers to identify active zones and uncover factors contributing to their vibrancy, see Fig. 4. This understanding guides the efforts that enhance the spatial network and enrich the urban experience for both residents and visitors in the AlKarkh core for future urban development.

The spatial network analysis reveals varying levels of integration within the space syntax network. Spaces with high integration, indicated by red color, demonstrate strong connectivity and effectiveness, while spaces with low integration, represented by blue color and ranged from 0.536 to 0.876, exhibit weak connections. This analysis helps identify areas of high activity and spaces that require improvement in terms of connectivity and activity levels.

The spatial network analysis of the historical AlKarkh core shows a ring-shaped pattern of integration values, ranged from 1.8762 to 1.4491 and surrounded the historic fabrics in the heart of the study area, extending from the center to all parts of the space syntax network. Within the highly integrated nucleus, areas such as King Faisal Square and Al-Tala'i Square facilitate social interaction and experience high movement density. Enhancing the connectivity and accessibility of these areas can contribute to the revitalization and livability of the AlKarkh core.

The local integration analysis using radii R3, R5, R7, and R9 confirms the high integration of main streets, particularly Haifa Street, which serves as a vital link connecting different parts of the region. The street connecting Al-Shuhada Bridge Square and Bab Al-Mu'azzam Bridge also exhibits high integration, serving as an internal link within the area. However, the traditional organic historical fabric of AlKarkh's core shows low local integration values due to its complex path system, longer journey distances, and limited accessibility for strangers (Fig. 4).

The analysis of integration measure, which colors the most accessible lines on the map with red, indicates that the main movement axis, including Haifa Street and its connecting squares, experiences high movement density and activity. Secondary streets linked to the main ones also demonstrate medium integration values. In contrast, narrow and isolated areas, particularly narrow alleys, exhibit very low integration values, aligning with the characteristics of the traditional Arab-Islamic city.

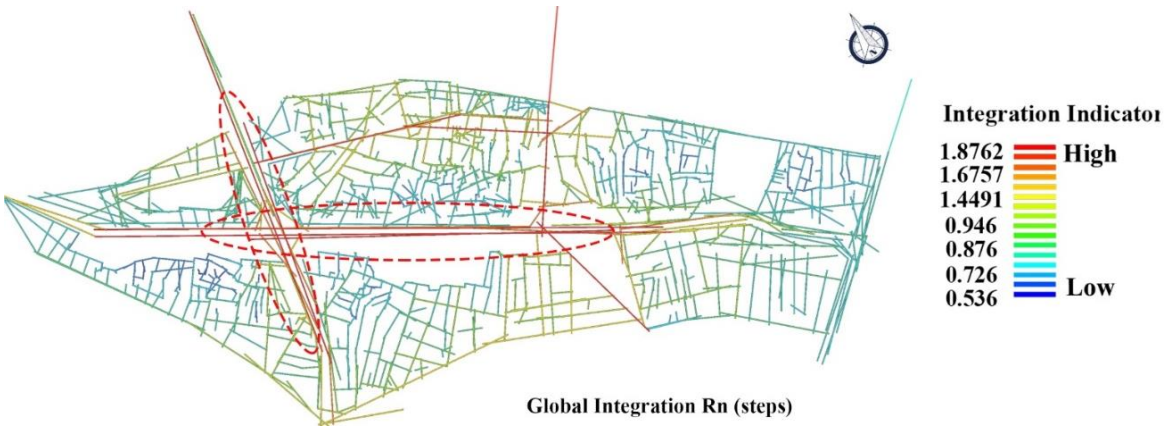

Fig. 4: The global integration Rn.
Source: Drawn by authors

The global angular choice analysis, based on the radius Rn, reveals that the main streets in the AlKarkh area are frequently used and surrounded by commercial establishments. These streets provide easy and convenient access for both residents and strangers. In contrast, the internal residential areas have lower choice values, indicating limited accessibility and lower activity levels, (Fig. 5).

The global choice values in the historical AlKarkh core range from 179886 to 0, with high values observed in commercial areas such as Haifa Street, King Faisal Square, Al-Tala'i Square, and Al-Shuhada Square. These areas are popular and easily accessible. In contrast, the residential areas within the core have lower global choice values, reflecting their limited accessibility and lower levels of activity.

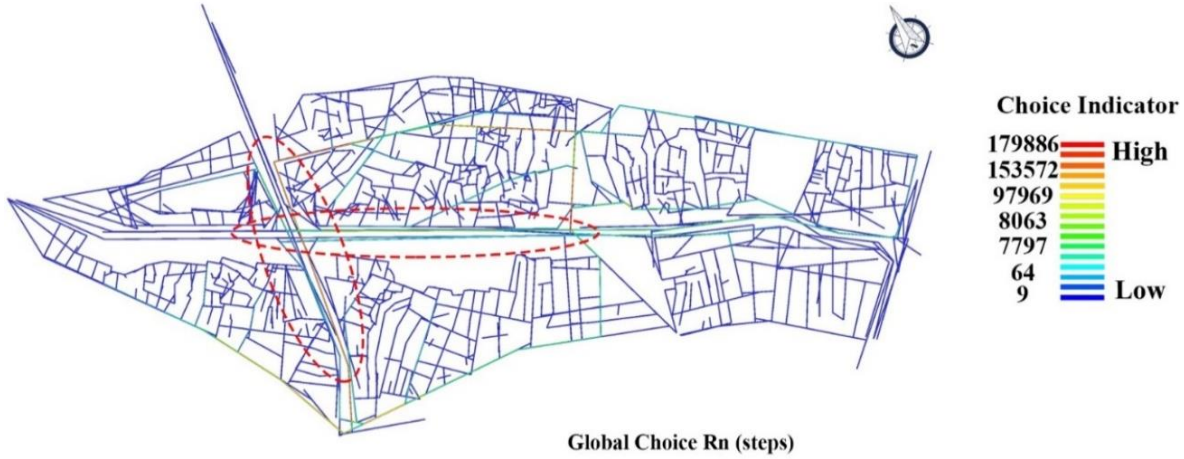

Fig. 5: The global choice Rn.
Source: Authors

The local choice analysis using the radius R3 shows that streets with high choice values are primarily secondary streets used by residents. In contrast, alleys and cul-de-sacs within the area have weaker choice values, indicating less frequent use.

These patterns are consistent across other radii (R5, R7, and R9), where streets with high choice values are secondary streets connecting with other secondary streets or the main ones. These

streets are primarily used by residents. On the other hand, alleys and cul-de-sacs within the area demonstrate weak choice values, see Fig. 6.

One notable finding of this research was the significance of radius values in accurately depicting the paths related to movement densities. It was observed that higher radius values yielded more precise representations of the complex interplay between spatial configurations and the flow of pedestrians and vehicles within the urban environment as shown in Fig. 7. Thus, Increasing the radius values measured in the integration and choice of axial and segment maps enhances the accuracy of representing the spatial properties in the given urban area.

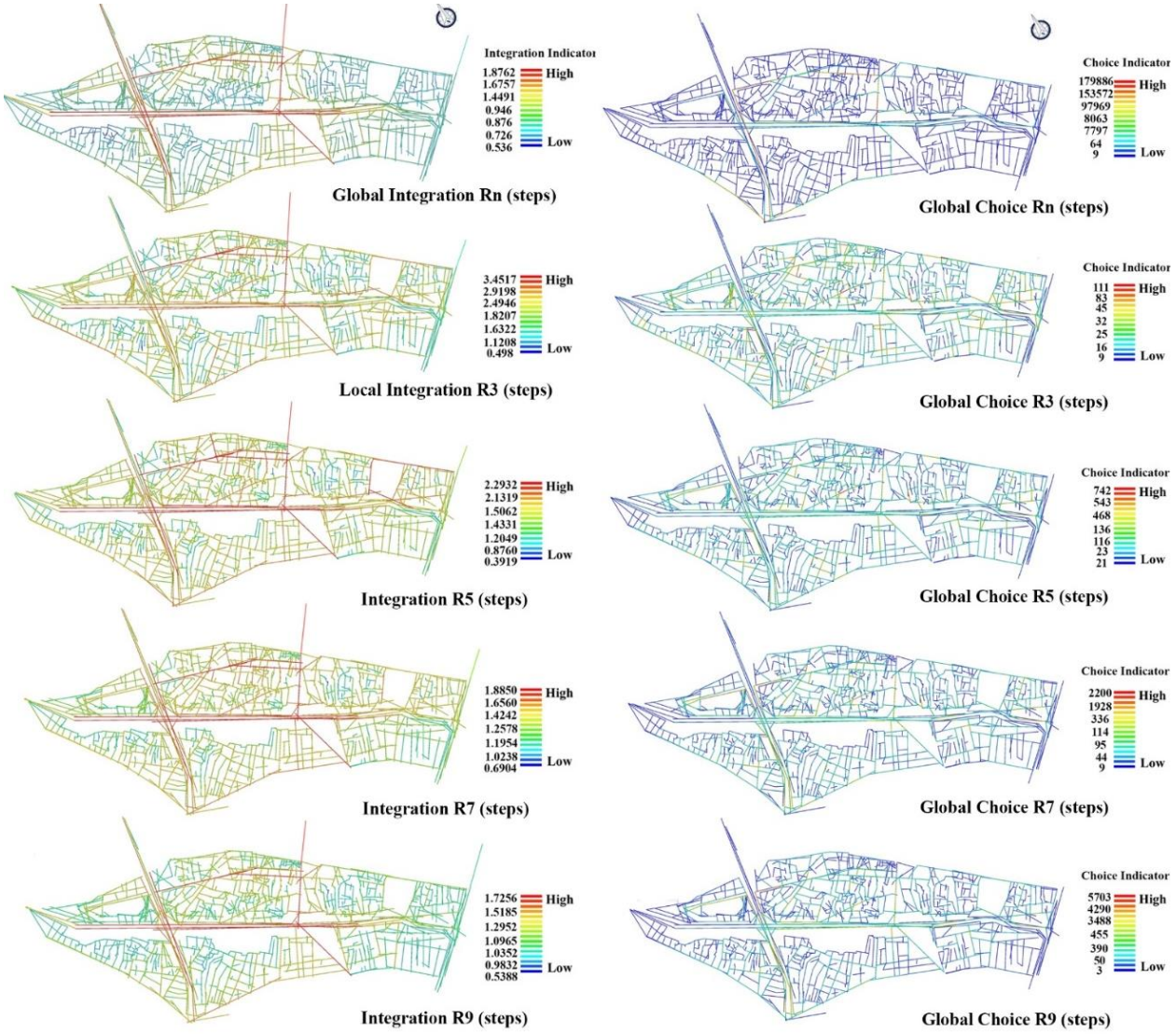

Fig. 6: The radii ranged for R3 to R9 for both measures Integration (on left) and Choice (on right).
Source: Drawn by authors.

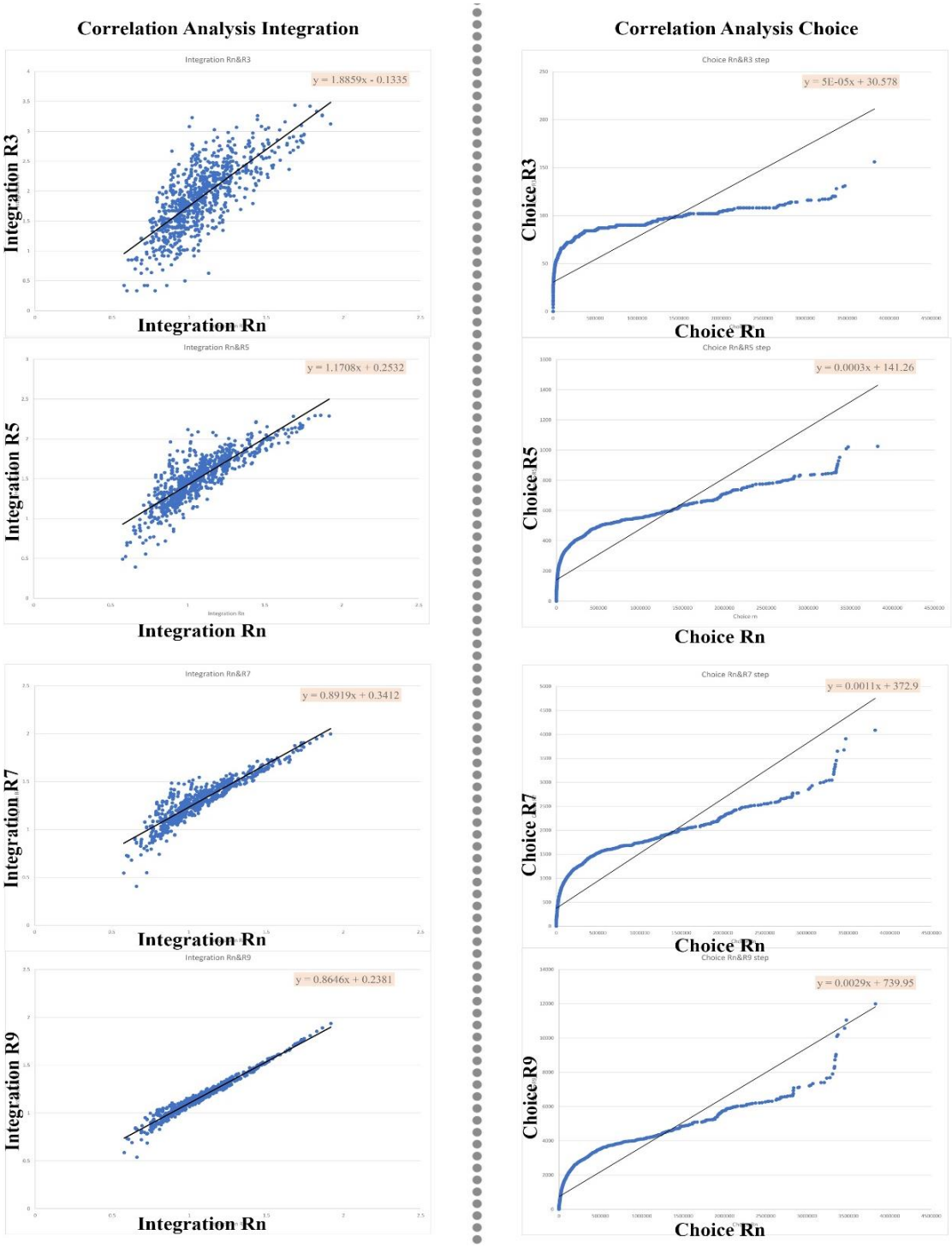

Fig. 7: The correlation analysis in radii ranged for R3 to R9 for both measures Integration (on left) and Choice (on right).
Source: Authors.

Conclusions

This research investigated the influence of spatial configurations within street networks on the built environment of historic cores. The specific case study area of AlKarkh in Baghdad was chosen as the focal point, with a particular emphasis on analyzing the movement densities and patterns observed among pedestrians and vehicles.

To gain comprehensive insights, a well-rounded and integrated methodology was employed, incorporating a variety of methods and techniques. This approach facilitated a nuanced analysis of movement densities and patterns, focusing particularly on weekdays and peak hours, thus shedding light on the intricate relationship between spatial layouts and human mobility.

The collection of valuable data through site observations and surveys played a significant role in this study. These efforts provided valuable insights into the densities of movement within and around highly integrated streets, as well as those characterized by a multitude of choices. Through the creation of axial and segment maps, these observations enabled a visual representation of the identified patterns, thereby deepening our understanding of the pathways associated with movement densities for both pedestrians and vehicles.

The current research provides valuable insights into the influence of spatial configurations within street networks on the built environment of historic cores. By highlighting the importance of appropriate radius values in analyzing movement patterns, the study offers practical implications for urban planners and designers working to create sustainable and livable urban spaces. However, addressing the weaknesses, such as the limited generalizability (focusing on a specific case study area restricts the broader applicability of the findings) and potential data biases like location selection would further strengthen the research's impact and applicability in diverse urban settings.

Comparing with the existing studies that employed the space syntax and case study approaches that explored the relationships between spatial configurations' properties and human dynamics (Rashid and Alobaydi, 2015), movement densities (Rashid and Bendagam, 2015), street centralities (Vaughan et al., 2022; Porta et al., 2012), urban segregation (Vaughan, 2007), sustainability (Ibrahim and Abdullah, 2023; Najah et al., 2023), and land use distribution (Alobaydi et al., 2022; Tutuko et al., 2022; Abdulla and Ibrahim, 2023; Al Hashimi and Alobaydi, 2023; Alsaffar and Alobaydi, 2023), the current research findings show important implications for urban planners and designers, underscoring the necessity of considering appropriate radius values when analyzing movement patterns. The representation of movement densities can be enhanced, by carefully selecting suitable radius values, thereby enabling more informed decision-making processes in the urban planning and design of historic cores. Finally, these insights may contribute towards the overarching goal of creating sustainable and livable urban spaces that effectively accommodate and enhance mobility for both pedestrians and vehicles.

Recommendations

Recommendations for urban designers and policymakers based on the research findings:

- Urban designers and policymakers should recognize the impact of spatial configurations within street networks on historic cores. This understanding should guide decision-making and optimize functionality and accessibility in urban spaces.
- To gain comprehensive insights into movement densities and patterns, embrace integrated methodologies that combine various research methods. This approach facilitates informed decision-making, especially during weekdays and peak hours.
- When analyzing movement patterns, carefully select suitable radius values. Higher radius values accurately represent the relationship between spatial configurations, pedestrian flow, and vehicle movement. Improved analysis accuracy enables informed decision-making in urban planning and design.

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