

Impact of Reach Centralities on Urban Accessibility and Connectivity: Insights from Iraq

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Abstract

Despite extensive research on spatial accessibility and connectivity, the specific role of reach centralities in differentiating areas with varying connectivity levels remains under-explored. In this context, this study examines the influence of reach centralities on the accessibility and connectivity of urban areas. It focuses on the Old Rusafa area in Baghdad, Iraq. Its aim is to determine if there is a correlation between reach centralities and the overall accessibility and connectivity of urban spaces.

The study employs a case study analysis, spatial urban network analysis through software and geographic information system platforms.

By incorporating reach centralities into the analysis and using a range of radii, extending from r:250 m to the entire area, the study produces a deeper understanding of the quality of the urban network, thereby highlighting the potential areas for development. The findings contribute significantly to data-driven decision-making in urban planning and design, advocating for the creation of urban environments that are not only more accessible but also intricately interconnected. This, in turn, promises to enhance the living standards of urban inhabitants.

Keywords: Reach centralities, Urban form, Accessibility, Connectivity, Urban network analysis

Introduction

Networks with robust connectivity and high accessibility are fundamental to the seamless transit of people and goods across a city. These two metrics, connectivity and accessibility, are vital for appraising the efficacy of urban networks (Hillier and Hanson, 1984; Hillier, 1996a). Connectivity is assessed by probing the interconnections among nodes within a network, identifying pivotal nodes that serve as conduits or choke points, often through measures like betweenness. Conversely, accessibility is gauged by the ease of reaching or connecting nodes to external entities (Sevtsuk and Mekonnen, 2012).

Urban Network Analysis (UNA) employs graph theory and spatial analysis to scrutinize urban networks, including those pertaining to transportation, communication, and social interactions (Marshall, 2005a; Batty, 2013) The objective of UNA is to dissect the

intricate interplay among individuals, locations, and urban infrastructure by delving into the physical and spatial attributes of cities, as evidenced in studies (Porta et al., 2006b; Barthélemy, 2011).

Utilizing UNA enables a comprehensive examination of transportation system of a city: its connectivity and accessibility. This is achieved by evaluating aspects such as network density, centrality, and accessibility. Moreover, UNA is instrumental in mapping the spatial distribution of city amenities, such as parks. As Corcoran and Lewis (2023) and Balleto et al. (2022) point out, understanding these characteristics of networks aids urban planners and policymakers in making judicious decisions regarding urban design, transportation planning, and resource distribution.

One seminal study in the realm of UNA is Hillier and Hanson (1984) work, which pioneered the “Space Syntax” theory. Hillier and Hanson (1984) point out that this theory scrutinizes the correlation between street layouts and movement patterns within urban areas. Subsequently, as Porta et al. (2012) illustrate, UNA has been applied to a spectrum of urban challenges, including social network structures, crime hotspot identification, and urban growth and development patterns.

A critical metric in UNA is 'reach centrality,' central to the measurements of the study analyses. Sevtsuk and Mekonnen (2012) note that reach centrality is one of five centralities used in UNA - the others being betweenness, closeness, gravity, and straightness. They also show that it is particularly pivotal for encapsulating spatial accessibility in urban areas, a significant determinant of their socio-economic functions as shown in the Fig. 1.

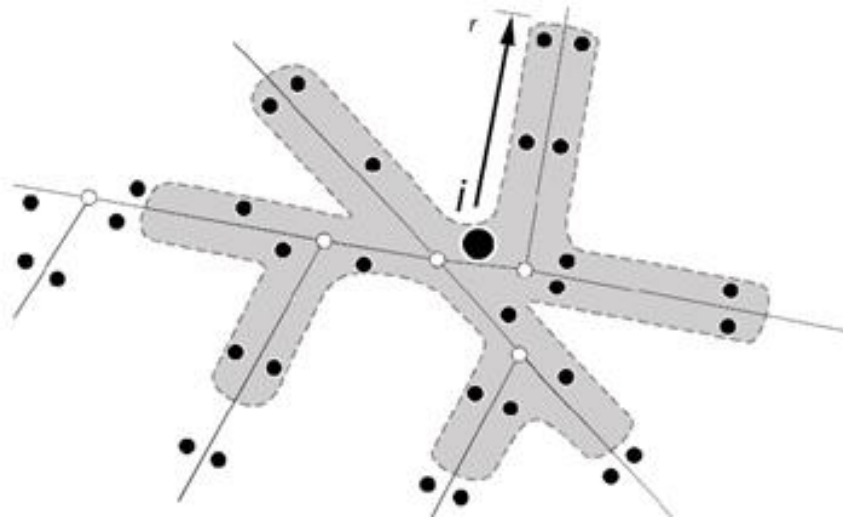


Fig. 1: Visual illustration of reach centralities.

Source: Sevtsuk and Mekonnen, 2012

In urban networks, reach centralities illuminate the efficacy of traversing different city areas, offering insights into the connectivity and accessibility of these regions (Porta et al., 2006b), as depicted in Table 1. By integrating reach centralities in urban form analysis, research can attain a holistic understanding the efficiency and connectivity of city sectors (Batty, 2013; Barthélemy, 2011). These metrics are essential for assessing the importance of nodes in connecting diverse network parts (the links). Such analyses reveal well-connected and accessible areas and those lacking in services. Indeed, these findings can guide enhancements in urban networks, ensuring citywide accessibility and connectivity.

Table 1: The equation of the reach centrality.
Source: Sevtsuk and Mekonnen, 2012

$\text{Reach}^r [i] = \sum_{j \in G - \{i\}; d[i,j] \leq r} W[j]$			
Reach Centrality	R ^r	Research Radius	r
node	i	The shortest path	d
graph	G	Weight a distance node	w

The aim of this study is to explore the relations between reach centralities and the overall accessibility and connectivity of urban spaces. The intention is to contribute to the creation of more sustainable and livable urban environments. Its objectives are as follows.

- To analyze the role of reach centralities and their influence on the accessibility and connectivity of different areas, in the Old Rusafa area in Baghdad, Iraq.
- To quantitatively assess the impact of various reach centralities on urban form and infrastructure.
- To establish the correlations between reach centralities and the overall accessibility and connectivity of urban spaces.
- To formulate practical and data-driven urban planning recommendations for urban designers, planners and policymakers, related to urban accessibility and connectivity,

Conceptual Framework

This study explores reach centralities and their impact on urban accessibility and connectivity, in the Old Rusafa area of Baghdad, Iraq, employing Urban Network Analysis (UNA). It is anchored in the theoretical underpinnings of UNA, which utilizes graph theory and spatial analysis to examine the intricate web of urban networks. As Marshall (2005a) and Batty (2013) show, this includes the analysis of transportation, communication, and social interaction networks. The framework adopts a multi-dimensional approach, integrating both global and local perspectives on urban network dynamics, drawing insights from studies by Sevtsuk and Mekonnen (2012) and Boeing (2019a) and others. It acknowledges the evolving nature of UNA, reflecting on its application in various urban challenges such as transportation system efficiency, spatial distribution of city amenities, and the socio-economic impact of urban form.

Within this framework, the study specifically focuses on 'reach centrality,' a key metric in UNA, to assess its role in shaping the spatial accessibility and socio-economic functions of urban areas. This metric is particularly pivotal for encapsulating spatial accessibility in urban environments, as noted by Sevtsuk and Mekonnen (2012). The methodological approach synergizes case study analysis with advanced spatial analysis tools, including UNA software and GIS platforms, to offer a nuanced understanding of urban networks (Fig 2). By employing a range of radii in the analysis, the study provides a comprehensive assessment of the quality of urban networks, identifying potential areas for development and improvement. This approach contributes not only to the theoretical discourse in urban planning but also informs practical and data-driven decision-making for enhancing urban living standards. The application of this framework to the Old Rusafa area serves as a prototype for understanding the broader implications of reach centralities in urban settings, contributes to the creation of more sustainable and interconnected urban environments.

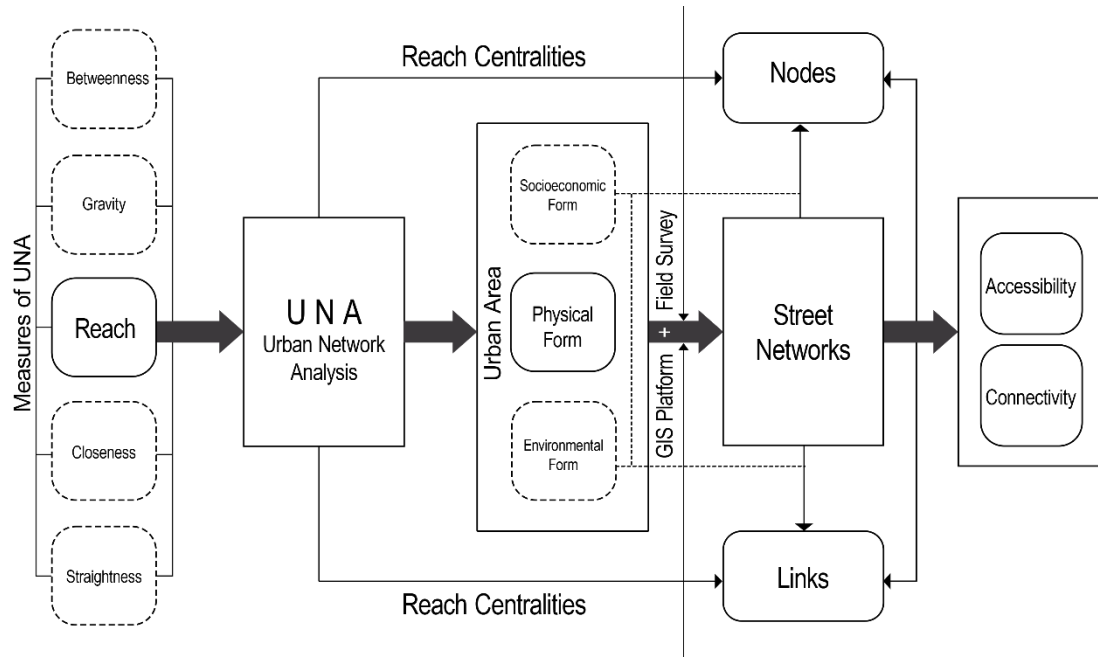


Fig. 2: The conceptual framework of the current study.
Source: Authors.

Literature Review

UNA represents a broad and evolving field, encompassing a variety of urban network aspects. The literature in this domain spans global and local studies. Global studies, like those by Sevtsuk and Mekonnen (2012) Noori et al. (2020) Dahlmanns et al. (2023) introduce methodologies applicable to large-scale urban networks (Boeing, 2019a; Porta et al., 2022; Arribas-Bel and Fleischmann, 2022; Fleischmann et al., 2022). Local studies, like those by Zhou and Lin (2019 and Amen (2022) delve into specific urban phenomena within certain contexts. The works of Porta et al. (2006b; 2009) Amen et al. (2023) Song et al. (2023), Loh et al. (2019) and Li and Zhang (2023) fall under global studies, shedding light on urban network dynamics across different scales.

Local studies between 2017 and 2023 have concentrated on individual cities or regions, addressing issues like urban gentrification, street centrality, and spatial characteristics. In this connection, Amen and Nia (2020) explore impact centrality values on Erbil's gentrification, while Al-Saaidy and Alobaydi (2021b) analyze the influence of street configurations and human density on the urban form of Baghdad (Amen and Nia, 2020; Al-Saaidy and Alobaydi, 2021b) (Fig. 3). Alobaydi and Rashid (2017a) investigate the morphological evolution of the urban core in Baghdad in the 19th and 20th centuries (Alobaydi and Rashid, 2017a). Other studies, such as those by Hammoodi and Al-Hinkawi (2023), Al Hashimi and Alobaydi (2023), and Alsaffar and Alobaydi (2023), examine the religious buildings of Mosul with spatial value reconstruction, historic urban networks of Baghdad, and the street configurations and land uses in downtown Baghdad, respectively (Hammoodi and Al-Hinkawi, 2023; Al Hashimi and Alobaydi, 2023; Alsaffar and Alobaydi, 2023; Alobaydi et al., 2020). These studies contribute significantly to the understanding of urban network analysis in specific settings.

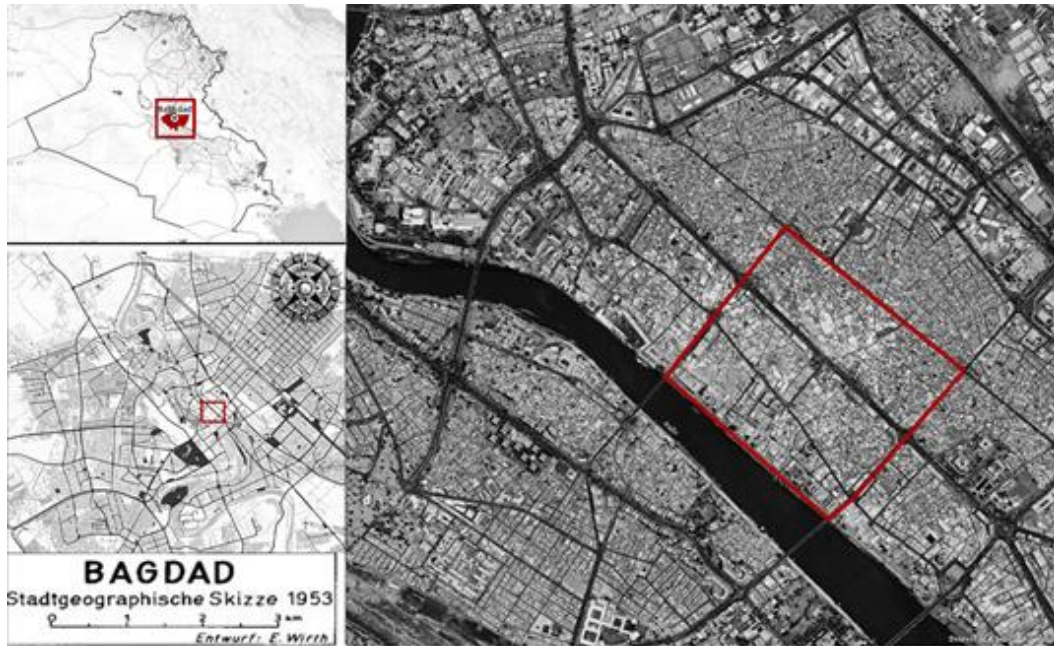


Fig. 3: The location of Old Rusafa in Baghdad, Iraq.
Source: Author

Despite the extensive use of UNA in exploring urban area connectivity and accessibility, the role of reach centrality in these metrics remains under-researched (Kanrak et al., 2024; Xiang et al., 2024; Song et al., 2023; Amen et al., 2023). This study seeks to bridge this gap by applying UNA and advanced analytical tools to assess Old Rusafa's urban. The research is divided into three main parts. Initially, it presents a comprehensive overview of the research topic, pinpointing the existing gap and highlighting the problem. Then, the methodology section introduces an approach that skillfully amalgamates the case study method with the utilization of spatial urban network analysis software, incorporating various measures and techniques. The methodology also leverages Geographic Information System (GIS) platforms for nuanced analysis and interpretation of data pertinent to the research question. The final segment of the research delineates and deliberates upon the results obtained. The conclusion of the study encapsulates the key findings and proffers recommendations for future research avenues in this field.

Research Methodology

This methodology is a fusion of three principal methods and techniques: the case study approach, the use of UNA software, and the application of GIS technology. Initially, a case study method is employed to delve into the Old Rusafa area in Baghdad, Iraq, seeking to discern its unique characteristics and challenges regarding accessibility and connectivity within a 1 square kilometer zone. This stage encompasses data collection from diverse sources, including historic maps, satellite imagery, field surveys, and observational studies. This data was continually updated to ensure the extraction of pertinent details.

Subsequently, spatial UNA software is utilized to scrutinize the urban networks and evaluate the area's accessibility and connectivity. The software's reach centrality feature is instrumental in pinpointing any deficiencies or impediments in the existing infrastructure that may affect accessibility and connectivity. In the final phase, GIS platforms are employed to create detailed mappings of the existing road networks, public transportation systems, pedestrian pathways, and other crucial infrastructural elements. These three methodologies, combined, offer an exhaustive analysis of the urban accessibility and connectivity in Old Rusafa.

Further elucidation of Old Rusafa's area, which is central to the analysis, is provided subsequently. The structured steps employed in this study include:

- Identifying the study area and delineating its boundaries.
- Gathering data on various facets of the built environment, such as land use, transportation networks, and public spaces, utilizing GIS technology.
- Mapping and analyzing the spatial distribution of these components in the study area, employing GIS-specific indicators and measures to assess urban performance, as shown in Fig 4.
- Analyzing the data with UNA software, integrating reach centrality as a crucial metric.
- Applying reach centrality measures (using varying radii based on the study objectives) to pinpoint pivotal nodes within the study area and delineate well-connected and poorly connected links (or streets).
- Displaying results on area maps using a color gradient from red to dark green, where red indicates high centrality values, and dark green denotes low values.
- In each analysis phase, the results are visualized using a color scale segmented into five categories: red, orange, yellow, light green, and dark green. These colours correspond to reach centrality values, with red representing the highest and dark green the lowest, as illustrated in Fig. 5.
- Discussing and interpreting the color-mapped areas in the context of urban connectivity and accessibility.
- Formulating recommendations for urban designers, planners, and policymakers based on the analysis, intending to foster more sustainable and livable cities.

By following these structured analysis steps, other researchers can replicate this study methodology and measurements, allowing them to compare their findings with those of the original study and validate its results.



Fig. 4: The processes conducted in the GIS Platform.

Source: Authors.

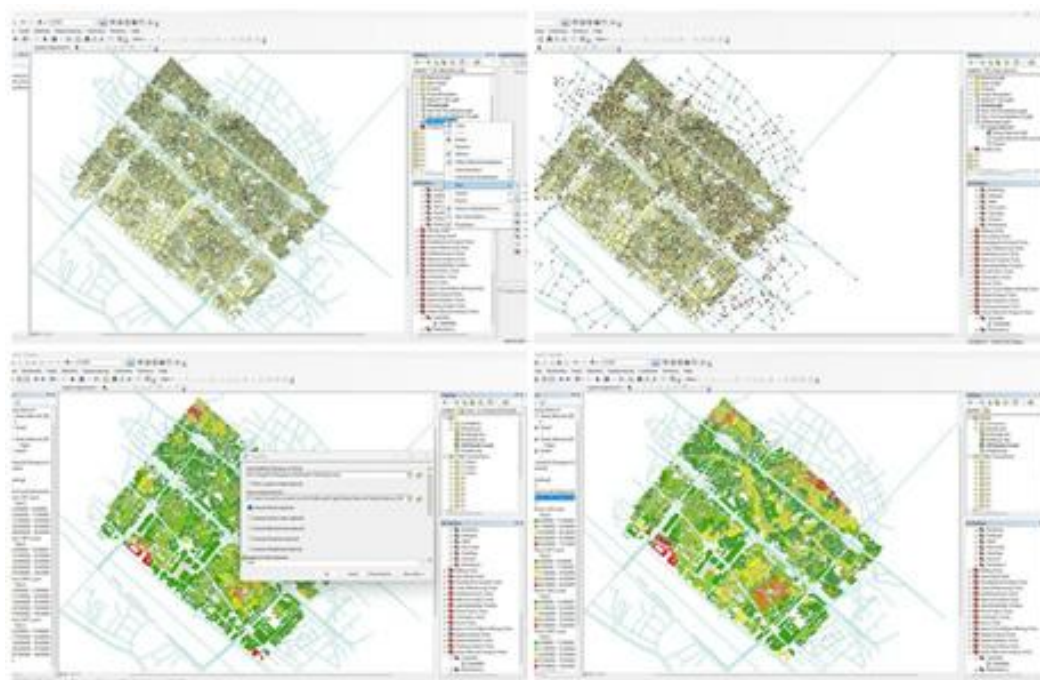


Fig. 5: The processes conducted in the UNA.

Source: Authors.

The Case Study

Old Rusafa, situated in Baghdad, Iraq, stands as a testament to historic urban design, renowned for its architectural richness, traditional motifs, and organically developed road networks. This area is distinguished by its predominantly low-rise structures, neighbourhoods that blend various uses, and densely populated residential areas, as documented in (Al-Ashab, 1974; Al-Hasani, 2012; Alobaydi, 2017; Al-Saaidy, 2020a; Al-Saaidy, 2020b). The street layout of Old Rusafa is characterized by a meandering, zigzag pattern, which has evolved naturally over time, mirroring the city's organic expansion. The architectural influence in this area is deeply rooted in traditional Iraqi styles, showcasing elaborate geometric patterns, arches, and domes, a reflection of the region's rich cultural heritage as cited in (Fethi, 1977). The use of local materials such as adobe and brick in construction lends the buildings a distinct character and maintains a human-scale ambience, as noted in Pieri (2008b), Al-Saffar, 2018, Albabely and Alobaydi (2023) and AlBayati (2023). This unique architectural style not only represents the historical and cultural context of the area but also contributes to the overall aesthetic and ambience of the neighbourhood.

Old Rusafa, a historic district in Baghdad, Iraq, pulsates with cultural and economic vibrancy, marked by its thriving handcraft industries, traditional marketplaces, and street vendors, as noted by Al-Ashab (1974) and Alobaydi (2017). This area is celebrated for its local production of textiles, ceramics, and metalwork, which cater to the regional markets and find their way to international destinations. These industries are vital contributors to the area's economic dynamism and cultural richness.

Furthermore, Old Rusafa is dotted with historic landmarks that are integral to its unique character, including mosques, schools, and baths. Fethi (1977) shows that these structures are more than just architectural marvels; they are emblematic of Baghdad's rich cultural and religious tapestry. Alobaydi (2017) says that these landmarks foster a strong sense of community and place, in Serving as central hubs in their respective neighbourhoods. These focal points enrich the area's cultural landscape and play a crucial role in nurturing community bonds and identity, as illustrated in Fig. 6.

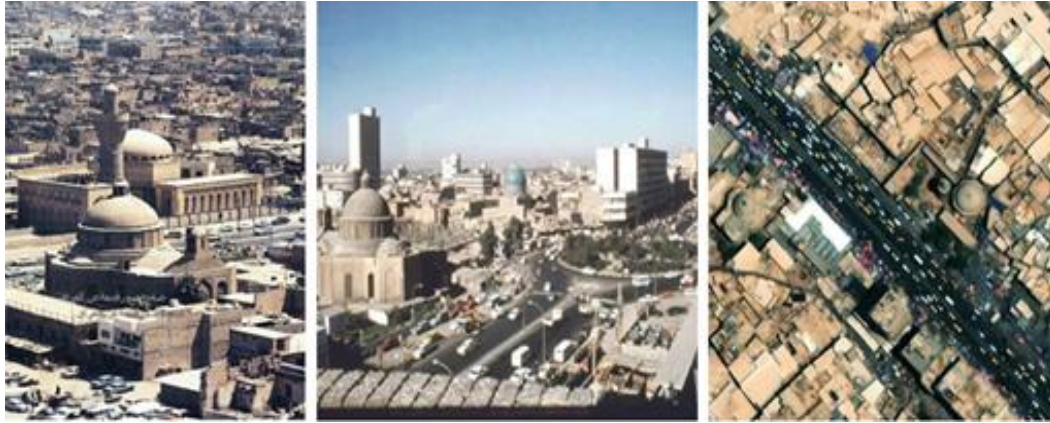


Fig. 6: The historic areas and bazaars in Old Rusafa.

Source: Authors

Alobaydi (2017) points out that in recent times, Old Rusafa in Baghdad, Iraq, has witnessed the introduction of modern urban planning practices, which have significantly transformed its urban landscape. These modern interventions include the implementation of grid-patterned streets for automobiles, the erection of high-rise concrete buildings, and the application of zoning principles. Pyla (2008), Theodosis (2008) and Gulick (1967) show that each of these developments has markedly influenced the traditional urban design of the area. However, Pieri (2008a) shows that the introduction of gridded streets for vehicular traffic has disrupted the historically organic road networks of Old Rusafa, leading to a diminution of its distinct character and human-scale design, as mentioned.

Indeed, the construction of taller buildings has not only altered the skyline but also cast shadows over traditional structures, thereby contributing to the erosion of the area's cultural heritage (Pyla, 2008; Pieri, 2016) and (Al-Hasani, 2012). Moreover, Al-Saaidy and Alobaydi, (2021a) and Al-Hasani (2021) show that the implementation of zoning has segregated different land uses, which has adversely impacted the area's longstanding mixed-use nature. However, as Alobaydi (2017) and Al-Hasani (2021) show, this segregation has led to a decline in the vibrant street life and the unique social interactions that once typified the area.

A comprehensive case study of Old Rusafa involves analyzing data from historical maps, satellite imagery, field surveys, and observations to understand its unique challenges. Utilizing spatial UNA software and GIS technology, the study focuses on evaluating the area's accessibility and connectivity, identifying infrastructural gaps through reach centrality analysis. This approach aims to balance Old Rusafa's historical preservation with modern urban development needs.

Findings and the Discussion

The research employed various methods, including distinct measurement techniques, to analyze a 1 square kilometer area of Old Rusafa using the UNA software. This analysis was conducted four times, each with a different radius setting (250, 500, 1000 meters, and encompassing the entire area), yielding the following results: In the first analysis, with a 250-meter radius, it was found that the highest reach centrality values predominantly appeared on the western side of the area, particularly around buildings designated for warehousing and administrative or institutional functions.

Conversely, areas with lower values, depicted in orange, were primarily situated in densely populated residential zones with some commercial presence. Notably, urban connectivity was generally modest across most of the evaluated areas. This low connectivity, along with limited urban accessibility, is largely attributable to the small size of the study area within the larger context of Old Rusafa, hence restricting access points to the broader network, as illustrated in Fig. 7.

The second analysis, extending to a 500-meter radius, demonstrated similar high and low-value distributions to the first. Notably, the second-highest values (orange areas) were located in the northeastern and southeastern parts of the study area, encompassed by commercial, cultural, and mixed-use zones. Like the first analysis, the lowest values were aligned with the main thoroughfares. This resulted in a slight increase in urban connectivity, although urban accessibility remained largely unchanged, given that the access points to Old Rusafa's larger networks were still consistent, as depicted in Fig. 8.

In the third analysis, with a 1000-meter radius, the highest values were found along streets and buildings adjacent to traditional bazaars, coffee shops, commercial markets, and public buildings, which are hubs for cultural and societal activities. Areas in orange, yellow, and light green were aligned with secondary streets, facilitating movement towards the more connected streets. This analysis indicated a rise in urban connectivity levels in comparison to previous analyses, enhancing social, cultural, and commercial interactions. However, the improvement in urban accessibility was marginal, as shown in Fig. 9.



Fig. 7: The reach centralities' results with r:250.

Source: Authors.

The final analysis, covering the entirety of Old Rusafa, revealed that high-value areas remained concentrated around the main streets, consistent with observations in the third analysis. However, there was a notable increase in areas marked in orange and yellow, indicating secondary streets with moderate social, cultural, and commercial activities. The light and dark green areas, representing the lowest values, remained largely unchanged. With the expansion of the radius, urban connectivity within the network improved, fostering better integration among the nodes in the entire system. Despite this, significant enhancements in urban accessibility were not observed, as indicated in Fig. 10.



Fig. 8: The reach centralities' results with r:500.
Source: Authors.



Fig. 9: The reach centralities' results with r:1000.
Source: Authors.

These findings underscore the nuanced dynamics of urban connectivity and accessibility in Old Rusafa, offering insights into the impacts of urban planning and development on traditional urban spaces.

Analysis from the four different examinations revealed that areas with the highest values were predominantly situated along major streets and hubs of diverse social, cultural, and commercial activities. It was observed that there was an uptick in urban connectivity as the radius of examination increased, while the level of urban accessibility remained largely unchanged, as illustrated in Fig. 11. These outcomes offer significant insights, serving as a foundation for data-driven decision-making in the field of urban planning and design.



Fig. 10: The reach centralities' results with r: whole.

Source: Authors.

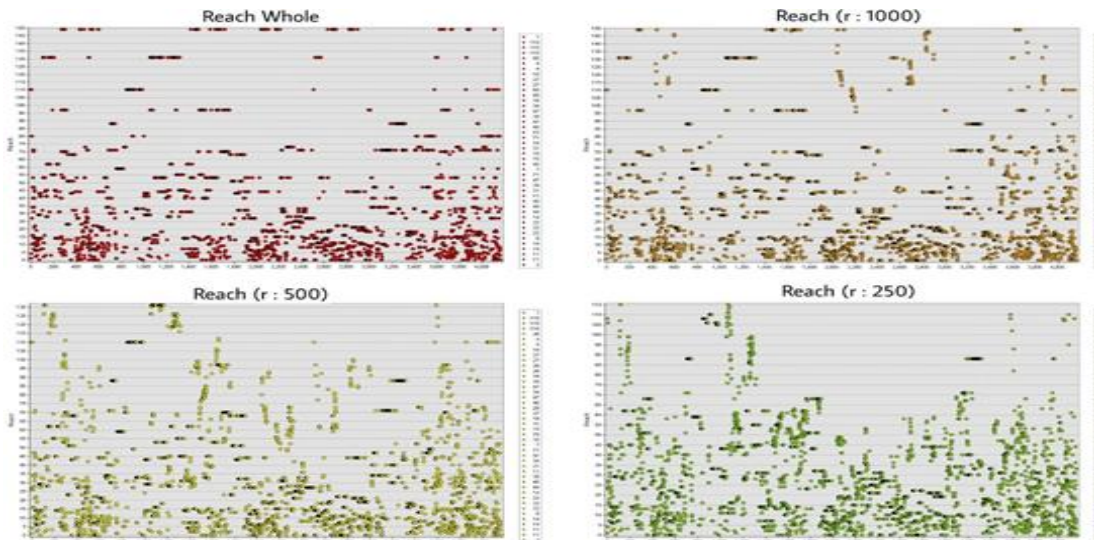


Fig. 11: Scatter plot graphs comparing reach centralities' results of four different radii.

Source: Authors.

Conclusions

This study provides an in-depth examination of the role of reach centralities in determining urban accessibility and connectivity, with a specific focus on Old Rusafa in Baghdad. It concludes that reach centrality is a pivotal factor in shaping the urban landscape's functionality. The distinct radii employed in the UNA software have revealed a clear correlation between the reach centralities and the spatial dynamics of urban areas.

Notably, the research findings illustrate those areas with higher reach centrality values, particularly along major streets and social, cultural, and commercial hubs, exhibit enhanced urban connectivity. This suggests that reach centrality, as a metric, effectively captures the essence of urban interconnectivity and can be instrumental in identifying focal points for urban development. However, a critical insight from the study is the relatively stable level of urban accessibility, regardless of the increase in connectivity implied by larger radii. This highlights a complex interplay between urban design, connectivity, and accessibility, indicating that improvements in one aspect do not necessarily translate to advancements in others.

The study underscores the need for urban planners and policymakers to consider the nuanced implications of reach centrality in urban development strategies. By integrating this metric into planning processes, more informed decisions can be made, leading to more connected and accessible urban environments. The research not only contributes to the theoretical understanding of urban network analysis but also offers practical insights for enhancing urban spaces, in historically and culturally significant areas like Old Rusafa.

It underscores the vital role of reach centralities in urban network analysis, crucial for understanding and improving urban interconnectedness and accessibility. It highlights the significance of various radii in analyzing the intricate link between connectivity and accessibility, providing key insights for future urban planning and development towards more cohesive and accessible urban spaces.

Recommendations

In the light of the findings from the study of Old Rusafa in Baghdad, the following three strategic recommendations are proposed to enhance both its urban structure and the quality of life within it:

- Focus on augmenting the connection between primary and secondary streets, emphasizing areas identified as orange and yellow in the UNA maps. This strategy uses to improve the overall flow and accessibility within the urban network.
- In areas marked by lower connectivity and accessibility, it's recommended to stimulate mixed-use developments. This can be achieved by establishing new commercial and cultural hubs in these zones, thereby uplifting their urban quality and vibrancy.
- Encourage blending social, cultural, and commercial activities within the urban framework. This could involve creating public spaces and venues dedicated to events and community gatherings, thereby fostering social interaction and enriching the urban living experience.

Research Limitations

This study however has a number of limitations. They are as follows.

- The current conceptual framework guides us to focus on specific aspects, potentially neglecting others, and focusing on the urban structures and forms of the given area. This can lead to an incomplete or biased understanding of the urban network, as certain variables or dynamics may be overlooked.
- The framework might be too narrow, limiting the generalizability of findings. The adopted theories and models that are not universally applicable, so the conclusions drawn may not be relevant and/or applicable to different urban contexts.
- The methodology dictated by the framework can influence data interpretation. Specific methods of data collection and analysis could lead to biased or narrow conclusions, if they do not adequately capture the complexity of urban networks.
- In trying to fit the complexities of urban networks into a manageable framework, important nuances or variables might be oversimplified or overlooked. This can result in a loss of critical insights into the urban environment.
- The applicability of the methodology might be limited to certain cultural and/or regional contexts. Especially in urban studies, different cities have unique characteristics, and a methodology developed based on specific case studies may not represent a diverse range of urban environments.

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