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# Measuring Social Segregation Through Street Network Centrality and Land use Diversity: A Spatial Design Network Analysis (sDNA) for Selected Neighbourhoods in Erbil

\*<sup>1</sup> Shahad Ashnaitar , <sup>2</sup> Mustafa Aziz Amen 

<sup>1</sup>Department of Architectural Engineering and Sustainability, School of Science and Engineering, University of Kurdistan Hewlêr, Iraq

<sup>2</sup>Department of Architecture, College of Engineering, The American University of Kurdistan, Iraq

<sup>1</sup> E-mail: [shahad.abdulameer@ukh.edu.krd](mailto:shahad.abdulameer@ukh.edu.krd), <sup>2</sup> E-mail: [mustafa.amen@auk.edu.krd](mailto:mustafa.amen@auk.edu.krd)

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## ABSTRACT

*Rapid urban expansion in Erbil has intensified socio-spatial differentiation between open neighbourhoods and gated residential communities. This study examines social segregation through an integrated framework combining street-network centrality, land-use diversity, and residents social outcomes in Kwestan and New Azadi. Spatial Design Network Analysis (sDNA) was used to measure betweenness and closeness/NQPD centrality at 400 m, 800 m, and 2000 m radii; land-use diversity was assessed using the Shannon entropy index; and a semantic differential survey was administered to 180 residents, equally divided between the two neighbourhoods. Results show that the non-gated Kwestan neighbourhood achieved higher network centrality, with BtE400 reaching 1408.9 compared with 106.9 in New Azadi, and BtE800 reaching 8986.6 compared with 472.4. Kwestan recorded higher land-use diversity ( $H = 0.81$ ) than New Azadi ( $H = 0.53$ ). Survey findings indicated stronger casual encounters, neighbour interaction, and service accessibility in Kwestan. Correlation analysis revealed positive associations between closeness/NQPD and social interaction ( $r = 0.299$ ,  $p = 0.004$ ) and sense of belonging ( $r = 0.259$ ,  $p = 0.014$ ). The findings suggest that permeable, mixed-use neighbourhoods can support social integration while strengthening economic vitality through improved accessibility, walkability, and local service distribution.*

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### Highlights:

- Street centrality increases social interaction within open Erbil neighborhoods significantly.
- Network permeability strongly enhances belonging in non-gated neighborhoods across Erbil.
- Land-use diversity weakly predicts perceived social outcomes at local scales.
- Gated morphology reduces accessibility and casual encounters substantially within residential environments.
- Mixed-use accessibility supports walkability and local economic vitality in neighborhoods.

### Contribution to the field statement:

This study advances segregation research by integrating sDNA-based street centrality, land-use diversity, and residents' perceptions to explain gated and non-gated neighbourhood outcomes. It contributes to urban economy by showing how permeability, accessibility, and mixed-use structure can enhance local interaction, service reach, walkability, commercial vitality, and equitable neighbourhood-level socio-economic development pathways.

\* **Corresponding Author:** Shahad Ashnaitar

Department of Architectural Engineering and Sustainability, School of Science and Engineering, University of Kurdistan Hewlêr, Iraq

Email address: [shahad.abdulameer@ukh.edu.krd](mailto:shahad.abdulameer@ukh.edu.krd)

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## 1. Introduction

Rapid urbanization has intensified scholarly concern regarding social segregation, particularly in cities where accelerated spatial expansion has produced uneven patterns of accessibility, mobility, and social interaction. Contemporary urban research increasingly conceptualizes segregation as a multidimensional urban process that extends beyond residential distribution to include patterns of movement, exposure, functional access, and everyday encounters within the built environment (Maffini & Maraschin, 2018; Liao et al., 2025). From this perspective, social segregation is not merely a socio-economic condition but also a spatial and experiential phenomenon shaped by the configuration of urban networks, the distribution of land uses, and residents' perceptions of safety, interaction, and belonging.

The structure of the street network plays a decisive role in shaping accessibility and opportunities for social encounter. Porta et al. (2009) demonstrated that highly connected street networks support greater movement integration, while Netto et al. (2015) linked spatial accessibility to opportunities for social interaction. Similarly, Sevtsuk (2014) showed that street centrality influences pedestrian movement and urban activity patterns. Configurational theories, particularly those derived from Space Syntax, argue that urban movement is strongly influenced by the spatial properties of street networks rather than by land-use attractions alone. In this regard, betweenness and closeness centrality provide measurable indicators of how strategically located or accessible a street segment is within a wider urban network, thereby influencing movement flows, land-use intensity, and opportunities for social interaction (Hillier, 2007; Yamu et al., 2021). Empirical studies further indicate that integrated street networks tend to support urban vitality, whereas fragmented or enclosed spatial configurations may reduce interaction and reinforce spatial isolation (Netto et al., 2015).

The functional structure of urban areas also plays a complementary role in shaping social dynamics. Mixed-use environments encourage overlapping activity patterns, increase pedestrian movement, and enhance the probability of social encounters, whereas mono-functional areas restrict access to services and limit interaction opportunities (Jacobs, 1961; Gehl, 2012). In parallel, recent research emphasizes the importance of experiential dimensions, particularly residents' perceptions of safety, belonging, and social interaction, as critical indicators of how spatial and functional conditions are socially interpreted in everyday life (Park & Kwan, 2018).

Despite these theoretical advances, significant empirical gaps remain in the application of integrated analytical frameworks, particularly in rapidly urbanizing Middle Eastern cities. In Erbil, the emergence of gated communities alongside established non-gated neighborhoods has produced contrasting residential morphologies characterized by different levels of permeability, connectivity, enclosure, and social exposure (Khoshnaw, 2023; Aliyar et al., 2023). Existing studies in this context have often focused on isolated indicators, such as land-use patterns or basic connectivity measures, without systematically examining how spatial configuration, functional diversity, and residents' perceptions interact to shape social segregation. Moreover, the application of advanced analytical tools such as Spatial Design Network Analysis (sDNA), which enables multi-scalar measurement of street-network centrality, remains limited in the local urban context (Cooper & Chiaradia, 2015). This study addresses these gaps by developing a comparative, multi-layered framework that links spatial configuration, land-use diversity, and residents' perceptions to examine social segregation in selected gated and non-gated neighborhoods in Erbil.

### 1.1 Background and Context

Urban segregation has progressively evolved from a concept primarily associated with residential clustering into a broader analytical framework concerned with mobility, accessibility, exposure, and everyday social interaction. Early theoretical perspectives, particularly those developed by the Chicago School, conceptualized segregation as the spatial expression of social distance, where physical separation within the city reflects underlying social, economic, and cultural divisions (Curran, 2017). Later theoretical developments expanded this view by framing segregation as a multidimensional phenomenon involving uneven exposure, accessibility, and interaction across urban systems (Massey



& Denton, 1988). These perspectives establish that segregation is not only a spatial condition but also a process through which unequal access to opportunities and social contact is produced and reproduced (Florida et al., 2008).

Recent scholarship has further advanced this understanding by emphasizing the role of activity spaces and daily mobility in shaping segregation. Rather than being limited to residential location, segregation is increasingly understood as extending across the full range of spaces that individual's access, use, and experience in everyday life (Müürisepp et al., 2022; Xian et al., 2022). Within this framework, the configuration of the street network and the distribution of land uses become central determinants of accessibility and interaction. Fragmented street networks and limited connectivity reduce opportunities for co-presence, whereas integrated networks facilitate movement and increase the likelihood of social encounter (Netto et al., 2015; Porta et al., 2009).

This conceptual shift has encouraged the adoption of network-based analytical approaches, in which urban space is examined as an interconnected system rather than as a set of isolated zones. Centrality metrics, particularly betweenness and closeness, allow researchers to quantify accessibility and model movement potential within street networks. These measures originate from graph-based approaches to network analysis (Freeman, 1978) and have been further developed within Space Syntax theory, which establishes a relationship between spatial configuration, movement, and co-presence (Hillier & Hanson, 1989). From this perspective, the spatial structure of the city plays a fundamental role in shaping social interaction. Centrality is not assumed to produce social cohesion directly; rather, it influences the opportunities for movement, co-presence, repeated encounters, and familiarity through which interaction, belonging, and community attachment may emerge.

The functional dimension of urban structure is equally important. Land-use diversity has been identified as a critical factor influencing social dynamics, as mixed-use environments support continuous activity and increase opportunities for interaction across different social groups. Conversely, mono-functional areas may restrict access to services, reduce pedestrian activity, and limit exposure to diverse users (Jacobs, 1961; Gehl, 2012). These functional patterns directly influence movement, accessibility, and interaction, thereby either reinforcing or mitigating segregation within residential environments. The experiential dimension is also essential, as residents' perceptions of interaction, belonging, and safety reveal how spatial and functional conditions are interpreted in everyday urban life (Park & Kwan, 2018). These perceptions are closely related to the theory of sense of community, which emphasizes shared experience, social connection, membership, and emotional attachment as key components of community life (McMillan & Chavis, 1986).

Taken together, these theoretical perspectives suggest that social segregation can be understood as the outcome of interactions between spatial configuration, functional opportunities, and lived experience. Configurational theory explains how street-network structure shapes movement and accessibility; segregation theory highlights how unequal opportunities for contact emerge across urban space; and experiential perspectives capture how these conditions are perceived through interaction, belonging, and safety. Accordingly, the present study examines social segregation through interconnected spatial, functional, and experiential dimensions.

## 1.2 Problem Statement and Research Gap

Although the relationship between urban form and social outcomes has been widely examined, many existing studies continue to treat spatial configuration, land-use structure, and social perception as separate analytical domains. As established in the literature, segregation is increasingly understood as a multidimensional process shaped by spatial, functional, and experiential factors. However, there remains a limited number of studies that systematically integrate these dimensions within a single analytical framework capable of linking network structure, land-use diversity, and residents' perceived social outcomes (Netto et al., 2015).

In the context of Erbil, this limitation is particularly evident. Existing research remains fragmented and has largely focused on isolated indicators, such as land-use patterns or basic connectivity measures, without examining how street-network configuration, land-use diversity, and residents' perceptions



interact to produce or reduce social segregation (Khoshnaw, 2023). Consequently, it remains unclear whether higher street-network centrality and land-use diversity correspond with residents perceived levels of social interaction, belonging, and safety, and whether these relationships differ between gated and non-gated neighborhoods.

Furthermore, the rapid emergence of gated communities has introduced a distinct urban morphology characterized by restricted accessibility, fragmented street networks, controlled entrances, and privatised spatial environments. While previous studies acknowledge the exclusionary characteristics of such developments, their social implications have not been sufficiently assessed using advanced configurational tools. This indicates both a methodological gap, particularly in the limited application of Spatial Design Network Analysis (sDNA) to quantify street-network structure, and an empirical gap in understanding how these spatial characteristics relate to measurable social outcomes in rapidly developing urban contexts. Accordingly, this study investigates how gated and non-gated neighborhoods in Erbil differ in street-network centrality and social segregation, the extent to which network centrality and land-use diversity predict residents social outcomes, and which urban design features are most strongly associated with socially inclusive urban environments.

### 1.3 Objectives and Hypotheses

This study examines social segregation through spatial, functional, and experiential dimensions. The spatial dimension is represented by street-network centrality, measured through closeness and betweenness centrality. The functional dimension is represented by land-use diversity, measured through the Shannon entropy index. The experiential dimension is represented by residents perceived social outcomes, including social interaction, sense of belonging, and perceived safety. By integrating these dimensions, the study aims to evaluate how urban form contributes to different levels of social integration or segregation in selected gated and non-gated neighborhoods in Erbil.

The objectives of the study are to quantify differences in street-network centrality between gated and non-gated neighborhoods, assess variations in residents perceived social outcomes, evaluate the relationship between land-use diversity and social outcomes, and determine whether spatial and functional indicators are associated with measurable differences in social segregation. Based on these objectives, the study tests the following hypotheses:

**H1:** Non-gated neighborhoods exhibit higher street-network centrality than gated communities.

**H2:** Higher street centrality, measured through closeness and betweenness centrality, is positively associated with residents levels of social interaction.

**H3:** Higher land-use diversity corresponds with lower levels of social segregation within residential environments.

### 1.4 Significance and Structure of the Paper

This research contributes to urban studies by advancing a multidimensional understanding of social segregation that integrates spatial configuration, functional diversity, and lived experience. It provides empirical evidence from Erbil, thereby addressing a significant contextual gap in segregation research within rapidly urbanizing Middle Eastern cities. The study also demonstrates the applicability of Spatial Design Network Analysis (sDNA) as an advanced methodological tool for assessing how neighborhood morphology influences accessibility, movement potential, social interaction, and community integration.

The study contributes to contemporary debates on the socio-economic consequences of urbanization by showing how residential form, particularly the contrast between gated and non-gated neighborhoods, may shape opportunities for social encounter and inclusion. In practical terms, the research offers a transferable analytical framework that can support planners, urban designers, and policy-makers in evaluating the social implications of street-network design and land-use organization. This is particularly relevant for rapidly growing cities where residential privatization, car dependency, and fragmented urban expansion may intensify social separation.

The paper is structured around an integrated framework linking theory, variables, and analysis. Social segregation is examined through spatial, functional, and experiential dimensions using sDNA centrality measures, the Shannon entropy index, and survey-based social indicators. Spatial, land-use, and survey datasets are integrated through comparative and correlation analyses to evaluate the relationships between urban form and social outcomes, as illustrated in Figure 1.

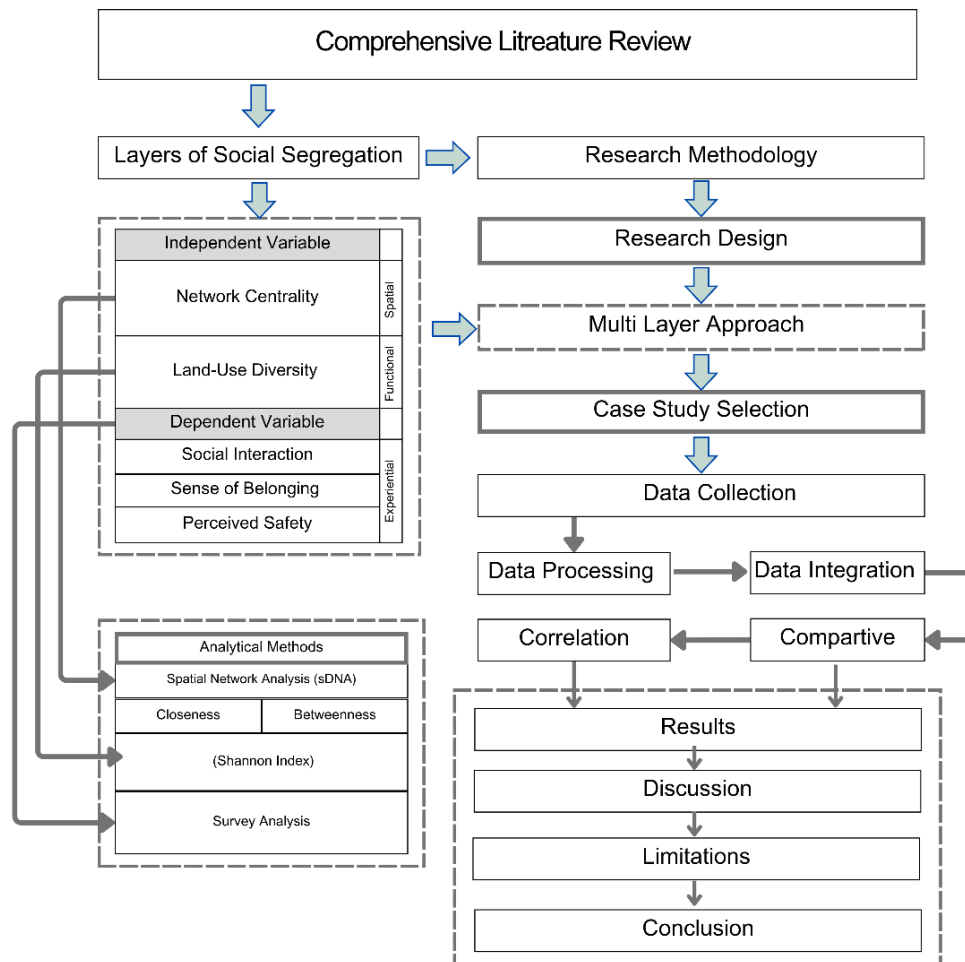


Figure 1. Structure of the research. Source: Authors.

## 2. Materials and Methods

The following section is a description of the materials and methods used to examine social segregation through an integrated analytical approach. It describes the data sources, analytical techniques, and procedures used to investigate the relationships between spatial configuration, land-use structure, and residents social perceptions.

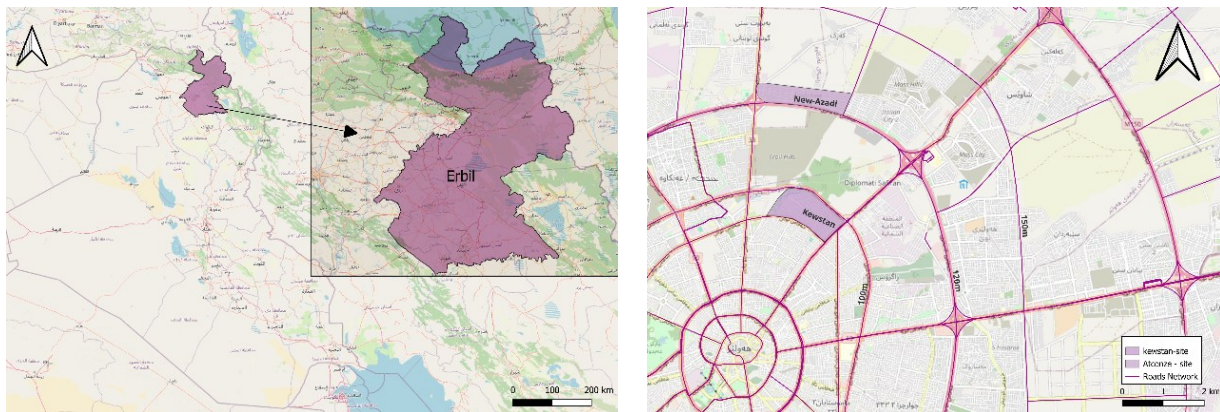
### 2.1 Study Design and Setting

This study is based on quantitative method, multi-layer analytical framework to investigate social segregation through the integration of spatial, functional, and experiential dimensions. The research design is grounded in contemporary urban theory, which conceptualizes segregation as a multidimensional process influenced by interaction between urban morphology, land-use patterns, and lived experience (Hillier & Hanson, 1989), (van Ham et al., 2021). A comparative case study approach is employed, focusing on two contrasting residential typologies in Erbil: a gated neighbourhood (New Azadi) and a non-gated neighbourhood (Kwestan). This approach enables the isolation of morphological differences while maintaining a consistent urban context (Yin, 2018). The analytical framework is structured into three interconnected layers to examine social segregation through its spatial, functional, and experiential manifestations.

- 1- Spatial layer: street network configuration, measured using centrality metrics
- 2- Functional layer: land-use diversity, quantified using entropy measures
- 3- Experiential layer: residents perceptions, captured through survey data

### 2.1.1 Case Study Selection

The study is conducted in the city of Erbil, which represents one of the fastest growing centres in the Kurdistan Region of Iraq (Al-Hity and Ashnaitar, 2025). Two residential neighbourhoods in Erbil were selected based on their contrasting spatial and morphological characteristics: New Azadi, representing a gated residential community, and Kwestan, representing a non-gated (open) neighbourhood, Figure (2).



**Figure 2.** Case Study Location and Selection.

The selection of these case studies was guided by three key criteria. First, the neighbourhoods represent contrasting residential typologies, enabling the examination of differences between enclosed and permeable urban forms. Second, both neighbourhoods are located along Erbil's peripheral ring roads, ensuring comparable urban conditions in terms of accessibility, development patterns, and exposure to recent urban expansion (Amen et al., 2026). This locational consistency allows the analysis to isolate the effects of internal morphology rather than broader urban variation. Third, the case studies are comparable in spatial extent, with New Azadi covering approximately 120 hectares and Kwestan approximately 104 hectares. Differences in size were methodologically controlled through the use of standardized network-based catchments, ensuring consistency in spatial analysis. The objective was not to achieve statistical representation of all neighbourhoods in Erbil, but to compare two contrasting residential morphologies under comparable urban conditions. This comparative design enabled the investigation of how differences in urban form relate to spatial and social outcomes while controlling for broader location-al influences.

### 2.2 Spatial Network Analysis

Spatial network analysis constitutes the primary methodological component for evaluating urban configuration. The street network is modelled as a graph consisting of nodes (intersections) and edges (street segments), enabling the application of graph-based measures to quantify accessibility and movement potential (Freeman, 1978). The analysis was conducted using QGIS (version 3.4) as the primary GIS platform, with Spatial Design Network Analysis (sDNA) implemented for network-based computations. Street network data were derived from OpenStreetMap (OSM) and supplemented with governmental GIS datasets to ensure completeness and reliability. These datasets were cross-validated using satellite imagery and field observations. All spatial data were projected to WGS 84 / UTM Zone 38N (EPSG:32638) to ensure accurate metric-based calculations. (Longley et al., 2015).

### 2.2.1 Centrality Measures

Centrality analysis was conducted using Spatial Design Network Analysis (sDNA) used by Cooper & Chiaradia (2015) to measure the accessibility and movement in urban networks. Betweenness centrality measures the extent to which a street segment lies on the shortest paths between other nodes, indicating its role in facilitating movement flows (Freeman, 1978). Higher values indicate segments that function as key connectors within the network (Hillier, 1989). Consequently, street segments with high betweenness centrality are expected to accommodate greater movement flows and play a more significant role in connecting different parts of the urban network. Betweenness can be defined as, according to the study by Amen et al. (2023):

$$\text{Betweenness}(x) = \sum_{y \in N} \sum_{z \in R_y} W(y)W(z)P(z)OD(x, y, z)$$

The parameter  $OD(x,y,z)$  defines the contribution of segment  $x$  to the shortest path between origin  $y$  and destination  $z$ . Different weighting values are assigned depending on the position of  $x$  along the geodesic route. Closeness centrality reflects the accessibility of a segment relative to all others. In sDNA, this is operationalised using Network Quantity Penalized by Distance (NQPD), a gravity-based measure (Cooper & Chiaradia, 2015):

$$\text{NQPD}(x) = \sum \frac{W(y) P(y)^{nqp} dn}{dM(x,y)^{nqp} dn}$$

Default setting for NQPD is 1 but it can take other values as well, depending on the advanced configuration settings (representing numerator and denominator of NQPD, respectively (Cooper & Chiaradia, 2015; Amen et al., 2023). Higher NQPD values indicate street segments that are more accessible within the network and can be reached with relatively lower travel impedance. Lower values indicate more spatially isolated locations with reduced accessibility to surrounding destinations. Centrality measures were computed across multiple spatial scales to capture variations in accessibility and network integration. At the micro-scale, network radii of 400 m and 800 m were applied to represent walkable distances associated with everyday pedestrian movement (Arar & Kazaz, 2025; Cervero & Kockelman, 1997; Talen, 2011). At the macro-scale, a 2000 m radius was used to examine broader urban integration and the extent to which each neighbourhood is connected within the wider city network (Long et al., 2023; Yuan et al., 2022).

### 2.3 Land-Use Analysis

The functional dimension is examined through land-use distribution and diversity, where the data has been obtained from governmental GIS datasets, OpenStreetMap, and satellite imagery, and validated through field surveys. All land uses were standardised into five categories: residential, commercial, services, public/green spaces and others (Jacobs, 1961; Montgomery, 1998; Sevtsuk, 2014). Land-use diversity was quantified using the Shannon Entropy Index (Shannon, 1948). To integrate the functional and experiential dimensions, entropy values were calculated around the survey sampling locations selected through the spatial network analysis outputs. A 200 m buffer was generated around each sampling point to represent the immediate neighbourhood environment surrounding respondents (Rodríguez et al., 2009), as illustrated in Figure 3. Unlike the centrality analysis, which was conducted at multiple radii to capture network accessibility across different spatial scales, the entropy analysis was designed to assess local land-use diversity within the area most directly associated with respondents' daily neighbourhood experience. Therefore, a 200 m buffer was adopted to facilitate direct linkage between land-use diversity and individual perception-based responses. The Shannon Entropy Index was then calculated within each buffer area to evaluate local land-use diversity patterns. The Shannon Entropy Index is expressed as:



$$H = - \sum_{j=1}^J P_j \ln(P_j)$$

$P_j$  = proportion of land-use category

$J$  = total number of categories, to ensure comparability, entropy values were normalized:

$$H' = \frac{H}{\ln(J)} \quad \text{Where values range from } (0 \rightarrow \text{homogeneous land use, } 1 \rightarrow \text{maximum diversity)}$$

### 2.4 Survey Design

The experiential dimension was examined through a structured questionnaire designed to measure residents' perceptions of the urban environment and its social implications. The survey was conducted using a semantic differential scale, which enables the transformation of subjective perceptions into quantifiable variables suitable for statistical analysis (Marogna et al., 2016; Naghibi et al., 2024). The survey was divided into three main parts. Part A to collect demographic information, including gender, age, marital status, length of residence, and neighbourhood type. Part B focused on experiential indicators associated with social segregation, including social interaction, sense of belonging, and perceived safety. All these indicators have been drawn from the literature and are based on a survey previously validated in urban studies by (Larimian & Sadeghi, 2021), (Alnaim et al., 2025), (Naghibi et al., 2024), (Mela et al., 2025). Part C examined residents' perceptions of spatial and functional conditions, including perceived accessibility, connectivity, and access to services. The inclusion of perception-based accessibility measures reflects the multi-dimensional nature of accessibility, which encompasses both physical and social factors influencing how residents experience urban environments (Wang et al., 2015). The questionnaire structure and measurement indicators employed in the study are summarised in Table 1.

**Table 1:** Summary of Survey Structure and Measurement Indicators.

Section	Variable	Indicators (Items)	No. of Items
<b>A. Demographic Information</b>	Respondent Characteristics	Gender, Age Group, Marital Status, Length of Residence, Neighbourhood Location	5
	Social Interaction	Social activities; Formation of new social relationships; Neighbour interaction frequency; Opportunities for casual encounters	4
<b>B. Experiential Indicators</b>	Sense of Belonging	Familiarity among neighbours; Participation in neighbourhood communication groups; Feeling part of the community; Willingness to remain in the neighbourhood	4
	Perceived Safety	Safety of streets and sidewalks; Safety of public spaces; Safety when walking alone at night	3
<b>C. Perceived Spatial &amp; Functional Qualities</b>	Connectivity (Spatial Proxy)	Ease of movement; Availability of alternative routes; Street intersections; Presence of cul-de-sacs	4
	Perceived Accessibility to Services	Access to daily services; Services within walking distance; Variety of services; Distribution of services	4



The questionnaire was prepared in English and translated into Arabic and Kurdish. The translated versions were reviewed to ensure consistency of meaning across languages prior to distribution. Reliability testing was conducted using Cronbach's Alpha to assess the internal consistency of the experiential indicators. The Social Interaction scale demonstrated good reliability ( $\alpha = 0.862$ ), while the Sense of Belonging ( $\alpha = 0.679$ ) and Perceived Safety ( $\alpha = 0.730$ ) scales exhibited acceptable levels of internal consistency for exploratory urban research, as presented in Table 2.

**Table 2:** Reliability statistics for experiential indicators.

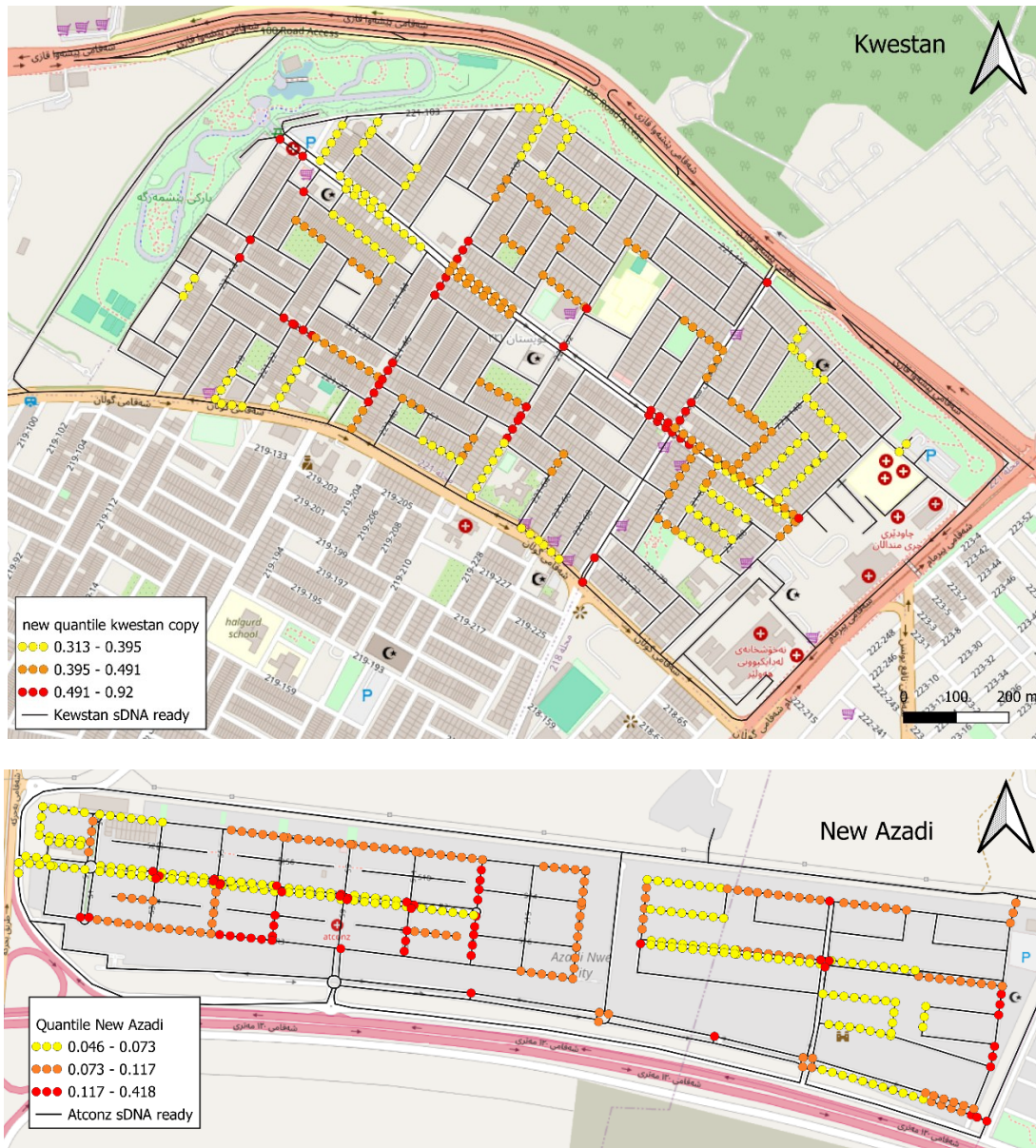
Indicator	Number of Items	Cronbach's Alpha
Social Interaction	4	0.862
Sense of Belonging	4	0.679
Perceived Safety	3	0.730

Normality testing was conducted using the Kolmogorov-Smirnov and Shapiro-Wilk tests. The results indicated significant departures from normality across the experiential, spatial, and functional variables ( $p < 0.05$ ) (Table 3). Therefore, Spearman's rho was selected as the appropriate non-parametric measure for examining associations between variables.

**Table 3:** Normality Test Results for Spatial, Functional, and Experiential Variables.

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
<b>Social Interaction</b>	0.094	180	0.001	0.960	180	0.000
<b>Sense of belonging</b>	0.103	180	0.000	0.952	180	0.000
<b>Perceived Safety</b>	0.282	180	0.000	0.747	180	0.000
<b>Closeness/NQPD</b>	0.152	180	0.000	0.903	180	0.000
<b>Betweenness</b>	0.256	180	0.000	0.750	180	0.000
<b>Entropy</b>	0.107	180	0.000	0.967	180	0.000

A purposive sampling technique was employed to ensure spatial representation across different network conditions (Creswell, 2003), (Patton, 2002). Sampling locations were selected according to the spatial network analysis outputs, where street segments were classified into low, medium, and high centrality categories based on NQPD values generated through sDNA (Figure 3). Each respondent was assigned the NQPD and entropy values corresponding to the sampling point and 200 m buffer within which the survey was conducted, enabling direct comparison between spatial metrics and experiential responses. This approach enabled the integration of experiential responses with the measured spatial characteristics of the street network. A total of 180 questionnaires were collected, comprising 90 responses from New Azadi and 90 responses from Kwestan. The collected data were coded and processed using SPSS to support comparative and correlation analysis between spatial configuration, land-use diversity, and experiential perceptions.



**Figure 3.** Spatial Distribution of Sampled Points.

### 3. Results

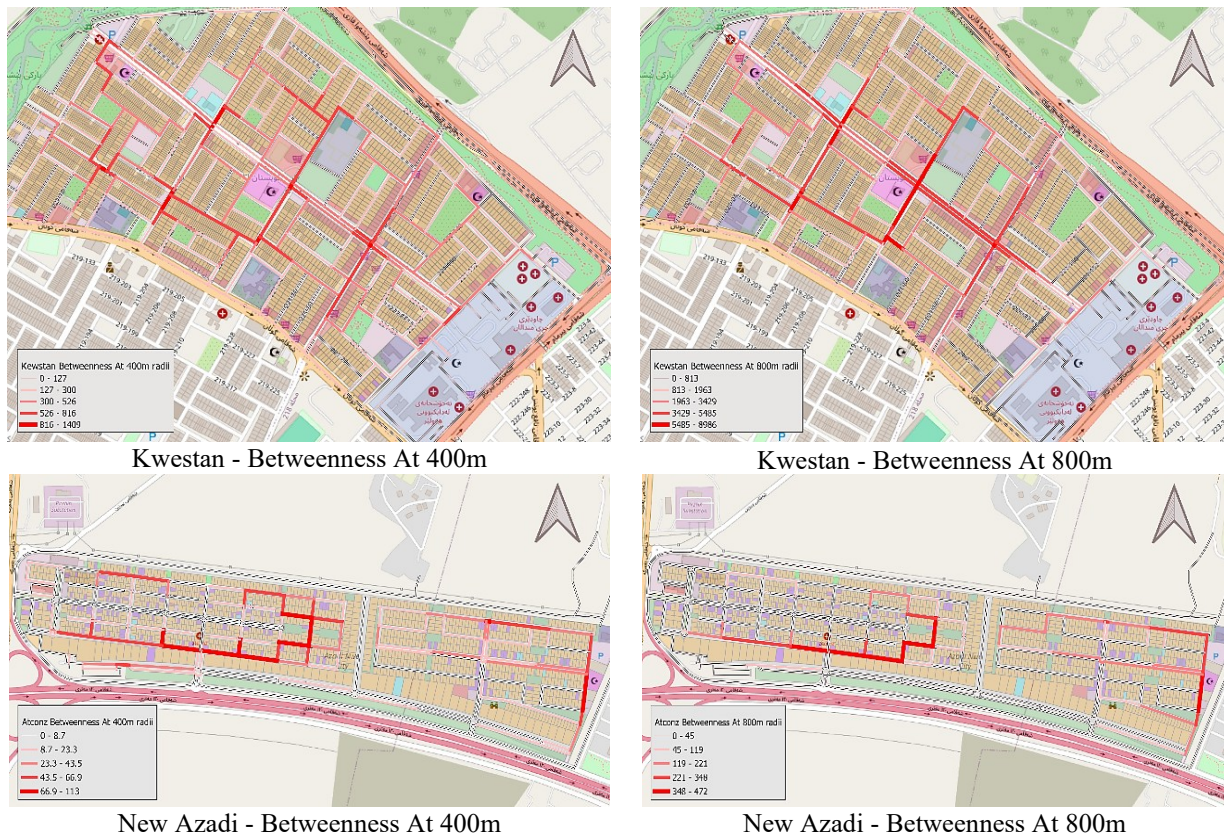
The results revealed clear differences between the gated and non-gated neighbourhoods across spatial accessibility, land-use diversity, and social perception indicators. Overall, Kwestan demonstrated higher network integration, stronger functional diversity, and more positive experiential outcomes compared to the more enclosed and hierarchical structure of New Azadi.

#### 3.1 Spatial Results

The spatial network analysis revealed clear configurational differences between the gated and non-gated neighbourhoods across all analytical radii. Kwestan exhibited a more permeable and integrated street network than New Azadi. In contrast, New Azadi exhibited a more hierarchical and inward-oriented configuration shaped by gated entrances, elongated blocks, and restricted permeability. These morphological differences directly influenced movement distribution and accessibility patterns within both neighbourhoods.

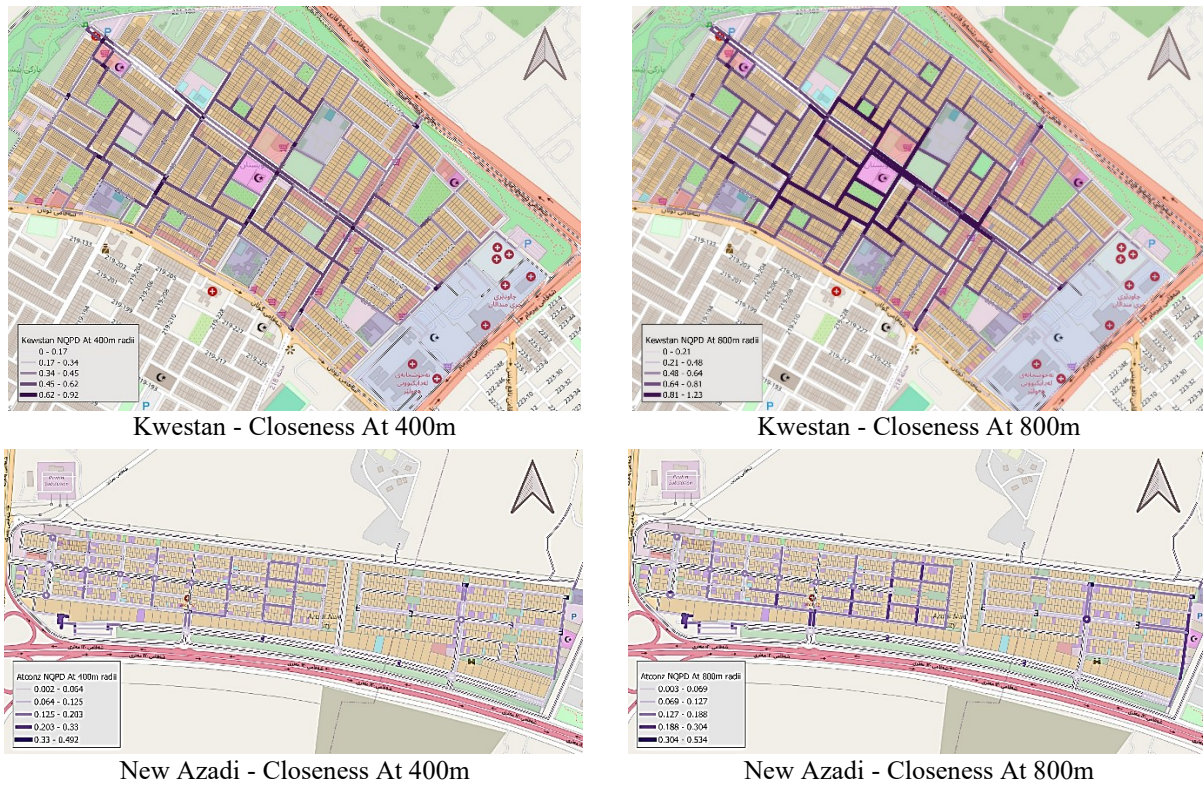
Betweenness centrality analysis showed substantially higher movement integration in Kwestan at local and macro scales. At the 400 m radius, Kwestan recorded a maximum BtE400 value of approximately

1408.9 compared to 106.9 in New Azadi. Similar differences appeared at the 800 m radius, where Kwestan reached approximately 8986.6 while New Azadi recorded 472.4. At the 2000 m radius, Kwestan maintained significantly stronger macro-scale integration with a maximum BtE2000 value of approximately 70,097 compared to 23,495 in New Azadi. The results indicate that movement flows within Kwestan were distributed across multiple interconnected streets, whereas New Azadi concentrated movement along a limited number of primary corridors associated with the gated circulation structure. Micro scale analysis illustrated in Figure (4) and (5), while Figure (6) represent the macro scale.

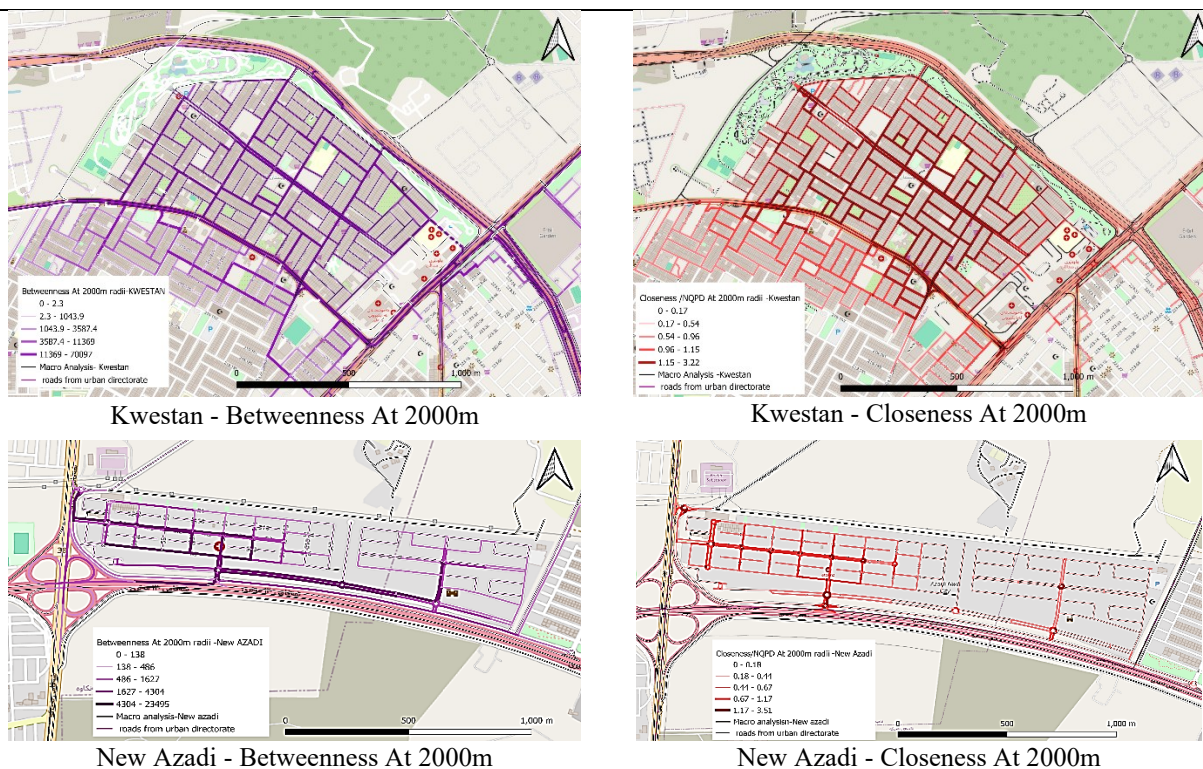


**Figure 4.** Betweenness Centrality for Both Cases at the Micro Scale.

Closeness/NQPD analysis further confirmed stronger accessibility and spatial continuity within the non-gated morphology. Kwestan recorded consistently higher accessibility values across all radii, with maximum NQPDE400 and NQPDE800 values reaching approximately 0.92 and 1.23, respectively. In comparison, New Azadi recorded lower and more fragmented accessibility patterns, with maximum values of approximately 0.49 and 0.53. Although New Azadi reached a localised peak NQPDE2000 value of approximately 3.51 near the main arterial entrance, accessibility was still concentrated around limited gateway corridors rather than distributed throughout the neighbourhood. These results confirm higher accessibility and integration in Kwestan than in New Azadi.



**Figure 5.** Closeness Centrality for both cases at micro scale.

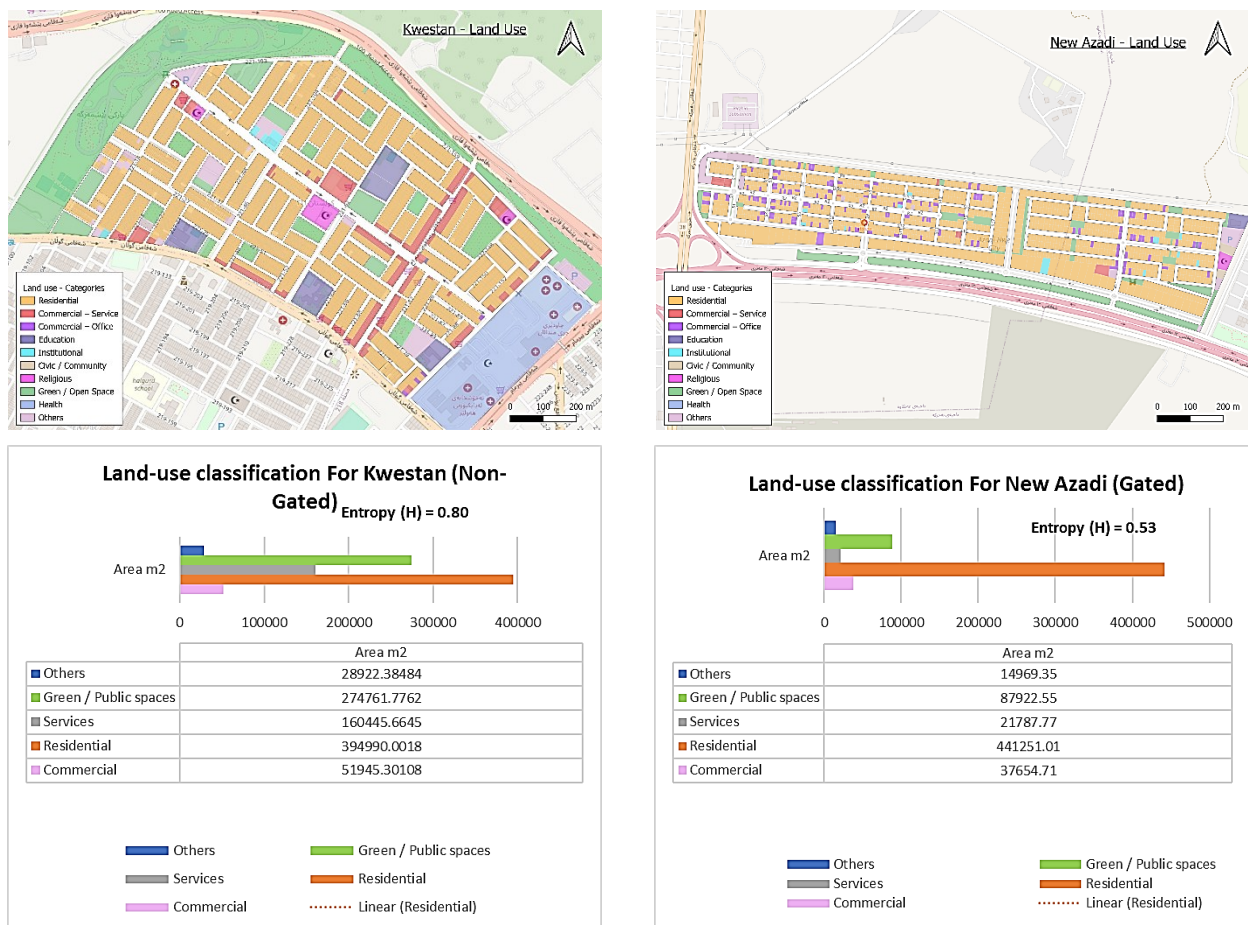


**Figure 6.** Macro-Scale Analysis for Both Cases.

### 3.2 Land-Use Diversity Results

The functional analysis demonstrated a variation in land-use diversity between the two cases. Kwestan exhibited a relatively mixed structure, with residential use for approximately 43.35% of the total

composition; services, commercial activities, and public spaces were distributed throughout the urban fabric. The normalised Shannon Entropy Index reached approximately 0.81, indicating high functional diversity and balanced land-use distribution (Figure 7).



**Figure 7.** Land Use Analysis for Both Cases

**Table 4:** Mean Centrality and Entropy Values by Centrality Category in Kwestan

Category	Mean NQPD	Mean Betweenness	Mean Entropy
High Centrality	0.703	886.2	0.605
Medium Centrality	0.435	340.2	0.644
Low Centrality	0.325	151.9	0.648

**Table 5:** Mean Centrality and Entropy Values by Centrality Category in New Azadi

Category	Mean NQPD	Mean Betweenness	Mean Entropy
High Centrality	0.223	69.60	0.372
Medium Centrality	0.106	12.76	0.431
Low Centrality	0.056	3.90	0.461

In contrast, New Azadi demonstrated a predominantly residential and more homogeneous land-use composition, where residential use represented approximately 73.10% of the total area. Commercial and service functions remained spatially concentrated along limited corridors and edge locations. The neighbourhood recorded a substantially lower normalised entropy value of approximately 0.53, reflecting reduced functional diversity and greater mono-functional segregation, Figure (7). Local-scale entropy analysis based on 200 m buffers further reinforced these findings. Kwestan maintained relatively high and evenly distributed entropy values across low, medium, and high centrality classes. Tables 4 and 5 indicate that Kwestan maintained consistently higher entropy values across all centrality



categories compared with New Azadi. While mean entropy values in Kwestan remained relatively stable across high, medium, and low-centrality locations, New Azadi recorded lower values throughout, reflecting a more homogeneous land-use structure. These findings suggest that functional diversity is more evenly distributed within the non-gated morphology, whereas New Azadi remains predominantly residential regardless of local centrality conditions.

### 3.3 Experiential Survey Results

The experiential analysis revealed consistent differences between the two neighbourhood typologies regarding social interaction, sense of belonging, and perceived accessibility. Kwestan generally recorded higher perception values across most indicators, reflecting the influence of stronger connectivity and functional diversity on residents everyday urban experience. Social interaction indicators demonstrated the clearest variation between the two case studies. Kwestan recorded higher mean values for opportunities for casual encounters (4.87), interaction between neighbours (4.67), and neighbourhood social activities (4.23). In contrast, New Azadi recorded substantially lower values, particularly regarding social activities (2.67) and opportunities for casual encounters (3.03). These findings suggest that the permeable and mixed-use structure of Kwestan corresponds with greater everyday social exposure and interaction opportunities.

Sense of belonging results revealed more balanced outcomes between the two neighbourhoods. Kwestan demonstrated stronger perceptions of community familiarity and neighbourhood integration, while New Azadi recorded the highest willingness to remain living in the neighbourhood despite lower social interaction levels. Perceived safety values remained relatively high within both case studies, although Kwestan consistently recorded slightly higher mean values across all indicators. Perceived spatial and functional qualities also differed substantially between the two urban forms. Kwestan recorded higher values regarding route availability, movement continuity, and accessibility to services. Respondents perceived services as more spatially distributed and accessible within walking distance compared to New Azadi, where service concentration and limited land-use diversity corresponded with lower accessibility perceptions.

### 3.4 Correlation Analysis and Hypothesis Testing

The Spearman rho correlation analysis test was employed for analysing the relationships between spatial centrality, land-use diversity, and experiential indicators within the two case studies. The statistical analysis was used to evaluate the three research hypotheses through comparative and correlation testing between the spatial, functional, and survey datasets.

H1, which proposed that non-gated neighbourhoods exhibit higher street-network centrality than gated communities, was supported by the spatial network analysis results. Kwestan consistently recorded substantially higher betweenness and closeness/NQPD values across all analytical radii compared to New Azadi, indicating stronger movement integration, accessibility continuity, and network permeability, Figures (4,5,6).

H2 proposed that higher street centrality corresponds with stronger social interaction levels. The correlation analysis demonstrated a statistically significant positive relationship between closeness/NQPD centrality and social interaction within Kwestan ( $r = 0.299$ ,  $p = 0.004$ ). A positive significant relationship was also identified between closeness/NQPD and sense of belonging ( $r = 0.259$ ,  $p = 0.014$ ), Table (6). In contrast, New Azadi demonstrated weaker and partially negative associations between spatial accessibility and social outcomes, indicating that increased accessibility within the gated structure did not necessarily improve neighbourhood interaction or community integration. These findings partially support H2 and suggest that the relationship between accessibility and social outcomes varies according to neighbourhood morphology.



**Table 6:** correlation analysis in kwestan – significant values.

Correlations / Kwestan			Social Interaction	Closeness NQPD
Spearman's rho	Social _Interaction	Correlation Coefficient	1.000	.299**
		Sig. (2-tailed)	.	<b>.004</b>
		N	90	90
	Closeness _NQPD	Correlation Coefficient	.299**	1.000
		Sig. (2-tailed)	.004	.
		N	90	90
Correlations / Kwestan			Sense_of Belonging	Closeness NQPD
Spearman's rho	Sense Of Belonging	Correlation Coefficient	1.000	.259*
		Sig. (2-tailed)	.	<b>.014</b>
		N	90	90
	Closeness _NQPD	Correlation Coefficient	.259*	1.000
		Sig. (2-tailed)	.014	.
		N	90	90

H3 proposed that higher land-use diversity corresponds with lower levels of social segregation. At the neighbourhood scale, Kwestan recorded a substantially higher normalized entropy value ( $H = 0.81$ ) than New Azadi ( $H = 0.53$ ), indicating greater functional diversity and mixed-use integration. However, correlation analysis between local entropy values and experiential indicators revealed weak and statistically insignificant relationships in both case studies. In Kwestan, entropy demonstrated almost no relationship with social interaction ( $r = .006$ ,  $p = .958$ ) and sense of belonging ( $r = .008$ ,  $p = .943$ ) Table (7), while New Azadi similarly recorded weak and non-significant relationships with social interaction ( $r = .120$ ,  $p = .259$ ) and sense of belonging ( $r = .042$ ,  $p = .697$ ) Table (8). These findings suggest that although neighbourhood-level differences in land-use diversity correspond with broader differences between the two neighbourhoods, local-scale entropy values did not directly predict residents social perceptions. Therefore, H3 was only partially supported.

**Table 7:** Correlation values between social outcomes and land use diversity values for Kwestan.

Correlations Kwestan			Social Interaction	Sense_of Belonging	Perceived Safety	Entropy
Spearman's rho	Social Interaction	Correlation Coefficient	1.000	.810**	.271**	0.006
		Sig. (2-tailed)		0.000	0.010	0.958
	Sense of Belonging	Correlation Coefficient	.810**	1.000	.490**	0.008
		Sig. (2-tailed)	0.000		0.000	0.943
	Perceived Safety	Correlation Coefficient	.271**	.490**	1.000	-0.187
		Sig. (2-tailed)	0.010	0.000		0.078
	Entropy	Correlation Coefficient	0.006	0.008	-0.187	1.000
		Sig. (2-tailed)	0.958	0.943	0.078	
		N	90	90	90	90



**Table 8:** Correlation values between social outcomes and land use diversity values for New Azadi.

Correlations New Azadi			Social Interaction	Sense_of Belonging	Perceived Safety	Entropy
Spearman's rho	Social Interaction	Correlation Coefficient	1.000	.642**	-.233*	0.120
		Sig. (2-tailed)		0.000	0.027	0.259
	Sense of Belonging	Correlation Coefficient	.642**	1.000	-.106	0.042
		Sig. (2-tailed)	0.000		0.321	0.697
	Perceived Safety	Correlation Coefficient	-.233**	-.106	1.000	-0.040
		Sig. (2-tailed)	0.027	0.321		0.707
	Entropy	Correlation Coefficient	0.120	0.042	-0.040	1.000
		Sig. (2-tailed)	0.259	0.697	0.707	
		N	90	90	90	90

**4. Discussion**

The findings demonstrate that street-network configuration plays a significant role in shaping social outcomes in residential neighbourhoods (Raj et al., 2024). Across all analytical scales, the non-gated morphology of Kwestan consistently achieved higher levels of betweenness and closeness centrality, indicating stronger movement continuity, permeability, and accessibility compared to the gated structure of New Azadi. These results support configurational theories which argue that interconnected street systems increase opportunities for movement, co-presence, and social encounter, while enclosed and hierarchical layouts reinforce spatial isolation and restricted accessibility. The correlation analysis partially confirmed the second hypothesis by identifying statistically significant but relatively weak positive associations between closeness/NQPD centrality and both social interaction ( $r = 0.299$ ) and sense of belonging ( $r = 0.259$ ) within Kwestan. These findings suggest that spatial accessibility may contribute to positive social outcomes; however, the modest correlation coefficients and low explanatory power ( $R^2 = 0.107$  and  $0.095$ ) indicate that centrality represents only one of several factors influencing residents social experiences. However, similar relationships were not observed within New Azadi, where accessibility remained concentrated along limited corridors. This indicates that accessibility alone may not be sufficient to improve social outcomes when movement remains internally controlled and spatially fragmented. The results therefore suggest that the social influence of centrality depends not only on accessibility magnitude but also on the broader configurational structure through which accessibility is distributed.

The land-use analysis revealed that Kwestan achieved substantially higher entropy values and stronger functional diversity than New Azadi. At the neighbourhood scale, these findings support the third hypothesis by indicating that mixed-use environments correspond with stronger functional integration and perceived accessibility. However, the local-scale entropy correlations within the 200 m buffers produced statistically insignificant relationships with social interaction and sense of belonging. Although these results cannot be interpreted as conclusive evidence, they suggest that localized land-use diversity alone may not directly determine residents social perceptions. Instead, social outcomes may emerge through the combined interaction between spatial accessibility, movement continuity, and broader urban activity patterns rather than isolated land-use variation within small catchments.

An important finding concerns the divergence between social interaction and residential satisfaction within the gated neighbourhood. Although New Azadi recorded lower levels of social interaction and accessibility, residents expressed relatively strong willingness to remain in the neighbourhood and reported favourable perceptions of safety. This suggests that residential preferences may be shaped by factors beyond opportunities for interaction, including privacy, environmental control, perceived



security, and the social status often associated with gated living. Similar observations have been reported in studies of gated communities where residents value exclusivity and residential stability despite reduced levels of everyday social encounter. Consequently, lower interaction levels should not be interpreted as evidence of dissatisfaction, but rather as reflecting different residential priorities and lifestyle preferences.

#### 4.1 Comparison with Previous Studies

The experiential findings further reinforce this relationship. Residents within Kwestan reported stronger levels of social interaction, neighbourhood familiarity, and perceived accessibility to services, corresponding closely with the neighbourhood's higher network integration and land-use diversity. These findings align with previous research demonstrating that permeable street structures increase opportunities for movement and social encounter. Porta et al. (2009) and Netto et al. (2015) reported positive associations between network connectivity and interaction opportunities, while Maffini and Maraschin (2018) linked spatial integration to broader socio-spatial inclusion. Similarly, Khoshnaw (2023) found that higher connectivity and mixed-use characteristics contributed to improved accessibility within neighbourhoods in Erbil. In contrast, the gated morphology of New Azadi appeared to prioritise controlled accessibility and residential exclusivity, resulting in weaker interaction patterns despite relatively high perceptions of safety and residential satisfaction. These findings contribute to broader debates on gated urbanism by suggesting that social outcomes cannot be understood solely through residential enclosure or openness. While gated developments may restrict permeability and opportunities for everyday encounter, they may simultaneously provide forms of residential stability, privacy, and perceived security valued by residents. This highlights the need to distinguish between spatial integration and residential satisfaction when evaluating the social implications of gated neighbourhoods.

The findings also extend existing configurational research by demonstrating that the relationship between accessibility and social outcomes is context-dependent. While previous studies generally report positive associations between network integration and social interaction (Netto et al., 2015; Porta et al., 2009), the contrast between Kwestan and New Azadi suggests that similar accessibility levels may produce different social experiences depending on neighbourhood morphology and patterns of enclosure. This observation supports recent debates within mobility and segregation research that emphasize the importance of examining accessibility alongside the social and institutional contexts through which movement occurs.

#### 4.2 Strengths and Limitations

Beyond the empirical findings, the study contributes methodologically by extending conventional configurational approaches that primarily focus on spatial structure and movement potential. The study was limited to two case studies within Erbil, the findings should be interpreted as evidence from two contrasting neighbourhood typologies rather than as representative of all gated and non-gated urban forms. The comparative design was intended to examine the influence of urban morphology under comparable urban conditions rather than to achieve city-wide generalization. While the target sample size of 90 responses per typology is suitable for statistical modelling within this comparative framework, the overall size does not represent the whole residents' perception in both case studies. The purposive sampling strategy was designed to ensure representation across different centrality conditions rather than to provide a statistically representative sample of the wider population. Although this approach facilitated comparison across varying levels of street-network accessibility, it may have introduced selection bias by structuring the sample around the independent variable under investigation. Consequently, the findings should be interpreted as indicative of the surveyed neighbourhoods and analytical framework rather than statistically generalizable to all residents of Erbil. The experiential analysis relied on self-reported perceptions that may be subject to response bias. Although demographic characteristics such as age and length of residence were collected and



analysed descriptively, they were not incorporated as control variables within the correlation analysis. Consequently, differences observed between the two neighbourhoods may reflect not only variations in urban form but also underlying demographic and socio-economic characteristics. In addition, the correlation analysis identifies associations between variables rather than direct causal relationships. The local entropy analysis was also restricted to 200 m buffer measurements, which may not fully capture wider activity spaces and daily mobility patterns beyond the immediate neighbourhood environment.

### 4.3 Implications and Future Directions

Unlike many Space Syntax and socio-spatial segregation studies that examine spatial, functional, or perceptual dimensions independently, the proposed framework integrates street-network centrality, land-use diversity, and residents' experiential perceptions within a single analytical structure. This integration enables a more comprehensive assessment of social segregation by linking objective measures of urban form with residents' lived experiences, providing a transferable methodology for comparative studies across different neighbourhood typologies and urban contexts.

### 5. Conclusion

This study developed an integrated framework for examining social segregation through spatial, functional, and experiential dimensions within gated and non-gated neighbourhoods in Erbil. The findings indicate that the non-gated morphology of Kwestan was associated with higher street-network centrality, greater land-use diversity, and more positive social outcomes compared with the gated structure of New Azadi. Correlation analysis further identified statistically significant but modest associations between selected centrality measures and social outcome indicators, particularly within the non-gated neighbourhood. Although local entropy values demonstrated weak and statistically insignificant relationships with experiential indicators, neighbourhood-level differences suggest that functional diversity may contribute to broader patterns of accessibility and everyday urban activity. These findings have been interpreted as statistical associations reflecting the comparative and correlational nature of the research design.

From a planning perspective, the findings suggest that neighbourhood design strategies promoting street-network permeability, distributed accessibility, and functional diversity may contribute to more socially connected urban environments. As urban expansion continues across the Kurdistan Region, greater attention to connectivity and mixed-use development may help support inclusive and socially sustainable neighbourhood growth while reducing the risk of spatial fragmentation associated with highly enclosed residential forms. Academically, the proposed framework provides a transferable methodology for comparative investigations of social segregation across different neighbourhood typologies and urban contexts. Future research may extend this approach by incorporating socio-economic variables, additional case studies, or longitudinal analyses to further examine the relationship between urban form and social dynamics.

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### Conflicts of Interest

The author(s) declare(s) no conflicts of interest.



### Data Availability Statement

Data available on request due to privacy/ethical restrictions.

### Institutional Review Board Statement

All ethical standards were rigorously observed, including assurances of confidentiality, voluntary participation, and the right to withdraw from the study at any time without penalty.

### Credit Author Statement

Shahad Ashnaitar: Writing - review & editing; Visualization; Software; Resources; Investigation; Data curation; Formal analysis. Mustafa Amen: Writing - original draft; Supervision; Project administration; Validation; Methodology; Roles. Both authors have read and approved the final version of the manuscript.

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