



Urban Injection in Historic Centers: Space Syntax Approach

Hawraa Oleiwi Shakeer ^{1,*}, Sabeeh Lafta Farhan ^{1,2}

¹Department of Architecture Engineering, Faculty of Engineering, University of Wasit, Iraq, hawraa303@uowasit.edu.iq

²College of Engineering, University of Warith AL-Anbiyaa, Karbala 56001Iraq, drsabeeh@uowasit.edu.iq

*Correspondence: hawraa303@uowasit.edu.iq

Abstract

This study presents a comprehensive analytical-applied framework for the revitalization of historic urban centers through the application of an urban injection strategy guided by the results of spatial structure analysis. The historic Rusafa district of Baghdad serves as a case study. Field surveys, digital maps, and Depth map X analysis were employed to measure indices of integration, clarity, intensity, and selection. This allowed for the identification of areas with high structural coherence, visually prominent axes, and centers of urban activity. The results reveal a dual urban structure within the historic core. This structure is characterized by highly integrated and spatially dominant main axes, such as Al Khulafa Street and Al-Khilani Square, contrasted with secondary streets and pathways suffering from weak coherence and functional performance, particularly sections of Al Rashid Street. Activity is clearly concentrated along the Al-Rashid-Al-Khulafa axis. Based on this diagnosis, the study proposes the Urban Injection strategy as a precise intervention approach. It draws inspiration from therapeutic and aesthetic intervention patterns in the medical field (intravenous, intramuscular, subcutaneous, intraosseous, cosmetic, preventative, and spiritual injections) and repurposes them within the field of architecture and urban planning, adapting them to the spatial functioning of the historic fabric. This approach allows for targeted interventions that revitalize urban areas while preserving heritage values. It provides planners and decision-makers with an evidence-based and replicable tool that supports the achievement of the Sustainable Development Goals, particularly Goal 11 (Sustainable Cities and Communities) and Goal 13 (Climate Action). The study is constrained by limited socio-economic data and restricted access to parts of the study area. Moreover, the analysis focuses mainly on spatial structure, with limited consideration of social and environmental variables. Future research should incorporate behavioral and environmental indicators to broaden the framework's analytical scope.

Keywords: Revitalization, Urban Injection Strategy, Depth map x, Historic Centers, Al-Rusafa Center, Baghdad

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I. INTRODUCTION

Historic urban centers in Arab cities are essential repositories of cultural identity, social memory, and accumulated urban experience [1]. These centers are not merely remnants of past settlement patterns, but rather dynamic spatial systems shaped by long term interactions between society, the economy, and the environment. In Baghdad, the historic Rusafa district is one of the city's most important cultural and commercial hubs; however, decades of neglect, social and political unrest, uncontrolled densification, and deteriorating infrastructure have severely damaged its urban vitality and the integrity of its heritage [2].

While previous studies have focused on preserving heritage and cultural identity in historic centers, most remain descriptive in nature and lack practical mechanisms for prioritizing and guiding urban interventions. In particular, insufficient attention

has been paid to clear quantitative and spatial methods capable of identifying streets, alleyways, and vital centers that require targeted revitalization. This reveals a clear research gap: the absence of evidence-based frameworks that translate spatial performance analysis into actionable urban intervention strategies [3].

To address this gap, this study proposes an integrated analytical-intervention framework that activates the concept of "urban injection" as a targeted strategy within a process aimed at addressing deterioration and balancing preservation and development in the city's historic center. While urban renewal focuses on comprehensive transformation at the physical, social, and economic levels, "urban injection" is conceived here as a precise and localized intervention mechanism designed to revitalize neglected urban sectors and strategically restore vitality to the deteriorating historic urban fabric. This framework establishes a

structural relationship between spatial diagnosis and intervention classification, where spatial composition indicators guide the type, location, and intensity of the intervention .

The proposed conceptual model consists of three interconnected and integrated layers.

- The first layer is the spatial diagnosis layer, which relies on spatial structure indicators derived from the Space Syntax methodology. These indicators include the Integration Index, the Choice Index, the Intensity Index (or Movement Density Index), and the Intelligibility Index. The aim is to assess the spatial performance of the historical urban fabric and identify its structural characteristics without relying on angular analysis based on sectors.
- The second layer is the interpretation layer, where the quantitative values resulting from the spatial analysis are transformed into spatial conditions with clear planning implications, such as centrality, isolation, movement density, and functional attractiveness. This layer helps link the digital indicators to the existing urban reality and clarifies their impact on movement patterns, activity distribution, and the degree of vitality in urban spaces.
- The third layer represents the urban intervention layer, where appropriate types of urban injections whether therapeutic or aesthetic, and including cultural, commercial, structural, visual, or social interventions are identified based on the nature of the spatial conditions diagnosed and interpreted in the previous two layers. This layered structure allows for the transformation of analytical outputs into planning decision support tools capable of guiding precise, high-impact, and implementable interventions. To measure the urban spatial structure, indicators of integration, choice, intensity, and clarity were adopted to determine intervention locations and priorities, as well as the most appropriate type of intervention within the urban injection strategy. This strategy relies on a methodological approach inspired by the injection mechanism in medicine, distinguishing between therapeutic injections aimed at addressing structural and functional imbalances and aesthetic injections aimed at improving the mental image and visual prominence of the space. This approach enables the revitalization of the historical urban fabric based on quantitative evidence, while respecting the spatial and cultural specificities of the site.

The Depth map X software was used as an analytical tool to apply the Space Syntax methodology and extract the spatial indicators adopted in this research. This supports the development of the proposed analytical-intervention model and its potential generalization to other historical centers in Iraq and the region.

This integrated framework is applied to the historical center of Al-Rusafa to identify priority axes, nodes, and corridors, and to formulate targeted revitalization strategies that align with the spatial logic of the area. This study contributes scientifically by developing a clear quantitative and spatial model to guide

interventions in historical centers; practically by providing decision support tools for planners and municipalities; and socially by supporting the revitalization of Al-Rusafa as a vibrant urban center. This research aligns with Sustainable Development Goal 11 (Sustainable Cities and Communities) by improving accessibility, functional diversity, and quality of urban life, and with Sustainable Development Goal 13 (Climate Action) by promoting integrated urban structures and reducing environmental pressures associated with mobility [4].

II. LITERATURE REVIEW

Historic Urban Centers and Heritage-Led Regeneration
Historic urban centers have long been recognized as key drivers of cultural continuity and urban identity. Scholars emphasize that these areas embody layered socio-spatial meanings and act as anchors of collective memory. Contemporary heritage-led regeneration approaches argue for integrating conservation with socio-economic revitalization, rather than treating historic areas as static artifacts. However, in many Arab cities, regeneration efforts remain focused on physical restoration, with limited integration of functional, social, and spatial performance considerations [5].

Urban Regeneration and Targeted Interventions
Urban regeneration is widely understood as a comprehensive process addressing physical decay, social exclusion, and economic decline. Recent literature highlights the effectiveness of targeted, small-scale interventions in triggering wider urban transformation. Concepts such as urban acupuncture and tactical urbanism advocate for precise interventions in strategic locations. Despite their relevance, these approaches are rarely operationalized through quantitative spatial analysis, particularly in historic contexts [6].

Space Syntax in Urban Analysis and Decision-Making
Space syntax has been extensively used to analyze accessibility, movement patterns, and spatial configuration. Studies demonstrate strong correlations between integration values and commercial activity, pedestrian flows, and land-use intensity. However, in most applications, spatial syntax remains a diagnostic tool, used to explain existing conditions rather than to guide intervention strategies. The transformation of spatial indicators into actionable planning decisions remains underdeveloped, especially in Arab and Iraqi contexts [7].

Urban Injection Strategy
The concept of Urban Injection builds on the logic of targeted intervention, proposing precise, localized actions aimed at activating underperforming urban segments. While metaphorical parallels between medical treatment and urban healing have been discussed in urban theory, few studies have systematically translated this analogy into a structured methodological framework. There is a lack of empirical research that integrates spatial performance indicators with specific intervention typologies in historic centers [8].

The reviewed literature reveals three critical gaps:

- 1) The dominance of descriptive heritage studies lacking operational tools.
- 2) The limited use of spatial syntax as a decision-support mechanism.

- 3) The absence of integrated frameworks linking spatial diagnosis to targeted intervention strategies in historic urban centers.

This study addresses these gaps by proposing and testing a spatially driven urban injection framework in the historic center of Rusafa, Baghdad. This study is explicitly aligned with the United Nations Sustainable Development Goals through measurable urban performance indicators. In relation to SDG 11 (Sustainable Cities and Communities), the research addresses Target 11.2 (access to safe, affordable, and sustainable transport systems) and Target 11.4 (strengthening efforts to protect and safeguard cultural heritage) by improving spatial integration, connectivity, and accessibility of heritage corridors. The use of integration and choice indicators directly supports enhanced walkability and functional diversity, contributing to inclusive and accessible public spaces. Regarding SDG 13 (Climate Action), the study supports climate adaptation by promoting compact urban form, reducing dependency on motorized transport, and enhancing local accessibility. High-integration and high-connectivity axes are prioritized for mixed-use and service injections, which contribute to reducing travel distances and associated emissions. These spatial strategies indirectly support climate resilience by limiting uncontrolled densification and encouraging efficient land-use patterns [9].

III. HISTORIC CENTER OF AL-RUSAFI, BAGHDAD

The study focuses on the historic center of Al-Rusafa in Baghdad, extending from Al-Sinak Bridge in the north to Al-Ahrar Bridge in the south along the eastern bank of the Tigris River. This area represents the oldest continuous urban core of Baghdad and has historically functioned as the city’s primary commercial, cultural, and administrative center. It contains a dense concentration of heritage buildings, traditional markets (Souq’s), religious landmarks, and civic institutions, making it a critical zone for understanding processes of urban transformation in historic Arab cities.

Al-Rusafa was selected as the case study for four main reasons:

- 1) high historical and symbolic value as the nucleus of Baghdad’s urban identity.
- 2) severity of urban deterioration and functional decline resulting from decades of neglect, socio-political instability, and infrastructure degradation.
- 3) complex spatial configuration, characterized by narrow alleys, organic street patterns, and layered land-use structures.
- 4) strategic role within Baghdad’s metropolitan structure as a central connector between major commercial, administrative, and cultural zones.

These characteristics make Al-Rusafa a representative and critical case for testing the applicability of space syntax-based urban injection strategies in historic urban centers.

A) The spatial structure of the study area

Table I and Figure 1 illustrate the spatial map of the study area within the historic district of Al-Rusafaa [10]. The area is clearly bounded by Al-Ahrar Bridge to the south and Al Sinak Bridge to the north, forming a continuous urban strip along the

Tigris River. It includes a concentration of buildings, squares, and urban axes of architectural and historical value, most notably Al-Wathba Square, Al-Khilani Square, Al-Rashid Street, and Al-Khulafa Street [11]. These elements constitute the backbone of the historic urban fabric and represent key reference points in the spatial structure of the area [12].

TABLE I. GENERAL CHARACTERISTICS OF THE STUDY AREA

Indicator	Description
Location	Eastern bank of the Tigris River, Baghdad
Northern Boundary	Al-Sinak Bridge
Southern Boundary	Al-Ahrar Bridge
Historical Core	Pre-1930 urban fabric around Al-Rashid Street
Main Axes	Al-Rashid Street, Al-Khulafa Street
Major Nodes	Al-Wathba Square, Al-Khilani Square
Dominant Land Use	Residential and Commercial
Building Heights	Predominantly 1–2 floors
Heritage Density	High concentration of historic buildings
Urban Issues	Deterioration, congestion, lack of open space, functional imbalance



Fig. 1. Spatial Structure and Key Heritage and Institutional Components of the Study Area

The urban fabric of Al-Rusafa is distinguished by a dense mix of functions, combining commercial, administrative, religious, educational, and cultural uses within a compact and layered spatial configuration [13]. Official institutions such as the Baghdad Municipality and the Ministry of Trade reflect the administrative character of the area, while educational and religious buildings, including Al-Nidal School and the Latin Church, highlight its social and cultural diversity [14].

In addition, heritage cinemas such as Al-Zawraa Cinema and the National Cinema represent tangible evidence of the area’s cultural life during the mid-twentieth century and its role as a center of public gathering and social interaction [15]. The study

area is therefore not limited to its heritage value alone; rather, it constitutes an integrated urban fabric that blends historical symbolism with contemporary daily functions [16]. Al-Wathba Square and Al-Khilani Square function as high-density urban focal points, while Al-Rashid Street continues to serve as a major commercial and cultural corridor despite its relative decline and reduced spatial integration [17]. The coexistence of official institutions, commercial activities, and cultural landmarks demonstrates that Al-Rusafa is not a static historical enclave, but a dynamic urban environment shaped by continuous social, economic, and spatial interactions. This complexity justifies the need for targeted urban intervention strategies aimed at preserving its identity while reactivating its functional role within the city.

B) Urban Nodes and Movement Axes

Figure 2 illustrates the principal urban nodes and movement axes within the study area, highlighting the traffic infrastructure that structures spatial interaction and accessibility [18]. The most prominent nodes include Al-Wathba Square and Al-Khilani Square, which function as pivotal urban points characterized by high pedestrian and vehicular density. These squares act as convergence zones for multiple movement paths and serve as important interfaces between commercial, social, and transport activities.

The main movement axes are represented by Al-Rashid Street and Al-Khulafa Street, which constitute the most significant commercial and cultural corridors in the urban fabric of Al-Rusafa. Al-Rashid Street, in particular, has historically been the symbolic spine of Baghdad’s modern urban life, while Al-Khulafa Street functions as a major connector between traditional markets and administrative zones. In addition, the direct connection of the study area to Al-Ahrar Bridge and Al-Sinak Bridge reinforces its role as a strategic corridor linking the two banks of the Tigris River and facilitating cross-city movement [19]. This configuration of nodes and axes indicates that Al-Rusafa is not an isolated historic quarter, but rather a central movement hub that influences the spatial dynamics of Baghdad as a whole.



Fig. 2. Main Urban Nodes and Movement Axes in the Study Area.

The intensity of movement, the convergence of commercial and administrative functions, and the strategic river crossings all contribute to its urban significance. Consequently, any intervention within this area must be informed by an

understanding of these interconnected spatial relationships. This reinforces the relevance of employing space syntax analysis to diagnose spatial performance and to guide the formulation of urban injection strategies that are spatially targeted, functionally responsive, and context-sensitive.

C) Land Use Patterns

Figure 3 presents the land use map of the study area in the historic center of Al-Rusafa, Baghdad, illustrating the spatial distribution of urban functions within the traditional urban fabric. The analysis aims to identify dominant activities—including residential, commercial, service, educational, cultural, and religious uses—and to examine the degree of overlap, concentration, and functional conflict among them. The figure also depicts the road network at two main hierarchical levels: primary streets with widths ranging between 20–35 meters and secondary streets with widths less than 20 meters, enabling an integrated reading of the relationship between land use patterns and traffic structure [20]. Residential use clearly dominates the core of the study area, reflecting Al-Rusafa’s long-standing role as a continuous historical residential quarter. This predominance confirms the persistence of traditional living patterns within the historic fabric. Commercial use represents the largest land use category and is primarily concentrated along the major urban axes, particularly Al-Rashid Street and Al-Khulafa Street, where commercial activities intersect with religious and tourism-related services [21].

This overlap highlights the multifunctional character of the main corridors and their role as economic and social spines of the district. Educational, cultural, and service uses occupy relatively limited areas within the urban fabric and are often associated with significant religious buildings, indicating a close functional relationship between institutional and spiritual life. Green and open spaces are notably scarce and are mainly distributed along the peripheries of the study area, underscoring the limited availability of public open spaces within the dense traditional fabric [22]. This functional pattern reflects a typical characteristic of historic Arab city centers, where residential and commercial activities dominate, while educational, health, and cultural functions remain modest in scale and spatial presence.



Fig. 3. Land Use Distribution in the Study Area

The spatial distribution of land uses reveals a clear functional imbalance, suggesting the need for carefully targeted urban

interventions to redistribute activities, enhance functional diversity, and improve the overall quality of urban life. Such interventions are essential to mitigate land-use conflicts, strengthen underrepresented functions, and support sustainable revitalization within the historic core.

D) Building Heights and Urban Density

Figure 4 illustrates the spatial distribution of building heights (number of floors) within the study area in the historic center of Al-Rusafa. This analysis seeks to clarify the relationship between vertical development, urban structure, land-use patterns, and variations in urban density. The figure also highlights the hierarchical road network, distinguishing between main streets (20–35 meters wide) and secondary streets (less than 20 meters wide), as well as the location of open spaces that provide essential breathing zones within the dense urban fabric [23].



Fig. 4. Building Height Distribution in the Study Area

The analysis shows that the overwhelming majority of buildings in the area consist of one to two stories, representing traditional heritage structures that embody the historical Baghdadi architectural character. These low-rise buildings define the dominant skyline and reflect the human-scale morphology typical of the Islamic city. In contrast, limited clusters of three to four-story buildings are present, while scattered structures of five to eight stories appear in isolated locations. Only a very small proportion of buildings exceed nine stories, representing recent development attempts that are largely inconsistent with the historical urban character and scale of the area [24]. Open spaces, shown as shaded areas in the figure, are sparse and mainly concentrated along the edges of the study area, further emphasizing the scarcity of public spaces within the historic core. The road network pattern indicates that wide streets, such as Al-Khulafa Street, function as the primary traffic arteries, while narrow streets (less than 20 meters wide) remain dominant within the internal fabric, reinforcing the traditional organic structure of the district [25].

This vertical and spatial reading reveals a pronounced urban imbalance resulting from the irregular introduction of high-rise buildings and the severe lack of open spaces. Such inconsistencies disrupt the visual harmony and morphological integrity of the historic fabric. Consequently, the area requires thoughtful and context-sensitive interventions aimed at

preserving architectural identity, controlling vertical growth, enhancing public spaces, and improving the overall quality of the urban environment [26].

E) Chronological Structure of Buildings and Urban Evolution

Figure 5 presents the chronological map of buildings in the historic center of Al-Rusafa, Baghdad, illustrating the temporal distribution of construction phases within the urban fabric. The map distinguishes between historical buildings dating to before 1930, intermediate phases of development extending through the mid-twentieth century, and more recent constructions up to 2013.



Fig. 5. Building age in the study area

The analysis of building age constitutes a fundamental tool deterioration, and functional change, and for prioritizing interventions within the framework of urban conservation and renewal strategies [27].

A significant proportion of buildings in the Al-Rusafa district date back to before 1930, representing heritage structures of high historical and architectural value. These buildings are particularly concentrated in the heart of the old city center, especially around Al-Rashid Street and its associated side alleys, forming the core of the traditional Baghdadi urban fabric. This concentration reflects the historical role of Al-Rusafa as the primary commercial and social nucleus of Baghdad during the late Ottoman and early modern periods. Buildings dating to before 1950 are more widely dispersed throughout the surrounding urban fabric, forming an intermediate temporal layer that reflects patterns of urban expansion and modernization during the mid-twentieth century [28]. These structures often represent transitional architectural typologies, combining traditional elements with early modern influences, and illustrate the gradual transformation of the historic fabric in response to socio-economic change. In contrast, modern buildings constructed between 1980 and 2013 are primarily concentrated in the southern and western parts of the study area, where they have replaced numerous demolished or severely deteriorated heritage buildings. These newer structures typically reflect functional and economic priorities rather than contextual or heritage considerations, contributing to morphological and

visual discontinuities within the urban fabric [29]. The chronological map thus reveals a clear temporal and spatial contrast between an old core rich in historic buildings and peripheral zones dominated by modern, functionally driven development. This contrast highlights the intensity of urban pressures exerted on the historic center and underscores the ongoing processes of erosion and replacement affecting its architectural heritage. Consequently, the findings emphasize the necessity of adopting urban policies that prioritize the restoration and adaptive reuse of historic buildings, reintegrating them functionally into the contemporary urban fabric while achieving a balanced relationship between heritage preservation and urban development. Such an approach is essential to sustain the cultural identity of Al-Rusafa and to ensure the long-term vitality of its historic environment.

IV. THEORETICAL BACKGROUND AND ANALYTICAL POSITIONING

This study adopted a While a substantial body of literature has addressed the regeneration of historic urban centers, much of this work remains descriptive and heritage-oriented, focusing primarily on documentation, architectural value, and cultural identity. Although such approaches are important for conservation, they often lack analytical depth and fail to provide operational mechanisms for prioritizing urban interventions within complex and deteriorated urban fabrics.

In recent decades, quantitative and configuration-based approaches have emerged, particularly Space Syntax theory, which conceptualizes urban space as a relational system where spatial configuration directly influences movement patterns, land-use distribution, and socio-economic interaction. Hillier's theory of natural movement demonstrates that spatial accessibility and integration are not merely physical properties, but active generators of urban vitality. However, despite the wide application of Space Syntax in analyzing historic environments, most studies remain confined to diagnostic analysis and rarely translate syntactic outputs into decision-oriented intervention strategies. This reveals a critical theoretical and methodological gap: the absence of integrative frameworks that systematically connect spatial configuration analysis with targeted urban intervention mechanisms in historic centers. In response, this study positions Urban Injection as an operational sub-strategy within the broader paradigm of urban regeneration. Urban injection is conceptually grounded in the logic of focused, localized, and high-impact interventions, aligned with spatial performance indicators. By integrating Space Syntax analysis with urban injection typologies, the research advances a theoretically justified and analytically driven framework that transforms spatial diagnosis into actionable planning decisions. This integration moves beyond descriptive narratives and contributes a structured model for evidence-based revitalization of historic urban fabrics.

This study is guided by the following research questions:

- 1) How does the spatial configuration of the historic center of Al-Rusafa perform in terms of integration, choice, connectivity, and visibility?
- 2) Which urban axes, nodes, and segments exhibit the highest spatial potential and which suffer from spatial underperformance?
- 3) How can Space Syntax indicators be systematically translated into targeted Urban Injection strategies?
- 4) To what extent can an integrated analytical–interventional framework supports the revitalization of deteriorated historic urban centers?

Research Objectives Accordingly, the study aims to:

- Analyze the spatial configuration of Al-Rusafa using segment-based Space Syntax techniques.
- Identify structurally dominant and spatially marginalized corridors within the historic fabric.
- Develop an operational framework linking spatial diagnosis to urban injection typologies.
- Propose spatially targeted interventions to enhance accessibility, functional diversity, and urban vitality.

V. METHODOLOGY

The study adopts a case study methodology to examine Al-Rusafa's historic center as a complex urban system shaped by spatial, historical, and socio-cultural layers. It integrates qualitative morphological analysis with quantitative Space Syntax techniques to objectively assess spatial configuration and urban vitality as in Figure 6.

A) Research Methodology

This study adopts a case study approach focusing on the historic center of Al-Rusafa in Baghdad as a complex urban system rich in historical, spatial, and socio-cultural layers. The case study method is particularly appropriate for investigating historic centers, as it enables an integrated understanding of morphological structure, functional dynamics, and spatial behavior within a real-life context. The methodology combines qualitative spatial reading of heritage and architectural characteristics with quantitative spatial analysis using digital tools to objectively measure spatial performance. This integrative approach responds directly to the theoretical premise that urban vitality in historic centers is not solely a product of heritage value, but is strongly conditioned by spatial configuration and accessibility patterns.

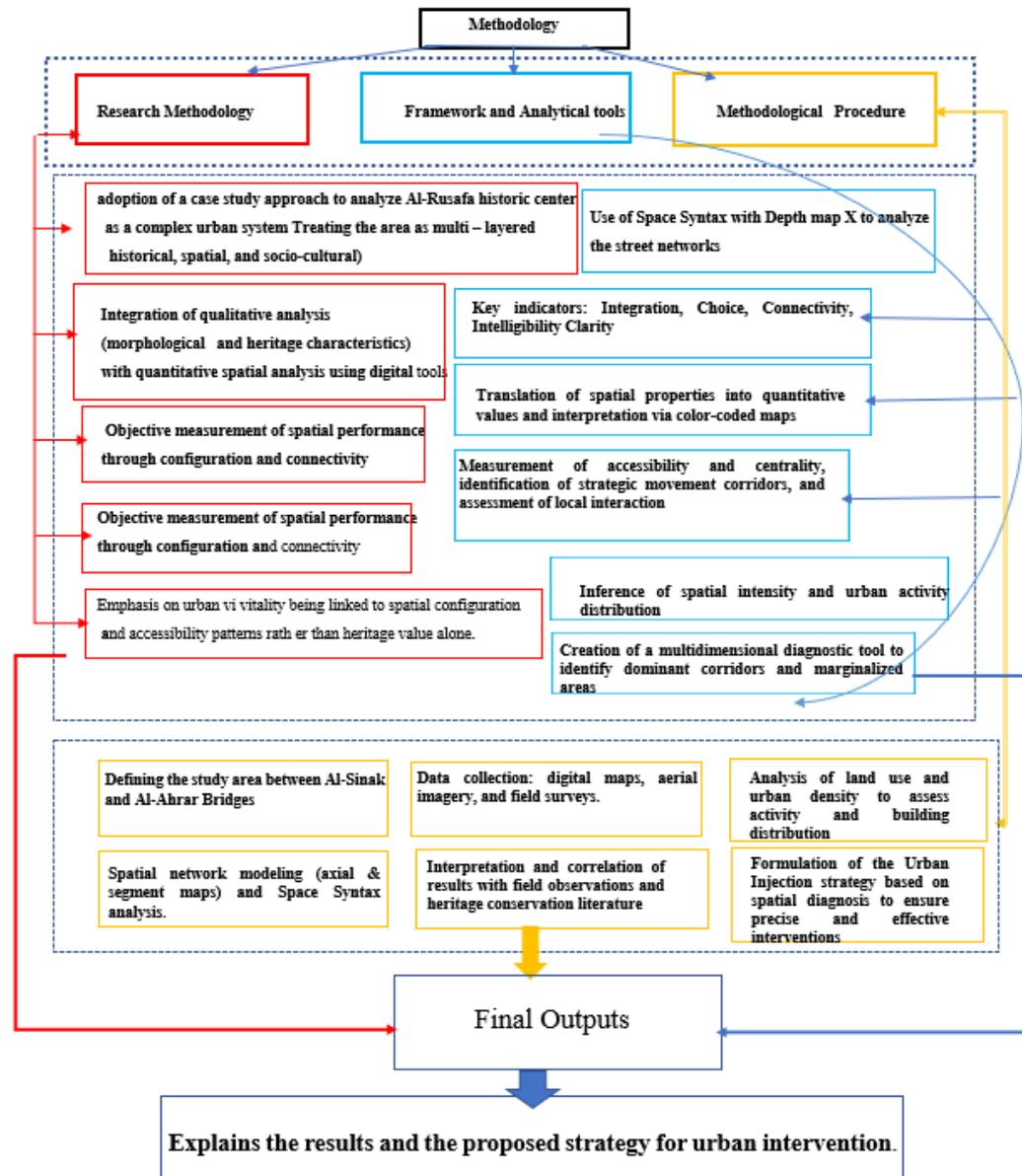


Fig. 6. The Research Methodology

B) Framework and Analytical Tools

The study employs Space Syntax analytical tools using Depth map X software to evaluate the street network through four principal indicators: integration, choice, connectivity, and visibility. These indicators are selected based on their theoretical relevance to movement generation, spatial centrality, and perceptual clarity.

The spatial indicators used in this research are derived from space syntax analytical diagrams generated through network-based analysis software (e.g., Depth map X). Each indicator translates a specific spatial property of the urban network into quantifiable values that can be directly interpreted through color-coded analytical maps.

Integration measures the relative accessibility and spatial centrality of each axial line or segment by calculating its mean topological depth in relation to all other elements of the network, followed by statistical normalization. Higher integration values, represented by warmer colors, indicate centrally positioned spaces that are easily reachable from across the system and therefore more capable of attracting movement and urban activities, making integration a key indicator of spatial vitality.

Choice represents through-movement potential and is calculated as the frequency with which a segment lies on the shortest paths between all pairs of spaces in the network. Segments with high choice values appear prominently on the choice map and indicate corridors of strategic importance for movement flow, commonly associated with commercial activity and daily commuting patterns.

Connectivity measures the number of directly connected segments to each spatial element and reflects the level of local permeability and immediate accessibility. High connectivity values indicate spaces that support smooth local movement and everyday interaction, while low values reveal spatial isolation within the urban fabric.

Intelligibility (Clarity) is derived from the statistical correlation between connectivity and global integration, typically visualized through a scatter plot. High intelligibility values indicate that local spatial cues reliably reflect the overall structure of the urban system, enabling users to understand and navigate the city intuitively through everyday movement.

Intensity is not a direct output of space syntax algorithms but is analytically inferred by interpreting areas where high integration and high choice values converge and relating them to observed urban activity. In addition, urban density is practically understood as the concentration of built mass and activities within the urban fabric, expressed through building heights, coverage ratios, and land-use density. Activity distribution refers to the spatial distribution of different functions (residential, commercial, cultural, religious, and service-oriented) and reveals patterns of functional dominance or dysfunction within the historic center. These indicators together constitute a multidimensional diagnostic tool that enables the identification of structurally dominant corridors, high-potential spaces, and spatially marginalized areas. This analytical foundation represents the scientific basis for guiding the proposed urban injection strategy, ensuring precise, targeted, evidence-based interventions that are sensitive to the spatial and historical context.

C) Methodological Procedure

The research was conducted through the following sequential steps:

- 1) *Defining the Study Area*: delineation of the area between Al-Sinak Bridge (north) and Al-Ahrar Bridge (south).
- 2) *Data Collection*: gathering digital maps, aerial imagery, and field survey data.
- 3) *Land Use Analysis*: classification of land uses (residential, commercial, service, mixed) and calculation of their spatial distribution.
- 4) *Building Age and Height Analysis*: documentation of building layers and number of floors to assess density and deterioration.
- 5) *Spatial Network Modeling*: preparation of axial and segment maps using AutoCAD and import into Depth map X.
- 6) *Space Syntax Analysis*: calculation of integration, choice, connectivity, and visibility values.
- 7) *Interpretation and Correlation*: linking syntactic results with field observations and literature on historic urban conservation.
- 8) *Urban Injection Formulation*: assigning intervention typologies based on diagnosed spatial conditions.

This structured procedure ensures a coherent integration between quantitative spatial analysis and strategic urban intervention planning.

VI. SPATIAL ANALYSIS RESULTS

The results are reorganized as an analytical reading of spatial analysis outputs to support decision-making rather than descriptive repetition. Integration values identify the structural hierarchy of movement and guide interventions along key connectivity corridors. Clarity scores explain spatial legibility and indicate where visual or morphological injections are required to improve orientation. Intensity values reveal the distribution of socio-economic activity, highlighting areas of vitality and zones of functional deficiency. By synthesizing these indicators, the analysis provides a diagnosis of spatial imbalance within the historic center, directly informing the selection, location, and priority of Urban Injection interventions based on spatial need rather than generalized treatment.

A) Integration Index

Figures 7, 8 present that Al-Khulafa Street had the highest integration value of 2.80, followed by Al-Khalani Square with a value of 2.50, confirming their importance as major axes with a high capacity to connect components of the urban fabric. Rashid Street, on the other hand, recorded a lower integration value of 1.20, reflecting its weak permeability compared to other axes, despite its symbolic and historical significance.

The integration index showed that Al-Khulafa Street and Al Khalani Square represent the axes with the greatest capacity for spatial connectivity, while Rashid Street has fallen to a lower rank, explaining the gradual decline in its central role in contemporary urban life.

These results indicate that future urban interventions should focus on enhancing the connection of Rashid Street to the higher integration axes (Al-Khulafa and Al-Khalani), to ensure the restoration of its pivotal role in the urban structure and its transformation once again into an attractive hub for economic and cultural activity

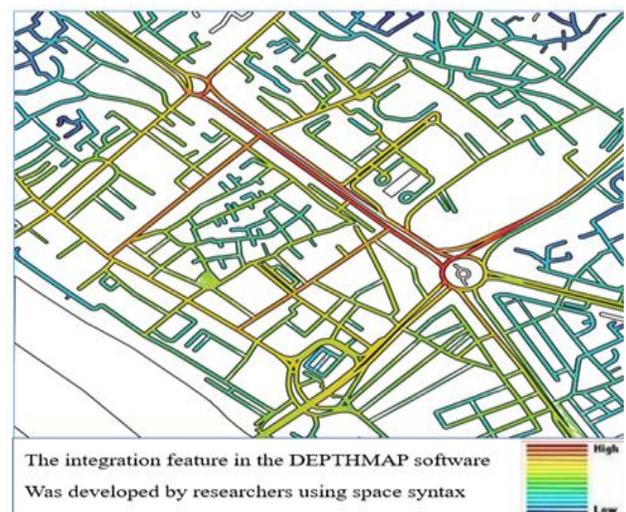


Fig. 7. The integration feature in the Depthmap x

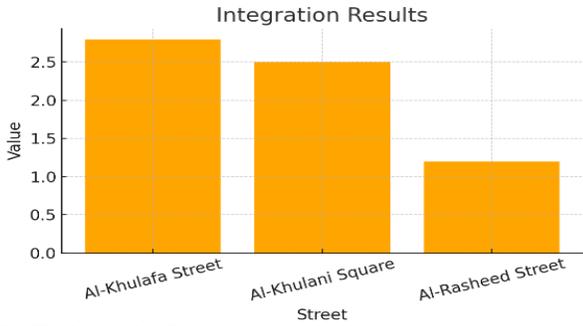


Fig. 8. The integration Results

B) Clarity Index

Figures 9, 10 show that AL- Rashid Street has the highest spatial clarity score of 12%, making it a clear and distinct visual path within the street network. Al Khalani Square came in second place with a score of 10%, while Al-Khulafa Street recorded only 5%, indicating its weak visual perception compared to other axes .

The clarity index confirmed that Rashid Street maintains its position as a prominent and easily recognizable visual façade, but it suffers from a disconnection in connectivity with other axes, limiting its effectiveness as an integrated route

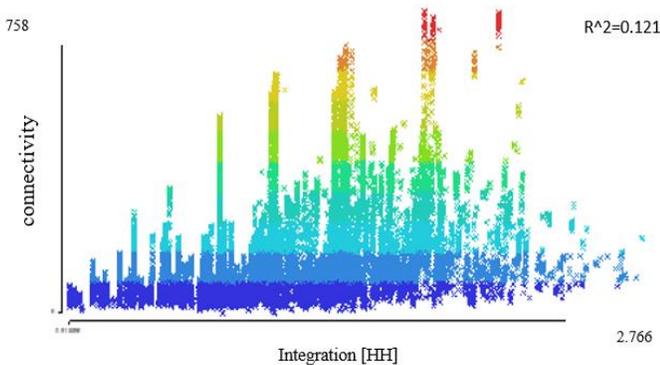


Fig. 9. The clarity property of the study area

These results reveal that Rashid Street continues to represent a strong visual façade, while some other axes suffer from weak visual perception. This calls for architectural and visual improvements (Facade treatment – Urban Lighting) to enhance the clarity of these axes and increase their attractiveness to pedestrians and visitors.

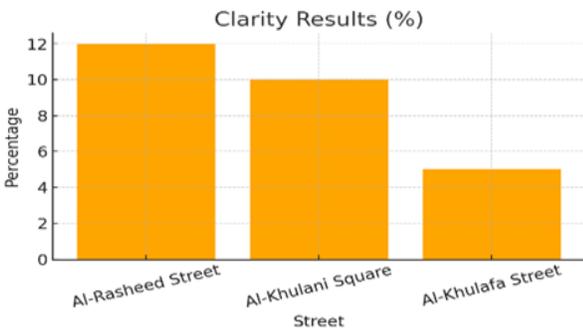


Fig. 10. The clarity Results

C) Intensity Index

Figure 11 illustrates that the Rashid-Khulafaa axis has the highest intensity value of 0.69, reflecting the concentration of commercial and traffic activity there. Khulafaa Street came in second place with a value of 0.55, while the secondary axes recorded a lower value of 0.40, indicating limited activity in these routes.

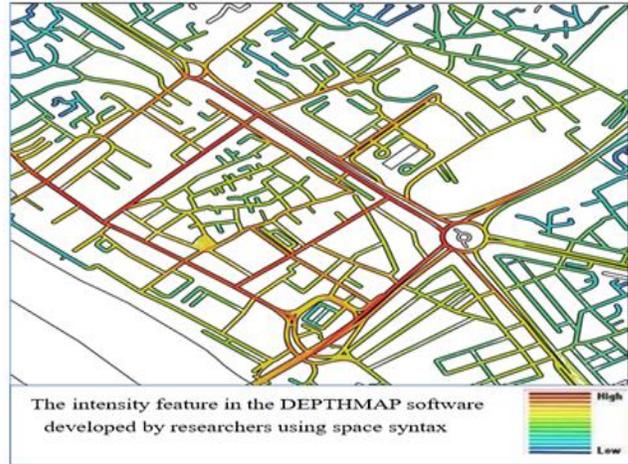


Fig. 11. The Intensity Results

These results indicate urban activity in Rusafa is concentrated in a small number of main axes, while the secondary axes remain virtually paralyzed in terms of movement and interaction. This highlights needs to redistribute activity through an urban injection strategy by supporting the axes with low values with cultural, commercial, and visual services that enhance their role in the public network as in Figure 12.

The spatial analysis reveal that the urban structure in the historic center of Rusafa suffers from a clear duality between highly efficient main axes and others with weak connectivity and activity.

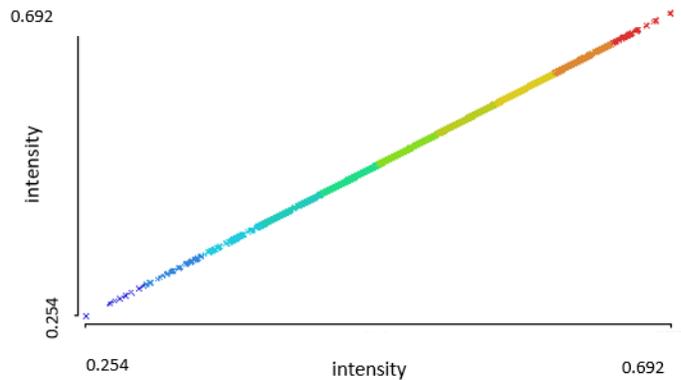


Fig. 12. Scatter plot for the intensity index

Figure 13 shows results of the intensity index showed that commercial and traffic activity is excessively concentrated in

the Rashid-Al-Khulafa axis, while secondary axes remain functionally inactive, resulting in a significant disparity in the distribution of activities.



Fig. 13. The intensity Results in the Depthmap x

These indicators indicate that the historic center of Rusafa faces a structural challenge represented by spatial and functional imbalance; traffic and activity are concentrated in a few axes, while others are subject to decline and neglect. Accordingly, it becomes necessary to adopt an urban injection strategy as an approach to rebalancing the city, by introducing carefully considered cultural, service, and commercial activities into low-integration and low intensity axes, while enhancing their visual clarity. This integrated vision not only contributes to the redistribution of traffic and activities, but also to restoring Rusafa's urban identity and strengthening its role as the historic heart of Baghdad and a vibrant urban center.

Collectively, the spatial indicators reveal a dual condition within Rusafa: a set of dominant, highly integrated corridors that attract most pedestrian flows, and a wider network of low-integration alleys that suffer from spatial and functional decline. The coexistence of visually prominent yet functionally weak streets—such as Al-Rashid— highlights the need to reconnect perceptual visibility with actual mobility. This synthesized diagnosis provides the foundation for structuring selective interventions that balance reinforcement of high-performing axes with the revitalization of neglected segments of the urban fabric.

Table II explains the relationship between spatial indicators and types of urban injection represents a direct translation from quantitative analysis to planning decision, and is the core of the proposed analytical-intervention model, ensuring precise, targeted, and generalizable interventions in historical centers.

VII. ANALYTICAL INTERPRETATION

The spatial syntax analysis, based on Integration, Clarity, Choice, and Intensity indicators, reveals a structural duality within the historic core of Rusafa: highly integrated primary axes coexist with marginal inner fabrics characterized by low connectivity and functional decline. This diagnosis forms the basis for selecting urban injection mechanisms through a targeted, evidence-based approach grounded in medical analogy.

Intravenous injection is assigned to the most integrated and permeable axes, namely Al-Rashid Street, Al-Khulafa Street,

and the Sayyid Sultan Ali corridor, which recorded Integration values ranging between 2.50 and 2.80. These axes function as urban “arteries” capable of redistributing vitality into adjacent tissues, justifying their prioritization for economic and cultural revitalization.

Intramuscular injection is directed toward historic inner neighborhoods with moderate connectivity and low intensity, such as Qambar Ali and Bab Al-Sheikh. The objective is to strengthen functional and service capacities without disrupting the morphological structure or displacing original residents, thereby supporting social sustainability.

Subcutaneous injection targets transitional edges where historic and modern fabrics collide. These zones, particularly along Al-Khulafa and Al-Jumhuriya Streets, require controlled interventions to regulate scale, height, and visual coherence, preventing progressive erosion of urban identity. Intraosseous injection is reserved for major urban nodes and squares, including Al Wathba and Al-Khilani, which demonstrate high Choice and Intensity values. These spaces act for reinforcing social, economic, and cultural interaction within the historic center. Complementary mechanisms include cosmetic injection along visually legible yet degraded corridors such as Al-Rashid Street to restore urban readability, preventive injection in fragile back alleys to mitigate future deterioration, and spiritual injection around religious landmarks to reinforce symbolic depth and collective memory.

Through this framework, spatial analysis is transformed from a diagnostic tool into a decision-making platform, and the medical analogy of injection evolves from a metaphor into an operational urban strategy. This demonstrates how Urban Injection mediates systematically between architecture and medicine, aligning intervention type, location, and intensity with the spatial logic of the city.

VIII. DISCUSSION

A) Integration Patterns and Urban Centrality

The high integration values recorded along Al-Khulafa Street (2.80) and Al-Khilani Square (2.50) confirm their role as the primary structural spines of movement within the historic core. This finding aligns with Hillier’s theory that highly integrated spaces naturally attract pedestrian flows, economic activities, and urban vitality. Similar patterns have been observed in historic centers such as Cairo, Fez, and Damascus, where a limited number of main axes dominate spatial accessibility despite the organic morphology of the fabric. However, the relatively low integration value of Al-Rashid Street (1.20) represents a notable divergence from these precedents. In many historic Arab cities, the main heritage street continues to function as both a symbolic and spatial center. In Al-Rusafa, by contrast, the results reveal a disjunction between historical importance and spatial performance. This can be attributed to prolonged neglect, traffic constraints, deterioration of the built environment, and loss of functional competitiveness. This finding highlights a critical spatial imbalance and justifies the need for targeted reconnection strategies within the urban injection framework.

TABLE II. THE RELATIONSHIP BETWEEN SPATIAL INDICATORS AND TYPES OF URBAN INJECTION REPRESENTS

Spatial indicator	Analytical Significance	Inferred Spatial State	Functional	Intervention Objectives
Integration	Measures centrality and accessibility within the urban network	High values: Central axes capable of attracting movement and activity Low values: Limited local pathways	therapeutic injection (Intravenous Injection) Subdermal therapeutic injection	Enhancing mobility, supporting commercial and service activities, strengthening the urban role of main axes Opening passageways, improving accessibility, reducing spatial isolation
Choice	Measures through traffic and the likelihood of passage through pathways	High values: Central axes capable of attracting movement and activity Low values: Marginal and poorly integrated spaces	Muscular injection Local therapeutic injection	Supporting continuity of movement, regulating flows, activating transit axes Promoting local use and reducing functional isolation
Connectivity	Reflects local permeability and connectivity	High values: Spaces with strong local interaction Low values: Weak connectivity and local isolation	Social-service injection Structural therapeutic injection	Improving spatial connectivity, reconnecting isolated spaces to the public network Enhancing social activities and daily services
Intelligibility	Measures the readability and comprehensibility of the spatial system	Low values: Confusing and difficult-to-orient environments	Cosmetic injection	Improving orientation, strengthening urban guidance, enhancing the public image
Intensity	Reflects the concentration of movement and activity (derived from integration and choice)	High intensity: Functional and kinetic stress Low intensity: Stagnation and weak activity	Regulatory-operational injection Functional stimulating injection	Organizing land uses, improving urban comfort, relieving pressure Attracting new activities, revitalizing stagnant spaces

B) Clarity, Visibility, and Urban Perception

The clarity analysis shows that Al-Rashid Street retains the highest visual clarity (12%), confirming its role as a strong perceptual façade despite its weakened integration. This corresponds with Lynch’s theory of legibility, where prominent linear elements remain embedded in collective mental maps even when their functional role declines.[30] Comparable studies in historic Islamic cities frequently report low legibility in inner quarters due to organic growth patterns. However, in Al-Rusafa, the contrast between the visual dominance of Al-Rashid Street and its reduced spatial connectivity reveals a unique condition: a visually strong but spatially disconnected corridor. This condition is intensified by visual pollution, informal encroachments, and inconsistent façade treatments. Therefore, while low clarity is common in traditional fabrics, the Al-Rusafa case demonstrates how neglect and uncontrolled modifications exacerbate perceptual disorientation, reinforcing the need for visual and architectural injections.

C) Intensity, Activity Concentration, and Functional Imbalance

The intensity results indicate that socio-economic activity is heavily concentrated along the Rashid–Khulafa axis (0.69–0.55), while secondary axes remain functionally inactive (0.40–0) commercial activities cluster along a few dominant corridors, leading to uneven vitality distribution. However, the degree of concentration in Al-Rusafa is particularly acute. Unlike cases in

European historic centers where secondary streets have been reactivated through adaptive reuse and micro-interventions, the secondary network in Rusafa remains largely paralyzed. This reveals that density alone does not generate urban life; rather, it must be supported by spatial accessibility, visibility, and functional diversity. The coexistence of high density with low vitality in many inner areas supports contemporary theories advocating qualitative density over quantitative accumulation .

D) Duality of Spatial Performance

The synthesis of integration, clarity, and intensity indicators reveals a clear dual structure within the historic center: a limited set of highly efficient, dominant axes and a wider network of low-integration alleys suffering from spatial and functional decline. This duality has been documented in many traditional cities; however, in Al-Rusafa it is intensified by decades of institutional fragmentation, absence of coherent conservation policies, and socio-political instability. The presence of visually prominent yet functionally weak streets, such as Al-Rashid, further emphasizes the structural contradiction between perception and performance. This condition is less evident in cities where continuous regeneration policies have maintained alignment between symbolic value and spatial functionality. Therefore, the Al-Rusafa case demonstrates how historical centrality can erode when not supported by spatial reintegration and functional adaptation.

E) *Urban Injection in Relation to Existing Regeneration Models*

Most regeneration models in historic centers rely on large-scale redevelopment or tourism-oriented revitalization. In contrast, the Urban Injection approach adopted in this study is closer to acupuncture urbanism and tactical urbanism but is distinguished by its quantitative spatial targeting. While previous studies often selected intervention areas based on visual assessment or policy priorities, this research identifies priority segments through measurable spatial performance indicators. This methodological positioning contributes to the literature by operationalizing Space Syntax as a decision-support tool rather than a purely diagnostic technique. It demonstrates how analytical outputs can be directly translated into intervention logic, strengthening the theoretical justification of the proposed framework .

F) *Contextual Specificity of Al-Rusafa*

Although many of the observed patterns correspond with international literature on historic urban decline, Al-Rusafa's case is distinguished by prolonged neglect, weak institutional coordination, and limited investment in heritage-led regeneration. These contextual conditions explain why spatial dysfunction is more pronounced than in comparable cities. Consequently, the proposed Urban Injection strategy should be understood as a context-responsive framework, adaptable to similar Middle Eastern cities facing layered deterioration.

G) *Synthesis*

In synthesis, the discussion demonstrates that:

- High integration corridors in Al-Rusafa conform to global spatial theories.
- The marginalization of Al-Rashid Street represents a context-specific deviation.
- The concentration of activity along few axes reveals structural imbalance.
- The integration of Space Syntax with Urban Injection offers a novel methodological contribution .

IX. CONCLUSIONS

This study developed and validated an integrated analytical–interventional framework that combines spatial syntax analysis with Urban Injection strategies to guide the revitalization of historic urban centers, exemplified by Al-Rusafa in Baghdad. The findings offer both scientific contributions and actionable policy guidance for heritage-sensitive urban regeneration.

A) *Main Scientific Contributions*

- 1) *Methodological Rigor:* The study demonstrates the effectiveness of space syntax indicators (integration, clarity, and intensity) in translating complex spatial configurations into measurable, decision-oriented outputs, offering a robust alternative to descriptive approaches.
- 2) *Operational Urban Injection Model:* By linking spatial diagnosis directly to intervention typology, the research introduces a spatially explicit framework for targeted

cultural, commercial, visual, and service interventions, enabling evidence-based urban regeneration.

- 3) *Regional Relevance and Transferability:* The integration of spatial syntax with Urban Injection addresses a documented gap in Iraqi and regional literature, providing a model that can be applied to other historic cities in Iraq and the Middle East facing similar spatial and heritage challenges. After testing the spatial analysis, the most integrated and permeable axes, the most clearly defined axes, and the most concentrated activity centers were identified. This demonstrates the research's methodological effectiveness in transforming spatial data into usable quantitative outputs for decision-making, moving beyond the impressionistic or descriptive approaches that dominated many previous studies. This underscores the value of spatial analysis as a standard methodological tool for urban planning and heritage sensitive renewal.

B) *Policy and Planning Recommendations*

- 1) *Prioritize High-Integration Axes:* Streets such as Al-Khulafa and Al-Khilani Square should be strengthened with commercial, cultural, and mixed-use interventions to reinforce their role as urban backbones.
- 2) *Enhance Visual but Weak Corridors:* Al-Rashid Street and similar axes require targeted architectural and visual interventions to reconcile perceptual prominence with functional connectivity and restore historic centrality.
- 3) *Support Low-Integration Secondary Axes:* Underperforming streets and alleys should receive selective cultural, social, and service injections to redistribute activity, reduce spatial imbalance, and enhance overall urban vitality.

C) *Implications for Sustainable Urban Regeneration*

The study demonstrates that heritage preservation and contemporary development are complementary when guided by spatial evidence. Selective Urban Injection offers a practical pathway for conservation-led development, supporting SDG 11 through improved accessibility and functional diversity, and SDG 13 by promoting compact urban structures and reducing mobility-related environmental pressures.

D) *Final Synthesis*

In sum, this study provides a scientifically grounded and practically applicable model for revitalizing historic urban centers. By bridging spatial analysis with intervention logic, it equips planners and policymakers with a clear, evidence-based tool to prioritize interventions, allocate resources, and guide sustainable, heritage-sensitive urban regeneration.

Following the quantitative spatial analysis, a decision-support matrix was developed to translate spatial indicators into targeted urban injection types.

Table III presents the mapping between spatial syntax indicators and corresponding intervention mechanisms across the historic center of Rusafa.

TABLE III. ANALYTICAL CORE OF THE PROPOSED URBAN INJECTION FRAMEWORK, ENABLING EVIDENCE-BASED PRIORITIZATION OF INTERVENTION LOCATIONS AND INTENSITIES

Urban Injection Type	Governing Indicators	Spatial Characteristics	Rationale for Selection	Axes / Areas in Al-Rusafa
Intravenous Injection	High integration, high choice, high connectivity	Dominant central axes with strong capacity to attract and redistribute movement	These axes function as the main urban “arteries” of the historic core, capable of redistributing economic and cultural vitality to adjacent areas	Al-Rashid Street, Al-Khulafa Street, Sayyid Sultan Ali Corridor
Muscular Injection	Moderate choice, low intensity, medium connectivity	Inner neighborhoods with predominantly local movement and daily-life functions	Enhances functional and service performance without disrupting the urban fabric or causing displacement	Qambar Ali, Bab Al-Sheikh, Aqed Al-Nasara
Subdermal Injection	Relatively low integration, weak visibility	Transitional zones between historic and contemporary urban fabrics	Prevents gradual erosion of urban identity by regulating heights, façades, and visual coherence	Transitional segments of Al-Khulafa Street and Al-Jumhuriya Street
Intra-osseous Injection	High intensity, high functional diversity, dense activity	Major urban squares and structurally significant nodes	These spaces represent the structural “bones” of the urban system and key centers of social and economic interaction	Al-Wathba Square, Al-Khilani Square
Cosmetic Injection	Low visibility, high visual exposure	Visually degraded corridors with strong symbolic value	Improves mental image, enhances landmark legibility, and supports visual readability of the urban space	Deteriorated segments of Al-Rashid Street
Preventive Injection	Spatial fragility, weak connectivity	Vulnerable back alleys and fragile historic fabrics	Limits future deterioration and maintains long-term urban stability	Inner alleys branching from Al-Rashid and Al-Khulafa Streets
Spiritual Injection	High symbolic value, high visitor density	Surroundings of religious and historic landmarks	Strengthens collective memory, symbolic depth, and cultural identity	Sayyid Sultan Ali Shrine, Murjan Mosque, Al-Haiderkhona Mosque

X. RECOMMENDATIONS

Targeted Activation of High-Integration Corridors: Prioritize cultural, commercial, and social interventions in highly integrated and permeable axes (e.g., Al-Khulafa Street, Al-Khilani Square, Sayyid Sultan Ali Axis) to redistribute urban vitality and reinforce centrality.

Selective Reinforcement of Marginal Areas: Strengthen secondary streets and inner neighborhoods with low connectivity through context-sensitive functional interventions (services, pedestrian access, heritage-friendly facilities) to achieve spatial and social balance.

Visual, Symbolic, and Public Space Enhancement: Enhance streets and nodes with high clarity or symbolic significance (e.g., Al-Rashid Street, major squares) through façade rehabilitation, lighting, pedestrian-friendly design, and activation of public and cultural spaces, ensuring coherence between visibility, function, and heritage preservation.

XI. FUTURE STUDIES

1) Expanding the Urban Injection Framework Across Historic Centers Future studies should apply the Urban Injection strategy to multiple historic centers at local and international levels. This expansion will enable comparative spatial analysis, test the adaptability of the framework under different urban conditions, and support

the development of a generalized, evidence-based model for selective interventions in heritage contexts.

- Integrating Advanced Digital and Analytical Technologies Incorporating artificial intelligence, 3D spatial modeling, and digital twin technologies can significantly enhance urban analysis. These tools allow simulation of intervention scenarios, prediction of long-term impacts, and optimization of decision making processes while minimizing physical, social, and economic risks.
- Strengthening Environmental, Social, and Economic Evaluation Future research should systematically assess the environmental, social, and economic impacts of urban injections. This includes measuring improvements in quality of life, social inclusion, cultural vitality, and economic performance, and linking these outcomes to climate resilience and sustainable development objectives.

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