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Analyzing the spatial structure integration with smart transformability capacities (case study: saqqez city)*

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Abstract

Iran's mid-sized cities, with their specific spatial structure and institutional-infrastructural challenges, require local models for smart realisation. This research aims to analyze the interconnection between the spatial structure of Saqqez city and its capacity for smart transformation, particularly in the transportation sector. The research method is a mixed approach, combining spatial configuration analysis and the Delphi method. Analysis of the street network using DepthmapX software and extraction of 3,863 nodes and 4,848 edges revealed that the city's spatial structure exhibits heterogeneity and a strong focus on central nodes. The average depth index in the central core is 0.0232 (indicating relative continuity). In contrast, the coefficient of variation of the access index, with 68.7 percent, indicates severe spatial inequality in access to services. Additionally, the connectivity index, with a mean of 0.01705 and a standard deviation of 0.02680, revealed a center-periphery pattern and the network's dependence on a limited number of critical nodes. On the other hand, a two-stage Delphi process involving 15 experts resulted in localization and final consensus on 40 items across five key indicators. The Kendall coefficient of agreement increased from 0.372 in the first round to 0.786 in the second round, indicating a strong level of expert consensus. The combined findings showed that nodes with simultaneous high values in the interstitial and accessibility indicators (such as the central nodes of neighborhoods 10 and 11) are key points for optimal deployment of smart infrastructure. In contrast, peripheral areas (neighborhoods 16 and 17), characterized by high spatial depth and low accessibility, require targeted interventions to reduce the digital divide and promote spatial equity.

Keywords

Connectivity
Saqqez City
Smart City
Smart Transportation
Spatial Structure

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1. Introduction

Contemporary cities at the beginning of the 21st century are undergoing fundamental transformations in their spatial, social, and managerial structures. The growth of the urban population, changes in consumption patterns and land use, environmental pressures, and the expansion of digital technologies have led to the redefinition of “space” in the city, not merely as a physical setting, but as a dynamic, data-driven product (Batty et al., 2012: 484). This redefinition compels cities to confront fundamental questions about how their spatial structure can be adapted to meet the requirements of sustainability, social justice, and smart development.

The concept of the “Smart City” is a prominent response to these changes. Contrary to the reductionist view that equates a smart city merely with the application of new technologies, the scientific literature defines it as a multidimensional approach aimed at enhancing the quality of life, increasing service efficiency, reducing spatial inequality, and strengthening urban governance (Albino et al., 2015: 5). The smart city is based on the interconnection of three key areas: technological infrastructure, social capital and participation, and spatial reorganization (Nam & Pardo, 2011, p. 285). Therefore, studying smartification capacity without considering its spatial structure and interaction with society and technology cannot provide a comprehensive picture of urban transformation. From a theoretical perspective, several key approaches can guide the analysis of this interconnection. First, technological modernization theory emphasizes that integrating digital technologies (IoT, big data, and AI) enables cities to respond instantaneously to environmental and social changes, thereby generating a more dynamic spatial structure (Giffinger & Haindlmaier, 2010, p. 8). Second, urban digital ecology focuses on the shift of citizens from passive consumers to data producers and active partners in spatial decision-making (Townsend, 2013: 18). This perspective views space not merely as a product of top-down policies, but as an interactive construct among data, technology, and social action. Third, space syntax analysis offers a method for analyzing physical structures, such as street networks and access hierarchies, in relation to social and functional patterns (Hegazi et al., 2022, p. 120; Xia et al., 2019, p. 129). Combining these approaches provides a framework to study the complex relationship between technology, society, and space holistically.

Global experiences from cities like Barcelona, Amsterdam, and Seoul demonstrate that integrating technological policies with spatial planning can lead to improved accessibility, reduced traffic, enhanced spatial justice, and increased citizen participation (Cocchia, 2014: 17; Hollands, 2015: 63). However, these experiences mostly pertain to megacities with extensive economic and institutional capacities. In contrast, mid-sized cities in developing countries often face three sets of challenges: 1) Institutional weakness and lack of coordination among decision-making bodies; 2) Infrastructural limitations in communication technology and energy; and 3) Socio-cultural barriers, including the absence of a data-driven culture and weak public participation (Caragliu et al., 2011, p. 70). This context renders smartification a challenging, yet strategic imperative, rather than an automatic process in such cities.

In Iran, efforts have been made over the last decade to develop smart city policies. However, these studies have mainly focused on metropolitan areas, such as Tehran, Isfahan, and Mashhad, with less attention given to mid-sized cities (Mousavi & Alizadeh, 2020, p. 34). Saqqez, a case study of an Iranian mid-sized city, clearly illustrates this gap. Its spatial development has primarily been driven by horizontal expansion, neglecting smartification capacities, resulting in the dispersal of land uses, weak functional hierarchy, and inefficient urban transportation networks. Simultaneously, Saqqez possesses several potential capacities, including a young population, a high internet penetration rate, and a growing tendency among citizens to utilize digital tools. These conditions create opportunities to link the spatial structure with smart capacities, providing the appropriate institutional and infrastructural groundwork.

A clear research gap exists regarding empirical and theoretical studies in this area. Internationally, theoretical research often focuses on macro frameworks or idealized dimensions of smart cities, while empirical studies tend to assess performance indicators or technological projects in specific cities. This split often overlooks the analysis of the connection between technology and the city’s spatial and social structure at a real-world scale. Methodologically, this gap is evident as most research relies on quantitative models and technological metrics, with limited use of analytical-spatial methods, such as space syntax, to examine the impact of technology on urban structure (Hartley, 2023; Toan & Nhu, 2020). Domestically, this disconnect is repeated: Iranian studies typically focus on introducing general concepts or designing technological systems, with limited investigation into the fundamental interconnectedness between technology, governance, and spatial structure, especially in mid-sized cities (Hosseinian-Rad et al., 2025; Norouzvand et al., 2025; Zamanian et al., 2015). Consequently, this research often lacks integrated theoretical foundations and analytical-spatial methodologies, remaining primarily descriptive or limited in application. This situation hinders the integration of global theoretical achievements with local Iranian realities, limiting the provision of robust analytical frameworks for testing new ideas. Therefore, the existing gap stems not only from a theory-practice mismatch but also from the absence of interdisciplinary analytical frameworks that enable a holistic study of the technological, spatial, and social dimensions of the smart city (Ghorbani et al., 2024).

Thus, the central question of this research is to what extent the spatial structure of Saqqez is interconnected and compatible with the requirements and capacities for smart transformation, particularly in the realm of smart transportation. The answer to this question can provide a picture of Saqqez's current status and offer a model for other mid-sized Iranian cities, enriching the scientific literature on the link between technology, society, and space.

2. Theoretical Foundations and Research Background

2.1. Space Syntax Theory: A New Approach to Urban Spatial Structure

The spatial structure of a city in contemporary international literature is defined as a complex, multi-layered, and dynamic system that reflects the interaction between physical form, urban functions, movement infrastructure, and users' behavioral patterns (Hagen, 2025). In modern approaches, spatial structure is not limited to the physical arrangement of urban elements, such as streets, blocks, and open spaces. However, it is analyzed as an intelligent network through spatial data, connection patterns, movement flows, accessibility, and spatial perception (Batty, 2013). Recent studies, including those based on space syntax, graph theory, and network modeling, regard spatial structure as a reflection of the social-economic logic of cities, where continuity, centrality, scalability, and spatial intelligibility play a decisive role in spatial justice, sustainability, and urban governance (Hillier & Hanson, 1989; Porta et al., 2012). This perspective has made spatial structure a key tool in the data-driven design and strategic planning processes of smart cities.

Space syntax theory, first introduced by Hillier and Hanson in The Social Logic of Space (1984) and later expanded in their other key work, Space Is the Machine (1996), offers a smart perspective for understanding urban and architectural spaces. Relying on philosophical and mathematical foundations, it provides accurate graphical models of physical spaces through digital tools, enabling the prediction of how humans utilize these spaces (Rashid, 2019). In this approach, "space" is not seen merely as the gap between buildings, but as the main essence of the urban experience. Unlike formal approaches, space is a dynamic, perceptual, and influential element in the urban structure within this theory. Although the theory appears positivist, the theorists themselves reject it (Zhong et al., 2014).

In classic studies, space syntax employs specific indicators to analyze spatial structure, including the axial map, connectivity, control value, integration, and intelligibility (Beig Mohammadi et al., 2025, pp. 64-65). However, space syntax indicators in recent research are generally examined in three main categories. First, configuration and accessibility indicators (e.g., integration and choice), which predict movement and aggregation behavior and are analyzed through the space syntax approach (Askarizad et al., 2024). Second, functional and organizational indicators (e.g., land use layout, permeability, and utilization factor) affect flow comfort and efficiency, providing a more accurate picture of satisfaction and productivity when combined with post-occupancy evaluation data and user-based indicators (Li et al., 2021; Parkinson et al., 2023). Third, environmental and consumption indicators (e.g., façade area to floor area ratio), which have a direct relationship with energy demand and have gained importance in optimizing space design (Du et al., 2022). Furthermore, new approaches to digitalization and the extraction of quantitative indicators (e.g., six quantitative indicators for urban park analysis) have enabled the link between real data and parametric modeling (Fan et al., 2024).

2.2. Smart transformability and smart transportation

In the international academic literature, a smart city is defined as a model for sustainable and smart urban regeneration that leverages new information technologies, data-driven infrastructure, and participatory governance to enhance the quality of life, service efficiency, and resource productivity (Albino et al., 2015; Caragliu et al., 2011). The leading indicators of a smart city in contemporary approaches include six key dimensions: smart governance, smart economy, smart people, smart living, smart environment, and smart mobility (Giffinger et al., 2007). These dimensions synergistically target sustainable urban development across social, technological, and environmental aspects, and are enhanced within the framework of data-driven cities using the Internet of Things (IoT), Big Data, and ICT infrastructure (Kitchin, 2014; Nam & Pardo, 2011).

Within this context, smart mobility is a key pillar of the smart city and is analyzed in modern studies based on five fundamental indicators. Accessibility and public transport mobility, which is measured by criteria like travel time, access distance, variety of travel options, and related costs. Multimodal integration, emphasized in smart transport schemes (especially in European experiences), refers to the efficient coordination of various modes of movement and the seamless integration of payment and scheduling systems. Environmental sustainability is pursued through reducing pollutant emissions, promoting clean methods (such as walking, cycling, and electric vehicles), and optimizing energy consumption. Data-driven and technological infrastructure development utilizes sensors, IoT, and predictive algorithms to enable smart traffic management and enhance the quality of user information. Equity and Fair Access: A fundamental principle, emphasizing equal benefit for all social groups and urban areas from transport services, particularly within the framework of systems like Mobility as a Service (MaaS) (Kamargianni et al., 2021; Gillis et al., 2016; Ahonen et al., 2025; Saeed et al., 2023; Bang et al., 2024). These indicators, along with citizen participation and data-driven policymaking, provide a foundation for the functional and structural transformation of the transportation network in smart cities.

A systematic and critical review of the research background provides a basis for an in-depth understanding of previous achievements and is key to identifying knowledge gaps and paving the way for new and original knowledge production. In the area of linking spatial structure and smart urban transformability, numerous studies have been conducted nationally and internationally; however, they often focus on fragmented dimensions rather than an integrated, contextual analysis.

In Iranian studies, the emphasis has primarily been on the role of technological and managerial infrastructures as prerequisites for the development of smart cities. For example, Abagheri Mahabadi et al. (2024) highlight institutional barriers and the infrastructure gap in comparison to global standards. Ramazanpour Karizki et al. (2023) emphasize the direct impact of technology on the city's physical and spatial structure. Meanwhile, Hajjarian (2025) and Ghorbani et al. (2024) focus on the outcomes of spatial structure reform, namely "balanced distribution of smart services" and "improving quality of life in the central fabric," respectively. Medghalchi et al. (2022) also correctly point to the reduced role of distance due to the spread of ICT. Crucially, while valuable, these studies are primarily descriptive and lack an operational framework for measuring the interconnectedness of spatial structure and smart capacities at the local scale.

International studies, leveraging big data and advanced quantitative methods, have addressed newer dimensions of the issue. For instance, Pian et al. (2025), analyzing 17 urban clusters in China, showed a significant relationship between "spatial concentration" and "low-carbon development." Zhou et al. (2024) discussed the polycentric pattern in Chinese cities and the effect of government interventions on spatial changes, confirming the key role of planning in determining spatial structure. Li and Li (2024) provided a three-dimensional framework, confirming the polycentric pattern of Guangzhou and emphasizing the need to integrate physical analysis with land-use planning and smart infrastructure. However, even advanced international research is primarily concentrated on megacities, and its generalizability to mid-sized and less-developed cities, especially in non-Western contexts, is questionable. Furthermore, while studies like Tekin and Dikmen's (2024) emphasize "spatial inclusion" and "equity in facility location" in the smart city of London, or Nyangon (2021) points to the benefits of polycentric patterns in smart energy planning, none provide clear implementation guidelines for cities with an unbalanced spatial structure and limited resources (like Saqqez).

The overall review of relevant sources indicates that the primary gap in previous research is the lack of a localized, measurable, and integrated framework that can simultaneously measure the city's spatial structure (with all its physical and functional dimensions), link it to smart transformability indicators (including technological infrastructure, institutional readiness, and sustainability metrics), and ultimately provide an operational model for smart planning in mid-sized Iranian cities with their specific characteristics and limitations. This situation is rooted not only in a theory-practice divide but also in the absence of interdisciplinary analytical frameworks, which prevents the comprehensive examination of the technological, spatial, and social dimensions of the smart city (Ghorbani et al., 2024).

Therefore, the theoretical framework of this research is based on the combination of three axes: (1) The technological dimension, including data-driven infrastructure, sensors, and smart algorithms; (2) The socio-institutional dimension, including public participation, social capital, and governance capacity; and (3) The spatial dimension, including space syntax indicators (integration, choice, intelligibility, and permeability). Linking these three axes in the proposed conceptual model allows the spatial structure of Saqqez city to be measured against the requirements of smart transformability, especially in smart transportation. This framework not only reflects the global literature but also, by emphasizing the characteristics of mid-sized cities and local limitations, is adaptable to the Iranian context. The conceptual model of this research, unlike linear models, has a network and hierarchical nature and is designed explicitly for Iranian mid-sized cities to account for local limitations and opportunities. Thus, the proposed research model can serve as a bridge between theory and practice, providing a basis for spatial analysis, urban policymaking, and enhancing spatial justice in the process of smartification.

3. Study Area

The city of Saqqez, the second most populous city in Kurdistan Province, is located at a latitude of 36°14’N and a longitude of 46°17’E, at an altitude of 1,476 meters above sea level, in the mountainous Zagros region. The Saqqez River, one of the four main branches of the Zarrineh River, flows through the city, acting as both a water source and a spatial divider, splitting the city into eastern and western sections. To the south are the Heijanan mountains, and to the west are the Malqarani mountains, which significantly influence the natural landscape and the city’s physical structure. According to statistics, the city’s population grew from 12,729 in 1956 (1335) to 226,451 in 2016 (1395). Concurrently, the urban area increased from approximately 33 hectares to over 1,600 hectares (16 square kilometers). Thus, the population grew nearly 18 times, and the urban area expanded about 47 times during this period.

According to the 2014 comprehensive and detailed plans, Saqqez includes two urban areas and 22 neighborhoods. However, the physical and functional structure of the city is not fully aligned with the needs and economic development of the growing population (Saeedpour et al., 2014). Unplanned and unregulated growth has led to a scattered population density across various neighborhoods, particularly in the central and northwestern areas, placing significant pressure on urban services and infrastructure. Furthermore, the presence of old and worn-out fabrics, combined with high population density and spatial dispersal, has led to social, environmental, and local economic issues. Currently, nearly one-third of the urban fabric—about 32%—falls into the category of worn-out and inefficient fabric. Based on the Detailed Plan studies, neighborhoods 6, 16, 17, 18, and 19 exhibit the highest vulnerability levels in terms of wear and inefficiency, and they also have the largest number of residents, despite limited access to urban services. In the domain of urban development, rapid and sometimes unregulated growth has led to structural problems and weakness in city management (Movahed et al., 2014).

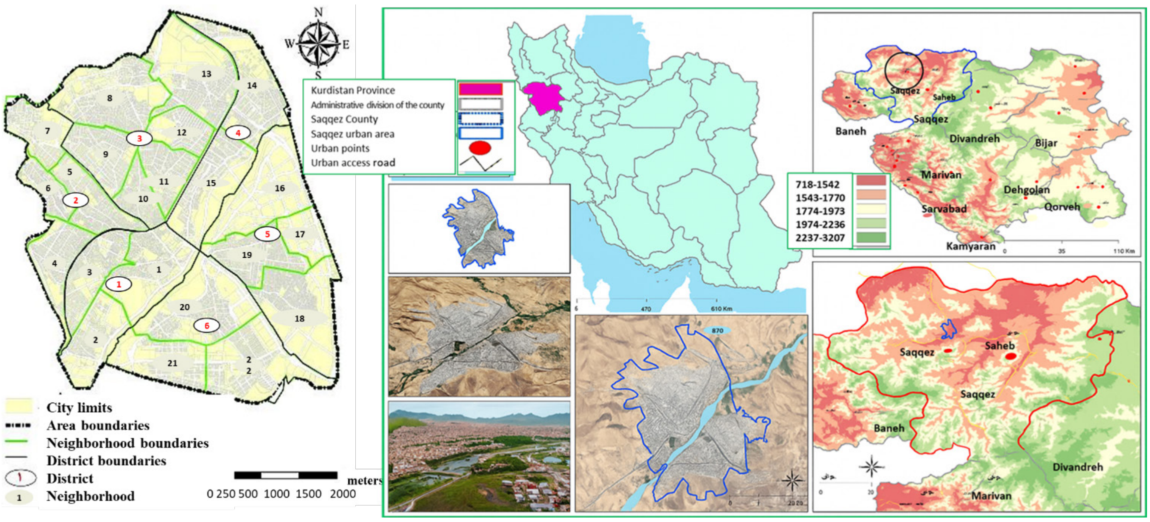

Figure 1. Geographical location of the city of saqqez, along with its districts and neighborhoods

4. Materials and methods

This research aims to analyze the spatial organization of Saqqez city and measure its compliance with the components and indicators of a smart city, with a special emphasis on smart transportation transformability capacities. Given the nature of the problem, which requires both a physical-spatial analysis of the city's structure and a conceptual explanation and validation of smart city indicators, a mixed-method approach is essential.

Therefore, the research method was designed within a mixed-method framework, employing spatial configuration analysis based on space syntax theory alongside the Delphi method as a mechanism for gathering and achieving expert consensus. This combination was chosen because neither approach alone could fully answer the research question: Spatial configuration analysis allows for identifying the internal logic of the spatial organization and movement network, but it cannot explain the dimensions of smartification and its connection to managerial and technological indicators; conversely, the Delphi method, especially in emerging fields like the smart city, provides a platform for validating indicators and gathering expert consensus, but it lacks quantitative and analytical capacities related to spatial structure. Thus, integrating these two approaches covers the existing gaps, allowing spatial findings to be combined with expert evaluations to form a localized model for assessing smart city capacity. The research process proceeded in three continuous and complementary stages. In the first step, the spatial structure of Saqqez city was analyzed based on the theory of space configuration to reveal the logic of activity distribution, hierarchy of passages, and key points of movement flow. This section directly responded to the first goal of the research, which is to understand the current state of the city's spatial organization. In the second step, indicators related to smart cities in the field of transportation were extracted through a systematic review of scientific sources and international experiences and redesigned to suit the local context of Saqqez city. This step established the link between the theoretical framework and local conditions, enabling the measurement of the research objectives. In the third step, a two-stage Delphi method was used to validate the developed indicators and items. The participation of experts in the fields of urban planning, transportation, and urban technology enabled the conceptual coherence of the indicators to be measured, in addition to content evaluation. To complete this process, the Kendall coefficient of agreement was used as a measure of consensus, and the reliability of the instrument was also assessed by measuring the consistency of judgments across two consecutive Delphi rounds. Accordingly, in addition to content validity, attention was paid to the construct validity and reliability of the instruments so that the final results were reliable. What makes this methodology stand out is the coherence between the analytical and conceptual layers. The spatial configuration analysis provided an objective basis for understanding the capacities and limitations of the urban structure. The indexing, based on a systematic review of sources, enriched the conceptual framework of smartization in accordance with local conditions.

The Delphi method ensured the final validity of the findings by creating a consensus among experts. This three-stage process not only answers the research question about the extent of alignment between the spatial structure of Saqqez and smart city indicators but also provides a practical model for analyzing smartification capacities in other mid-sized Iranian cities, which can serve as a basis for decision-making by urban managers and planners.

Table 1. Research process

Research Step	Main objective	Method/approach	Data and sources	Tools and software	Expected output
1. Spatial analysis of urban structure	Identifying the logic of spatial organization and the movement hierarchy of Saqqez city	space syntax theory and graph-based analysis (axial map)	Urban street network in spatial file formats (SHP, DXF)	UCL DepthmapX, ArcGIS, QGIS, Python (Pandas, Matplotlib)	Spatial indices, including integration, spatial intelligibility, connectivity, relative depth, and control value; maps of key routes and nodes
2. Design and localization of smart city indicators	Extracting suitable indicators for assessing smart transportation within the local context of Saqqez	Systematic literature review and comparative studies	Scientific texts, policy documents, and international experiences	Systematic content analysis	Five key indicators (data-driven infrastructure, environmental sustainability, intelligent traffic management, public transport integration, smart accessibility) and 40 specialized items
3. Validation of indicators and items	Ensuring validity, reliability, and expert consensus on the indicators	Two-round Delphi method + consensus analysis	Questionnaire, participation of 15 experts*	Excel, SPSS; Kendall's W test for concordance	Valid and conceptually coherent indicators and items with confirmed expert consensus, content validity, and reliability
4. Integration of Results and Final Modeling	Integrating spatial analysis with smart indicators and Delphi findings to produce a localized model	Mixed-method approach combining analytical, conceptual, and expert-based integration	Spatial data, localized indicators, expert judgments	Analytical integration and comparative inference	Localized model for assessing smart city potential in Saqqez and other medium-sized Iranian cities; foundation for urban decision-making

* Including four university faculty members, six executive experts, three independent research experts, and two graduate students with relevant specializations and more than 6 years of relevant work experience, who have been purposefully selected.

Table 2. Functional indicators and items for smart transportation based on research sources

Macro indicator	Operational (measurable) items	Selected references
Data-driven infrastructure	Percentage of traffic sensor coverage on main streets; percentage of air-quality sensor coverage at high-traffic nodes; number of transport stations connected to the internet of things; level of accessibility to open transport data (score 0–5); extent of big data use in traffic decision-making (number of active dashboards); existence of integrated crisis management systems based on real-time data; percentage of streets under real-time video surveillance; degree of data overlap between transport and other urban domains (energy, environment).	Zeng et al. (2025). Lin et al. (2020); Hu & Chen (2022)
Environmental sustainability & energy management	Per capita CO_2 emissions from intra-city travel (kg per capita); percentage of public fleet using clean or electric fuel; percentage of semi-public fleet (taxi/van) using clean or electric fuel; number of electric vehicle charging stations per 10 km of leading street network; share of standard pedestrian paths in the total transport network; share of standard bicycle lanes in the total transport network; total transport network energy consumption (kWh/year); rate of energy optimization over the past five years; green transport development index (combined share of walking, cycling, and clean vehicles).	Zheng et al. (2025); Wang et al. (2024); Zhang et al. (2020)

Macro indicator	Operational (measurable) items	Selected references
Smart traffic management	Percentage of intersections equipped with intelligent signal control; average system response time to incidents (minutes); rate of travel delay reduction after smart control implementation (%); percentage of routes equipped with intelligent priority for emergency vehicles; intersection efficiency index (vehicles per hour/nominal capacity); real-time accident detection rate (% accuracy); percentage of streets under smart congestion control (congestion pricing or entry restriction); coverage level of thermal and intelligent cameras at high-risk nodes.	Saigal (2025); Gajdzik et al. (2024); Wahyuilahi (2025)
Integrated public transport systems	Percentage of synchronized operation of public transport during peak hours; penetration rate of unified electronic ticketing (% of total trips); number of multimodal stations (bus/metro/bike) within urban areas; percentage of real-time schedule updates in information systems; share of shared mobility (bike, scooter) in total daily trips (%); number of active applications for integrated travel management (Mobility-as-a-Service); spatial coverage rate of public transport stations within 500 m of residential areas.	Tung et al. (2024); Chen (2023); Liu et al. (2023)
Smart accessibility & user-centric services	Percentage of users with access to smart mobility applications; number of active services offering online seat or route booking; user satisfaction with real-time travel information (average score out of 5); percentage of streets equipped with guidance systems for the visually impaired and people with disabilities; penetration level of location-based services (GPS) across the urban transport network (%); percentage of multilingual information services for tourists in city systems; percentage of stations equipped with public Wi-Fi supporting transport services; digital inclusion index in the field of smart mobility.	Yang et al. (2025); Shen (2022); Wang et al. (2025)

5. Research findings

5.1. Delphi analysis

In the first step, the Kendall coefficient of agreement was used to measure the level of expert consensus. As shown in table 3, the Kendall coefficient in the first round was 0.372, indicating a relatively moderate level of agreement among experts. According to table 4, in this step, out of the 40 extracted items, eight items were discarded because their average was less than 4 (the threshold of agreement); these items included items such as “crisis management system based on real-time data” and “live information on delays or lane changes,” which, although conceptually important, were either not feasible in the urban context studied by the experts or had not yet been adequately implemented. In addition to the deletion of these items, three new items were added based on the experts’ suggestions (including “intersection efficiency index,” “transportation network energy consumption,” and “level of open data accessibility”). Additionally, some items were revised to enhance transparency and measurability; for example, “use of green spaces in urban routes” was replaced with “share of standard pedestrian and bicycle routes in the entire transportation network.” These questionnaire modifications significantly improved the level of convergence among experts in the second round, with the Kendall coefficient reaching 0.786, a level that indicates strong consensus and stability of views. In terms of supplementary indicators, the overall mean of the items increased from 3.96 in the first round to 4.39 in the second round, and the standard deviation decreased from 0.4938 to 0.2266, indicating a reduction in the dispersion of views and an increase in theoretical convergence. In addition, the reliability coefficient (Cronbach’s alpha) for the second round of the questionnaire was calculated to be 0.872, indicating the desired reliability of the measurement tool. Also, the CVR value for most items was reported to be above 0.62 (the accepted threshold based on the Lavish table for the size of the expert sample), which confirms the appropriate content validity of the remaining items. Qualitatively, the analysis of the experts’ views showed that the most significant disagreement in the first round was around the items related to “emerging technologies” (such as the internet of things and guiding blind people with intelligent systems); some experts pointed to infrastructure limitations and high costs, while another group considered these items inevitable for the near future. In contrast, the highest level of consensus was achieved from the very beginning on the indicators of “smart traffic management” and “energy sustainability,” as these areas were more tangible and more closely aligned with the city’s immediate needs. Comparing the results of this study with international studies also reveals that the trend observed is consistent with the findings of Li and Li (2024) on the need for developing intelligent traffic management systems, as well as Nyangon's (2021) research on enhancing energy sustainability indicators in urban transportation. Accordingly, it can be said that the Delphi process not only refined the items and increased consensus but also provided a platform for adapting local findings to global frameworks.

Table 3. Kendall's coefficient of concordance in two delphi stages

Delphi Round (Stage)	Kendall's Coefficient
First	0.372
Second	0.786

Table 4. Results of the delphi rounds for research items

Indicator	Item	First round		Second round	
		Standard deviation	Mean	Standard deviation	Mean
Data-driven infrastructure	Percentage of traffic sensor coverage on main roads	0.7	4.26	0.29	4.46
	Percentage of air quality sensor coverage at high-traffic nodes	0.7	4.4	0.28	4.7
	Number of IoT-connected public transport stations	0.76	4.37	0.25	4.5
	Level of open data accessibility in the transport sector (Score 0-5)	0.6	4.4	0.3	4.45
	Level of big data usage in traffic decision-making (Number of active dashboards)	0.63	4.21	0.3	4.68
	Existence of integrated crisis management systems based on real-time data	0.66	3.22	*	*
	Percentage of roads under real-time video surveillance	0.69	3.17	*	*
Environmental sustainability	Level of data integration between transport and other urban data (energy, environment)	0.84	4.21	0.22	4.44
	Per capita CO_2 emissions from intra-city trips (kg per capita)	0.74	4.12	0.16	4.42
	Percentage of public fleet using clean/electric fuel	0.65	4.37	0.27	4.35
	Percentage of semi-public fleet (taxis/vans) using clean/electric fuel	0.65	3.69	*	*
	Number of electric vehicle charging stations per 10 km of the leading road network	0.64	4.51	0.25	4.48
	Share of standard pedestrian paths in the total transport network	0.64	4.44	0.26	4.69
	Share of standard bicycle paths in the total transport network	0.67	3.69	*	*
Public transport integration	Energy consumption of the transport network (kWh/year)	0.65	4.14	0.3	4.49
	The rate of energy consumption optimization in the network over the past 5 years	0.6	3.8	*	*
	Green Transport Development Index (Combined share of walking, cycling, and clean vehicles)	0.76	4.21	0.25	4.31
	Percentage of intersections equipped with intelligent traffic light control	0.84	4.29	0.25	4.56
	Average system response time to incidents (minutes)	0.82	4.47	0.2	4.31
	Rate of travel delay reduction after implementing intelligent control (%)	0.69	4.23	0.27	4.42
	Percentage of routes equipped with intelligent priority for emergency vehicles	0.69	3.77	*	*

Indicator	Item	First round		Second round	
		Standard deviation	Mean	Standard deviation	Mean
Intelligent accessibility	Intersection productivity index (vehicles per hour / nominal capacity)	0.73	4.22	0.2	4.69
	Real-time accident detection rate (% accuracy)	0.84	4.15	0.15	4.33
	Percentage of roads with intelligent vehicle volume control (Congestion Pricing or entry restrictions)	0.74	4.19	0.3	4.44
	Coverage level of thermal and intelligent cameras at high-risk nodes	0.6	4.55	0.19	4.3
	Percentage of public transport vehicles synchronized during peak hours	0.68	4.13	0.28	4.57
	Penetration rate of integrated electronic tickets (% of total trips)	0.63	4.18	0.22	4.31
	Number of multi-modal stations (Bus/Metro/Bike) in the urban area	0.63	3.88	*	*
	Percentage of real-time schedule updates in information systems	0.64	3.81	*	*
Intelligent Traffic Management	Share of shared fleet (bicycles, scooters) in total daily trips (%)	0.67	3.63	*	*
	Number of active applications for integrated travel management (Mobility-as-a-Service)	0.83	4.16	0.29	4.41
	Spatial coverage percentage of public transport stations within a 500m radius of residences	0.62	3.77	*	*
	Percentage of users with access to intelligent transport applications	0.66	3.44	*	*
	Availability of online seat or route reservation (Number of active services)	0.62	3.89	*	*
	User satisfaction level with real-time route information (Mean score out of 5)	0.62	4.57	0.24	4.31
	Percentage of roads equipped with guidance systems for blind people and people with disabilities	0.77	4.59	0.29	4.34
	Penetration level of location-based services (GPS) in the total urban transport network (%)	0.63	3.71	*	*
Total		0.4938	3.96	0.2266	4.39

According to the results of table 4 and in line with the systematic analysis of the spatial dimensions of the smart city with an emphasis on transformative transportation, the evaluation of macro indicators based on valid and approved items in the second round of the Delphi process provided a platform for deeper analyses and clarification of strategic priorities in urban planning. The findings indicate that the five leading indicators derived from the conceptual literature on the smart city, in light of the experts' views, have different levels of priority and function, such that the distinction between practical and less effective items in each indicator is clearly distinguishable. The results obtained from comparing the first and second stages show that, overall, the maturity level of the smartAization indicators for urban transportation in Saqqez has significantly improved. The overall average of the indicators increased from 3.96 in the first round to 4.39 in the second round, while the standard deviation decreased from 0.4938 to 0.2266. This indicates greater convergence of expert opinions and the achievement of a more stable consensus regarding the desired and actual status of the indicators. In other words, both an improvement in the performance level of the indicators and an increase in coherence in their assessment are visible. In the area of data-driven infrastructure, a significant improvement is evident in most items, especially in the index of "the rate of use of big data in traffic decision-making," which increased from 4.21 to 4.68, indicating an increasing role of data mining in transportation network management. The significant decrease in standard deviation in this section also emphasizes the consolidation of data as a key axis for intelligent decision-making. However, the omission of some items in the second stage, such as integrated crisis systems or real-time video monitoring, indicates institutional and administrative limitations in fully realizing these capacities. An improvement trend can also be observed in the environmental sustainability dimension. Indicators such as “level of overlap of transport data with other urban data” and “per capita reduction of CO_2 emissions” have improved, indicating convergence between transport policies and environmental goals. At the same time, the omission or stability of some items, such as “semi-public fleet with clean fuel” or “bicycle routes,” reveals that the transition to clean transport still faces infrastructural and administrative obstacles. The public transport integration sector has also experienced significant improvement. The increase in average indicators, such as “percentage of intersections equipped with smart control” and “reduction in travel delay,” indicates the positive impact of technology in optimizing the transportation network.

However, the decrease in the score of the “system response time to incidents” index still indicates the gap between technological capacity and traffic crisis management. The area of smart accessibility has the highest growth and the lowest standard deviation. The increase in the “intersection efficiency” index from 4.22 to 4.69, along with the improvement in the public fleet synchronism index during peak hours, indicates the network’s movement towards greater efficiency and balance. However, the decrease in the score of some items, such as “smart camera coverage,” indicates that simply using technology is not enough and that it needs to be supplemented with managerial and social mechanisms. Finally, although smart traffic management has improved in some indicators, such as “integrated travel applications” and “user satisfaction”, the removal or suspension of items such as “station spatial coverage” or “public access to smart applications” clearly indicates that spatial justice and digital justice have not yet been fully institutionalized in the traffic management structure.

The overall conclusion of this analysis indicates that the transition from the first to the second stage was accompanied by conceptual consolidation and functional improvement of the indicators, thereby strengthening Saqqez city’s path towards smart and sustainable transportation. However, the full realization of smart transformation capacities requires bridging the gap between the idealism of documents and executive constraints, strengthening institutional infrastructure, and paying more serious attention to social and spatial justice in the use of new technologies.

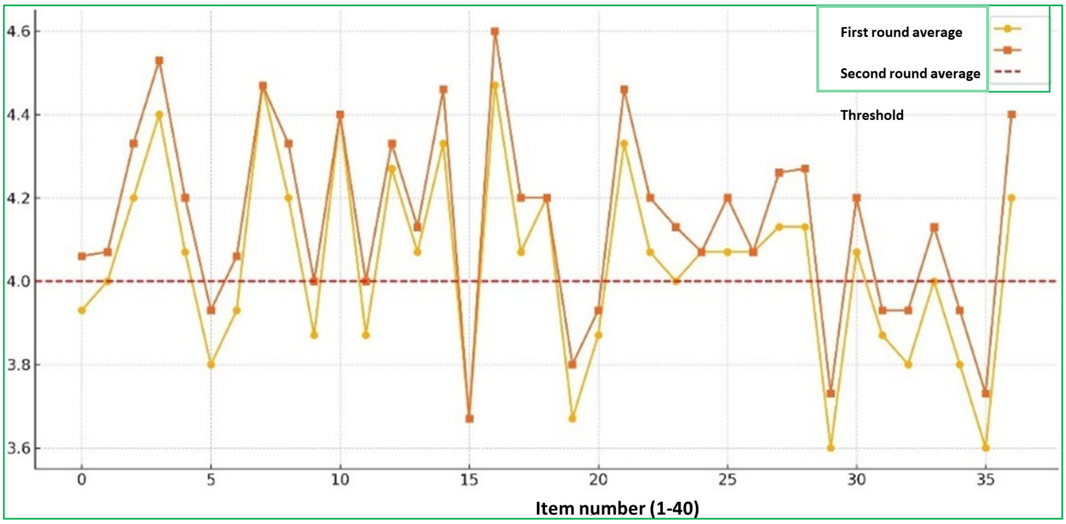

Figure 2. Comparison of mean values for qualified items

5.2. Analysis of spatial structure interconnection with smart transformability capacities

Since the mid-1970s (1350s), Saqqez has witnessed a continuous influx of rural migration, which not only caused quantitative changes in its population composition but also profoundly transformed the physical-spatial structure and urban management system. The influx of over 27,000 people between 1976 and 1986 (1355-1365) was not limited to increased housing demand but led to the reorganization of settlement patterns and spatial organization. The rushed development on mountain slopes with gradients of 25% to 35% is a clear example of the conflict between the immediate need for housing and environmental limitations, the consequences of which manifest as reduced physical resilience, increased costs for urban service provision, and heightened spatial inequalities. This trend indicated the inefficiency of urban governance and the absence of integrated strategies based on resilience and spatial justice.

In the decades that followed, formal planning efforts through comprehensive and detailed plans aimed to organize these environmentally incompatible patterns. Although the Comprehensive Urban Plan projected future development along the northern and southern axes, its approach primarily focused on the physical dimensions of development. It was less effective in providing a holistic response to the socio-economic forces driving change. The Detailed Plan, approved in 2017 (1396), despite laying a cohesive framework for guiding development, faced serious challenges during implementation due to a lack of alignment with the city's institutional and managerial capacities, as well as the utopian nature of its fundamental assumptions. Especially in the mid-2000s (1380s), the unorganized growth of informal settlements, such as Baharestan and Tazeh Abad, revealed a deep gap between formal planning and socioeconomic realities. This gap not only threatened the spatial and physical integrity of the city but also led to the weakening of justice in the distribution of urban services and facilities.

From the 2010s (1390s) onward, the complexity of spatial changes in Saqqez has increased. New factors, such as economic fluctuations, land fragmentation, street network expansion, and ongoing rural-to-urban migration, have increasingly led to the urban development pattern becoming more disunited and dispersed. This situation illustrates a transition from a single-dimensional, purely physical problem to a combined, multifaceted problem that encompasses social, economic, and environmental dimensions simultaneously. In such a complex context, the central question is how to activate smart transformability capabilities within the city's spatial organization by employing new approaches in urban management and planning. The Saqqez experience shows that without considering the dialectical relationship between spatial justice, social resilience, and structural coherence, any physical intervention is doomed to repeat the previous cycles of instability. Therefore, the transition toward a smart and transformable city in Saqqez requires moving beyond a purely physical view of development and focusing on strengthening managerial institutions, empowering the local community, and establishing a participatory decision-making system. This system can simultaneously curb informal development and ensure equitable distribution of opportunities and access to urban services.

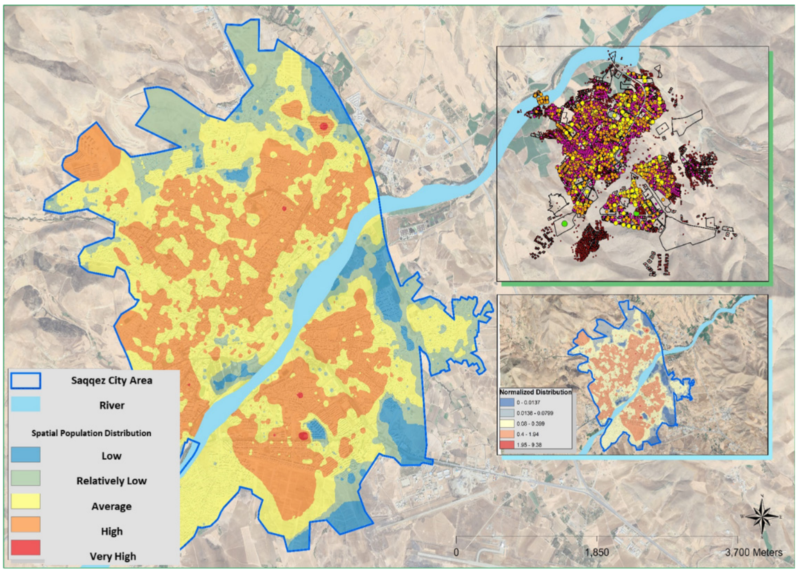

Figure 3. Population and physical development pattern of saqqez city

Using modern methods for analyzing spatial structure, particularly those based on graph logic and space syntax, is essential for reviewing the urban development trajectory. Linking these methods with smartification capacities and data-driven decision-making provides a new vision for evidence-based planning in cities like Saqqez—a city that, at the intersection of traditional physical development and the smart requirements of the new century, needs a more systemic, adaptive, and technology-driven perspective than ever before.

In this regard, the spatial structure of the Saqqez street network was analyzed by extracting 3,863 nodes and 4,848 edges and measuring key indicators such as degree centrality, Betweenness Centrality, closeness centrality, and mean depth. These indicators enable the examination of the network's continuity, concentration, accessibility, and coherence, thereby directly enhancing users' understanding of the potential for technological intervention.

As shown in figure 3, the findings indicate that the degree index has a very low average value (0.00065), suggesting limited connectivity in most network points and the prevalence of linear or radial structures. Such a pattern leads to the dependence of traffic flows on specific routes and nodes, creating vulnerabilities in the system. However, the concentration of nodes with high degrees in focal parts of the city is an important opportunity for the deployment of smart technologies, including the installation of intelligent intersection control systems, real-time monitoring sensors, and information stations. From a functional perspective, the betweenness centrality index identifies areas that play a pivotal role in directing traffic flows and can be selected as key points for traffic management or the deployment of intelligent transportation service centers. The proximity index also indicates which parts of the network are connected to other points more quickly and at a lower cost. This is particularly important in identifying priority areas for the development of public transport or shared services. The average depth also enables the measurement of spatial stratification and hierarchy, and can serve as the basis for modifying the distribution pattern of urban services. Based on these results, the relationship between numerical data and practical consequences in smart city planning becomes clearer; nodes with high degree and proximity have a higher capacity to improve accessibility and reduce travel time, while points with high betweenness centrality, as vital arteries of the network, should be prioritized for smart traffic management. Thus, network analysis is not only a set of numerical calculations, but also a tool for recognizing opportunities for technological intervention, strengthening spatial justice in accessibility, and promoting the structural resilience of the city. This approach, especially in the context of Saqqez, can serve as a bridge between technical data and policymaking, paving the way for a transition from traditional physical development to a smart and transformative city.

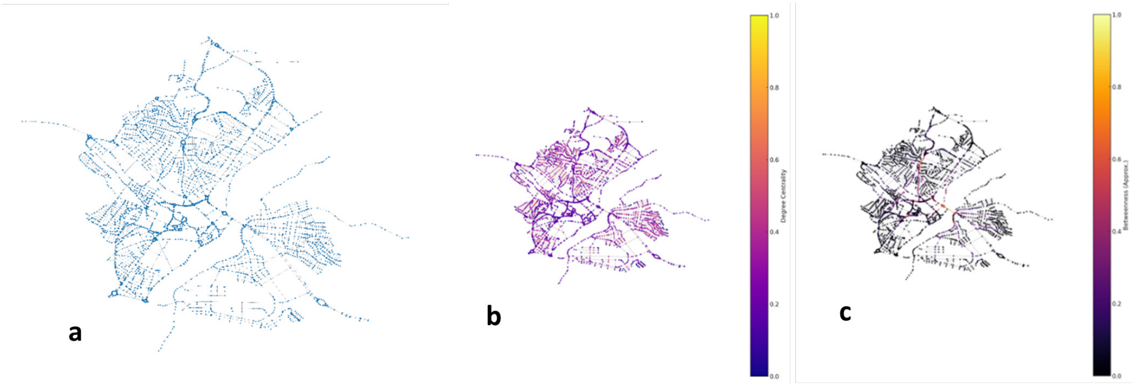

Figure 4. a) Saqqez city street network; b) degree centrality; c)betweenness centrality

The betweenness centrality index, which indicates the role of nodes as intermediate and vital points in the overall network flow, with a mean of 0.01705 and a relatively high standard deviation of 0.02680, reveals a heterogeneous structure characterized by a center-periphery pattern in the Saqqez road network. This index actually measures the number of shortest paths passing through each node. Nodes with high values of betweenness centrality have a strategic position in the network, as a significant portion of the city's traffic flows pass through these points. This concentration, on the one hand, indicates vulnerable points to congestion and disruption in the network, and on the other hand, provides an exceptional opportunity for the deployment of intelligent traffic management systems, prioritizing emergency vehicles, and optimizing route allocation. Such points can act as intelligent control cores of the network and play a significant role in increasing the resilience of urban flows. In contrast, the proximity index, which represents the average distance of a node from all other nodes in the network, has a mean value of 0.45 and a range of 0.1 to 25.64, indicating significant spatial dispersion and inequality in accessibility within the city of Saqqez. This index actually measures the degree of centrality and accessibility of each point. Nodes with higher proximity values (i.e., lower numerical values) are located in more central locations and have faster access to the entire network. This feature makes these points ideal locations for deploying smart city services such as electric vehicle charging stations, smart shared parking lots, and advanced logistics distribution centers. From a spatial justice perspective, deploying services in these points can lead to a more equitable distribution of facilities and increased citizen satisfaction. These findings not only provide a deeper understanding of the structure of the Saqqez road network but also provide a scientific basis for prioritizing smart urban interventions. By focusing on nodes with high betweenness centrality, the network resilience can be increased, and by utilizing nodes with optimal betweenness centrality, a more equitable distribution of urban services can be achieved.

By analyzing the betweenness centrality index in the Saqqez road network, a heterogeneous structure with a center-periphery pattern is revealed, which is similar to the pattern observed in historical cities with organic textures such as Isfahan and Shiraz. According to studies by Emami and Zavarat (2014) in Isfahan, the average of the aforementioned index in the central core of the city reaches 0.032, indicating an intense concentration of traffic flows along limited axes. This pattern contrasts with modern planned cities such as Copenhagen, which, according to Gol (2010), has a more balanced distribution of the betweenness centrality index (mean 0.008). In terms of the proximity index, the significant dispersion of values in Saqqez indicates deep inequality in accessibility. This situation is similar to the pattern identified by Shahinifar and Charejoo (2022) in Kermanshah, where the proximity coefficient of variation reaches 68.7%. In contrast, the Canadian city of Vancouver (2021), which is known for its model of equitable access, has a low proximity coefficient of variation (22.3%). A comparison of the results of the indices with international standards shows that the concentration of betweenness centrality in Saqqez is 2.4 times that of modern European cities, and the proximity coefficient of variation in Saqqez is 1.3 times that of cities leading in spatial justice. These findings underscore the importance of drawing on successful domestic and international experiences. For example, the road network improvement project in Tabriz (Mohammadzadeh, 2015; Mohammadzadeh, R., Fallahnejad, et al., 2016) successfully reduced the average betweenness centrality by 34% by creating alternative routes. Additionally, the experience of Vienna in implementing the Fair Access Plan (Urban Mobility Plan Vienna, 2025) demonstrated that by focusing on nodes with high proximity, urban service coverage can be increased by 40%. These comparisons demonstrate that, despite the significant challenges in the road network structure in Saqqez, it is possible to move towards a more balanced and equitable model by leveraging successful experiences and adopting smart strategies.

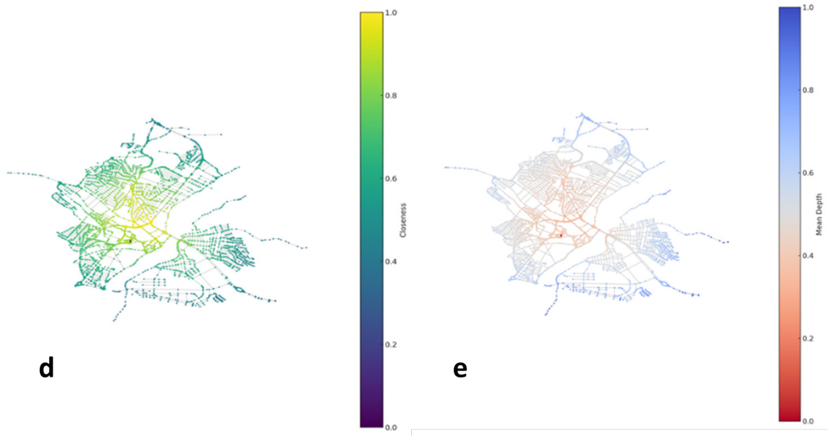

Figure 5. d) Closeness centrality e) mean depth

The mean depth index, derived from space syntax theory, evaluates the average depth of access for each node relative to the entire network. A low value for this index (0.0232), along with its limited standard deviation, suggests a relatively integrated and connected structure in the central core of the Saqqez street network. However, the wide range of values for this index (from 0.00025 to 0.0449) indicates significant spatial heterogeneity in the peripheral areas, which suffer from more limited access and higher spatial depth. These findings confirm the existence of an efficient and accessible core in the city center while revealing accessibility challenges in the marginal areas.

From an operational perspective, this analysis provides a valuable basis for planning optimal locations for smart urban infrastructure. Specifically, areas with low spatial depth (characterized by minimum index values) are suitable for deploying advanced navigation systems, smart information panels, and routing optimization algorithms. In contrast, areas with high spatial depth (characterized by maximum index values) require special attention in designing urban interventions and providing smart services to mitigate the spatial isolation of these areas. This analysis, particularly in the heterogeneous urban fabric of Saqqez, can lead to fairer and data-driven planning, contributing to a more balanced distribution of urban facilities and services. In essence, understanding spatial depth patterns is crucial for optimizing movement flows and achieving spatial justice in access to urban services.

Table 5 presents a comprehensive analysis of the network's centrality indices, providing a vivid picture of Saqqez's spatial structure. Degree centrality has a low mean of 0.00065 and a median of 0.00052, indicating relatively limited connections at the network level, which suggests a structure with low connectivity. This feature is confirmed by the relatively wide range of changes (from 0.00026 to 0.00181) and a standard deviation of 0.00018. In contrast, betweenness centrality, with a mean of 0.01705 and a relatively high standard deviation of 0.02680, reveals the heterogeneous distribution of nodes' roles in network flows, indicating the existence of a few nodes with very high values and a key intermediary role in the network. Closeness centrality, with a mean of 45.01 and a standard deviation of 9.39, reveals a wide range of accessibility (from 1.01 to 64.25), suggesting significant heterogeneity in access levels across different network points. This heterogeneity is clearly visible with an IQR of 14.81. Complementing this analysis, Mean depth, with a mean of 0.0232 and a standard deviation of 0.0052, suggests a relatively integrated structure in the network's central core. However, the wide range of variation (from 0.00025 to 0.0449) indicates the existence of peripheral areas with higher spatial depth and more limited access.

Overall, the findings suggest that while the Saqqez street network benefits from a relatively integrated central core, it faces significant challenges regarding structural heterogeneity and unequal access. Such characteristics underscore the importance of adopting smart and equitable approaches in urban planning and street network management, emphasizing the need for special attention to peripheral areas with limited access.

In summary, the analysis confirms that the spatial structure of Saqqez exhibits relative coherence in certain central areas, yet simultaneously faces functional concentration and poor connectivity in the marginal regions, reflecting a pattern of spatial imbalance. However, nodes where the degree, betweenness centrality, and closeness centrality indices are simultaneously at high levels are considered dynamic urban cores and are the most susceptible areas for the deployment of smart and transformable infrastructures. This analysis clearly shows that technological interventions in mid-sized cities should not be homogeneous or uniform, but rather be designed and implemented purposefully, phased, and based on the city's spatial network pattern, prioritizing critical nodes. Thus, the network analysis logic in this research has not only been a tool for interpreting the city's physical structure but has also provided a theoretical and applied foundation for guiding smart urban policies—policies that must simultaneously lead to spatial reorganization, data-driven infrastructure development, and functional system optimization toward spatial equity and systemic productivity. The graph analysis of the Saqqez street network plays a key role in this context. It can be generalized as a conceptual model for designing localized smart transformability models in other similar cities.

Table 5. Results of network centrality analyses

Metric / Index	Mean	Median	Standard Deviation	Maximum	Minimum	IQR (interquartile range)
Degree Centrality	0.00065	0.00052	0.00018	0.00181	0.00026	0.00026
Betweenness Centrality	0.01705	0.00691	0.02680	0.20107	0.00000	0.01644
Closeness Centrality	45.01	44.22	9.39	64.25	1.01	14.81
Average Depth	0.0232	0.0226	0.0052	0.0449	0.00025	0.00743

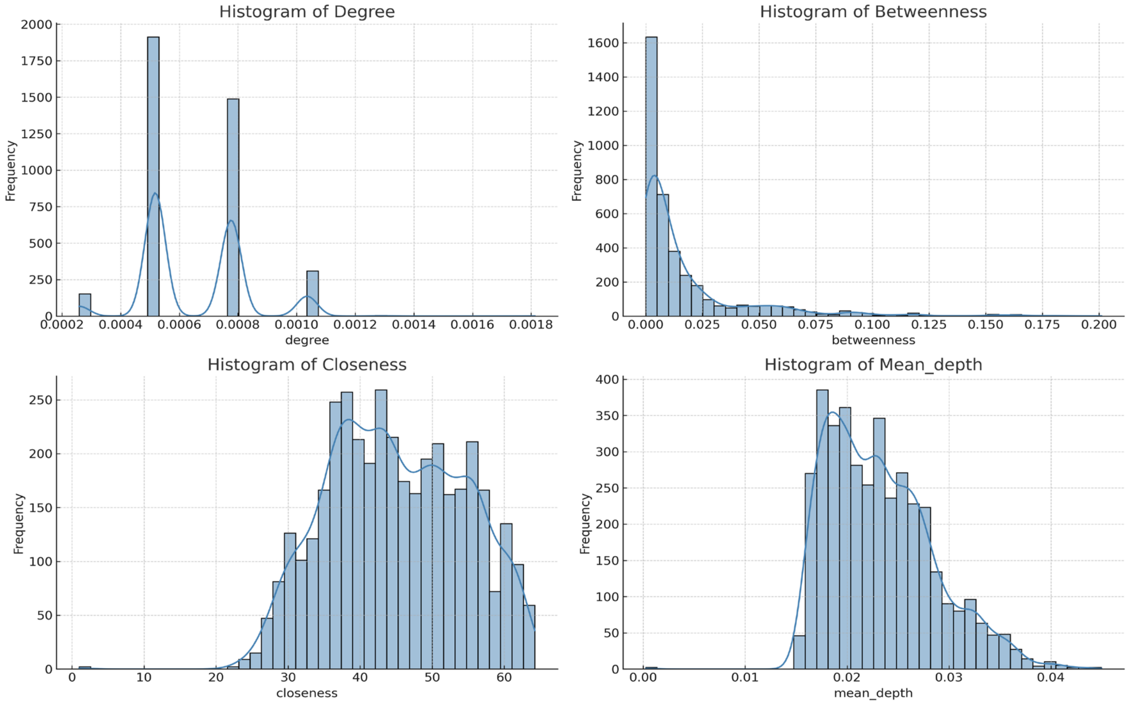

Figure 6. Statistical histogram of index distribution

6. Discussion and Conclusion

In recent decades, the rapid developments in information and communication technologies (ICT) and the expansion of smart urbanism approaches have made redefining the relationship between the spatial structure of cities and their transformability capacities a necessity for research and practice. Iran's mid-sized cities, with their specific position in the national urban network and unique physical, economic, and social characteristics, serve as arenas that, while facing resource constraints and the need for sustainable development, provide a suitable opportunity to test new models of management and smartification. However, existing studies have primarily focused on larger cities, and a comprehensive understanding of how the spatial structure of these mid-sized cities interconnects with smart technology and governance capacities is limited.

Theoretical research suggests that spatial structure not only shapes the physical framework for movement and social interaction but also determines a city's ability to absorb, process, and utilize smart data for dynamic decision-making. Practical experience in Iranian mid-sized cities indicates that the lack of street network integration, functional dispersal, and weak information infrastructure has limited smart transformability capacity, hindering the achievement of sustainable development goals and efficient urban services. Therefore, analyzing the interconnectedness of their spatial structure with smart capacities, using an interdisciplinary and data-driven approach, not only helps to identify bottlenecks and strengths in the urban network but also facilitates the design of operational strategies to increase flexibility, improve data-driven governance, and enhance the quality of urban life.

The findings of this research indicate that the spatial structure of Saqqez is in a dialectical position between an organic-historical development pattern and a planned modern pattern. Advanced network analyses, based on the space syntax approach and analytical algorithms, revealed that although the central core of the city benefits from an optimal level of structural integration (mean depth: 0.0232), the urban periphery suffers from significant functional disconnection (closeness centrality coefficient of variation: 68.7%).

The quantitative results of the research suggest that Saqqez city requires a strategic redefinition of its spatial governance model based on three principal axes: First, deployment of integrated data-driven infrastructure in the 12 identified critical nodes (with high betweenness centrality values). Second, implementation of demand-responsive smart transportation pilots in the eight key axes (with low closeness centrality). Third, design of a dynamic decision-making system capable of processing real-time urban data.

The current study faced significant methodological limitations, including a lack of access to real-time traffic data and urban mobility patterns, the omission of socioeconomic variables' effects in spatial modeling, and limitations in field validation of analytical findings compared to similar research. The findings of this study, on the one hand, corroborate Pian's (2025) results on the importance of integrated street network indices. On the other hand, in contrast to Townsend's (2013) purely technological paradigm, they emphasize the necessity of integrating physical-spatial strategies with smartification approaches. Additionally, similar to Giffinger's research (2018), it highlights the importance of localizing smartification models according to the characteristics of mid-sized cities. For future studies, four main research avenues are proposed: First, developing a system dynamics framework to simulate the impact of smart interventions on spatial structure. Second, designing an integrated IoT platform for real-time monitoring of key urban performance indicators. Third, conducting panel data studies to measure the social acceptance of smart urban technologies, and fourth, localizing artificial intelligence algorithms to predict spatial development patterns. Ultimately, this research is a step toward formulating a localized smartification model for Iranian mid-sized cities, which can serve as an operational roadmap for macro-urban planning. The realization of this model requires institutional resolve, investment in digital infrastructure, and the enhancement of urban managers' technological literacy.

Authors' Contributions

First author: 60%, Second author: 20%, Third author: 20%.

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Conflict of Interest

The authors declare that they have no conflict of interest regarding the authorship or publication of this article.

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