



Developing a Multi-Criteria Spatial Model to Guide Urban Injection Interventions in Historic Centers: A Case Study of Old Rusafa in Baghdad

Hawraa Oleiwi Shakeer¹, Sabeeh Lafta Farhan^{1,2*} 

¹ Department of Architecture Engineering, Faculty of Engineering, University of Wasit, Al-Kut 52001, Iraq

² College of Engineering, University of Warith AL-Anbiyaa, Karbala 56001, Iraq

Corresponding Author Email: drsabeeh@uowasit.edu.iq

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ABSTRACT

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Historic centers face increasing pressures resulting from functional and economic transformations, the deterioration of heritage buildings, and weakened spatial cohesion, threatening their identity and vitality. This research aims to develop a multi-criteria spatial model to guide urban regeneration interventions in Old Rusafa, Baghdad, by linking a quantitative diagnosis of the urban structure with an expert assessment of heritage and social values. The research adopted a mixed-methods approach, combining spatial structure analysis using DepthmapX software, morphological and field analysis, and a questionnaire administered to 26 experts. The analysis addressed indicators of overall integration, connectivity, clarity, and spatial intensity, while documented averages were used to directly derive weights for the criteria. The results showed high performance on Rashid and Khulafa Streets and low performance in the inner alleyways, with a spatial clarity coefficient of approximately 0.46. Preserving iconic buildings received the highest weight at 22.82%, followed by social activity and restoration at 20.63% each, while integrating modern architecture received the lowest weight at 16.07%. Sensitivity analysis confirmed the stability of the extremes of the criteria ranking, with limited changes in the middle ranks. The model proposes reinforcement interventions for high-performing areas, integration for transition zones, and incentivization for isolated sites, transforming spatial analysis from a descriptive tool into a transparent framework to support decision-making and sustainable urban conservation. Its contribution lies in aligning spatial performance with cultural value and determining the type, location, and priority of intervention within a highly sensitive historical context.

1. INTRODUCTION

Historic centers represent complex urban systems whose value is not limited to individual buildings, but encompasses the relationships between streets, markets, facades, activities, and social memory. The historic urban landscape approach emphasizes that urban heritage includes spatial organization, land uses, visual relationships, and cultural and economic practices [1]. Therefore, successful management means organizing transformation, not freezing the physical state.

The urban centers of the Middle East suffer from high ground pressure and traffic, declining maintenance and residential function, and fragmented management. These problems are evident in Old Rusafa through changes in land uses, building heights, and facades, the deterioration of public space, and the transformation of some symbolic buildings into warehouses or abandoned structures. Al-Rashid Street remains a powerful axis, but this power does not extend to the same extent to the inner alleyways, revealing the inadequacy of protection measures that focus on the building and neglect connection, activity, and the management of public space.

This research proceeds from the premise that comprehensive, large-scale intervention is not always the most appropriate solution in the historic fabric. Large projects may require significant resources, take a long time, and sometimes lead to the removal of spatial and social layers that are difficult to replace. In contrast, the concept of urban injection or urban revitalization offers the potential for qualitative improvement through small- to medium-sized interventions targeting specific points with the capacity to effect broader change. However, the effectiveness of this concept depends on the ability to answer clear operational questions: Where should intervention occur? What type of dysfunction exists? What indicator does it reveal? What type of intervention is appropriate? And how can priorities be set when heritage value conflicts with functional pressures or economic needs?

The research problem lies in the absence of an integrated operational framework that links measuring the spatial performance of the historic fabric with evaluating urban values that are not reducible to purely geometric indicators. While spatial composition studies can identify the most integrated or interconnected axes, they cannot, on their own, determine the

historical value of a building, the significance of collective memory, or community acceptance of a particular type of intervention. Conversely, expert and resident assessments can express cultural and social significance, but they may remain general if not linked to measurable sites and indicators. Hence the need for a model that integrates these two fields within a revisable and applicable decision matrix.

This research aims to develop a multi-criteria spatial model to guide urban injection interventions in Old Rusafa. This objective branches into four procedural goals: first, to diagnose disparities in integration, connectivity, clarity, and intensity within the movement network; second, to identify the morphological, social, and cultural values associated with buildings and main axes; third, to establish an operational relationship between performance level and intervention type; and fourth, to propose spatial priorities and actionable, follow-up measures. The research is based on the premise that integrating spatial analysis with expert assessment improves the accuracy of intervention planning compared to relying on either alone.

2. LITERATURE REVIEW

2.1 Historic centers: Between preservation and transformation

The concept of urban preservation has shifted from protecting individual buildings to understanding the historic city as a system of tangible and intangible values. A UNESCO recommendation calls for integrating heritage into development policies [1], while a study demonstrates that balance requires incorporating historical value into planning and urban economic choices [2]. This perspective necessitates distinguishing between the symbolic sensitivity of buildings, the pressures of commercial hubs, and the isolation of alleyways, rather than applying a uniform policy to all sites.

In Baghdad, studies have shown that Old Rusafa has suffered physical damage, functional transformations, and a decline in the clarity of its urban identity. An assessment of urban heritage in the historic center revealed that weak management, fragmented procedures, and a lack of integrated vision have contributed to continued deterioration [3]. Furthermore, a study on urban style discontinuity demonstrated that the emergence of multiple, inconsistent visual images along historic axes has weakened the relationship between valuable buildings and their surrounding landscape [4]. A visual quality study of Al-Rashid Street found that the evaluation of the historical landscape is linked to the condition of facades, advertisements, formal harmony, and visual elements, not solely to the age of the buildings [5]. A study of Al-Sarai Market confirms that the sustainability of heritage markets is linked to integrating conservation measures with daily functions and the social dimension [6]. A comparison with the old city of Najaf shows that uncontrolled changes in use and urban form weaken inherited characteristics and necessitate gradual strategies that consider the specificity of the context [7].

2.2 Urban injection as a selective intervention strategy

Urban injection is based on specific interventions, such as opening a pathway, reusing a symbolic building, or improving a junction, with the expectation that its impact will extend to a

wider network. However, choosing a site based on impressions can turn the concept into a mere slogan. Studies of Al-Rusafa have demonstrated the importance of catalytic points [8], linking the intervention to network performance [9], and selecting a renewal policy according to the condition of the buildings, their uses, and socio-economic objectives [10].

This research proposes distinguishing between five functional patterns of urban injection. The first is communicative injection, which aims to address fragmentation, poor permeability, and connect alleyways to main axes. The second is morphological injection, which deals with facades, heights, mass proportions, voids, and street continuity. The third is stimulating injection, which targets symbolic buildings or sites capable of attracting cultural or civic activity. The fourth is social and functional injection, which works to revitalize local spaces and activities and improve the relationship between residents and visitors. The fifth is environmental injection, which addresses shade, landscaping, thermal comfort, and pedestrian-friendly walking.

These approaches do not always work in isolation; a site may require a combination of them. However, distinguishing between them is crucial to defining the problem each intervention addresses. Rehabilitating a facade is insufficient to address the isolation of an alley, opening a new pathway does not protect the symbolic value of an abandoned building, and creating a green space alone does not resolve visual clutter. Therefore, the selection process should begin with diagnosis, followed by determining the type and scale of injection and the entities responsible for its implementation.

2.3 Spatial composition and measurement of urban network performance

Hillier and Hanson [11] established the spatial composition approach to understand the relationship between spatial configuration, movement patterns, and social interaction. This approach posits that the street network is not merely a neutral backdrop for activities, but rather a structure that influences accessibility, movement, spatial visibility, and land use distribution. Methodological literature indicates that compositional indicators help explain the difference between central axes and isolated areas, and examine the relationship between local perception and overall structure [12].

Integration expresses the topological proximity of an axis to the rest of the movement network and is therefore usually associated with accessibility and potential movement. Connectivity expresses the number of direct connections to an axis and is a local indicator that, on its own, does not reveal the axis's position within the entire system. Spatial clarity results from the relationship between local connectivity and overall integration; a strong relationship allows the user to infer the overall structure from their local experience, while a weak relationship indicates difficulty in reading and navigation. Turner and colleagues demonstrated the possibility of constructing visibility charts and measuring visual, local, and overall relationships [13]. Penn [14] also explained that the relationship between perception and composition is not merely geometric, but also involves a cognitive processing of topological relationships.

DepthmapX analysis relies on establishing a correct grid and determining the scale and type of distance. Colored maps do not represent a final planning result; they reveal spatial possibilities and do not judge cultural meaning or facade

quality [15]. Therefore, scales must be linked to field observation [16] and a clear spatial database [17].

The research proceeds from this methodological limitation. Spatial composition is suitable for identifying grid relationships, but it cannot, on its own, determine heritage value or the acceptability of intervention. Therefore, it is used as a quantitative layer within a broader model, and its results are reviewed in light of land use, building ages and conditions, symbolic functions, and expert assessments.

2.4 Multi-criteria analysis and direct rating weighting

Multi-criteria decision models are used when a decision requires combining quantitative and qualitative indicators of varying units. Weights can be derived in several ways, including pairwise comparisons in the analysis hierarchy, direct ranking, point distribution, and normalization of importance scores. Traditional analysis hierarchy relies on independent pairwise judgments on a Saaty scale, followed by deriving a priority vector and examining the consistency of the judgments [18-20]. Direct rating weighting begins with importance scores assigned by experts to each criterion, and these scores are then normalized so that the sum of the weights equals one.

The methodological issue lies in the need to name the method according to the data actually collected. The research questionnaire used a five-point Likert scale for each item and did not ask experts to perform pairwise comparisons between the criteria. Therefore, the research adopted direct weighting of scores, and the weight of each criterion was calculated by dividing its mean by the sum of the means of the five criteria:

$$\text{Criteria Weight} = \text{Mean of Criterion} \div \text{Sum of Means of Criteria}$$

To demonstrate the relative relationships between the weights, a reciprocal matrix was constructed, derived mathematically according to the relationship:

$$\text{Cell value between two criteria} = \text{Weight of the first criterion} \div \text{Weight of the second criterion}$$

This matrix allows for verification of the calculation, but it does not represent new pairwise judgments issued by experts. Therefore, its consistency value is approximately zero due to the construction method, and this should not be interpreted as evidence of perfect psychological consistency among the participants. This distinction ensures that the characteristics of the analysis hierarchy process are not attributed to an instrument that did not collect its original data, while maintaining the transparency and revision ability of the weights.

2.5 The research gap

The gap can be summarized on three levels. First, a proportion of studies on Rusafa focus on historical description, landscape assessment, or land-use analysis without translating the results into spatial rules for selecting the type of intervention. Second, spatial composition studies use indicators to interpret movement and isolation, but they do not adequately integrate the symbolic and social values of

buildings and pathways. Third, multi-criteria studies use expert weights, but they do not always clarify how normative values relate to actual location and classification boundaries.

This research addresses this gap with an operational matrix that links each indicator to its data source, calculation method, normalization, performance level, and proposed intervention type. This makes the transition from map to decision traceable: the reader can see why a particular axis is classified as high-performing, why a reinforcement intervention is proposed rather than a stimulus one, and what data needs to be updated when applying the model in another city structure.

3. METHODOLOGY

3.1 Research design

The research adopted a mixed-methods design combining quantitative analysis and qualitative interpretation. The first phase began with the development of a spatial database encompassing the street and alley network, land uses, building heights and ages, and the locations of buildings of value. A spatial structure analysis was then conducted to extract indicators of integration, connectivity, clarity, and intensity. The second phase involved a morphological and field survey of the condition of blocks, spaces, facades, landmarks, and activities. The third phase included reanalyzing the expert questionnaire data from the thesis from which the research was derived, followed by converting the documented criteria averages into direct weights. Finally, the results were integrated into a decision matrix to determine the performance level and the appropriate type of intervention.

The design does not assume that spatial indicators are a substitute for heritage assessment, or that expert opinion replaces measurement. Rather, each source has a specific function: the movement network reveals the hidden structure of spatial relationships, the field survey reveals the physical and functional condition, and the expert assessment reveals professional priorities and intangible values. The results are then compared to test their convergence or divergence.

As shown in Figure 1, the study area covers a defined section of Old Rusafa, extending along the historic urban fabric between the main movement axes and the internal alley network.



Figure 1. Boundaries of the study area in Old Rusafa, Baghdad

Source: Prepared by the researchers using Google Earth maps.

3.2 Study area and justification for its selection

The study area is located in Old Rusafa on the east bank of the Tigris River, extending from Sinak Bridge in the south to Ahrar Bridge in the north, with a focus on Al-Rashid Street and its parallel and intersecting axes. The boundaries were chosen based on three considerations: the cohesion of the historical fabric, the clear gradation between the main axes and the internal alleyways, and the diversity of values and functions within an area that can be analyzed both field-based and spatially.

As shown in Figure 2, low-rise buildings of one or two floors predominate within the historic fabric, while taller buildings are more concentrated along the main urban axes.



Figure 2. Distribution of the number of floors in the study area
Source: Baghdad Municipality, Geographic Information Systems Division.

The area is characterized by high building density, a network of streets that slope from main axes to narrow alleyways, and an overlap of commercial, religious, administrative, cultural, and residential uses. Low-rise buildings of one or two stories are prevalent within the urban fabric, while heights increase along the main axes, reflecting economic and morphological pressures. Open spaces are limited, and commercial activity is concentrated on Al-Rashid Street and the areas connected to Shorja.

The age distribution of buildings reflects overlapping historical layers; the oldest buildings are concentrated in the center, while relatively newer buildings are spread along the edges and areas of highest traffic volume. This overlap is not inherently problematic, but it becomes a source of distortion when new buildings are constructed without regulations

regarding height, facade, proportions, and their relationship to the street line.

The area includes a collection of landmarks of religious, cultural, administrative, and educational significance. Table 1 presents key examples used in the expert and field analysis.

As illustrated in Figure 3, the study area contains a diverse mixture of land uses, with commercial activities particularly concentrated along Al-Rashid Street and the areas connected to Al-Shorja.



Figure 3. Land use map of the study area
Source: Baghdad Municipality, Geographic Information Systems Division.

As shown in Figure 4, the study area contains overlapping historical layers, with older buildings concentrated mainly in the central historic fabric and relatively newer buildings distributed toward the edges and higher-traffic areas.



Figure 4. Distribution of building ages in the study area
Source: Prepared by the researchers based on available data.

Table 1. Selected historic landmarks in the study area: Functional types, construction dates, current conditions, and significance

Landmark Name	Functional Type	Year of Construction	Current Condition	Significance
Latin Church	Religious	1731	Neglected	One of the oldest religious landmarks, reflecting cultural diversity
Al-Nidhal Preparatory School	Educational	<1945	Existing	Historic institution with social value
Telecommunications Building	Administrative	20th Century	Rebuilt	Iraqi modernist architecture by Rifat Chadirji
Al-Zawraa Cinema	Cultural	1943	Commercial storage	Reflects Baghdad's cultural life
Al-Watani Cinema	Cultural	1943	Commercial storage	Historical and cultural importance
Ministry of Trade Building	Administrative	20th Century	Abandoned	Represents administrative heritage
Shrine of Sayyid Abu Tahir Al-Tayeb	Religious/Symbolic	Historical	Existing	Spiritual and social importance
Rafidain Bank	Financial	20th Century	Existing	Traditional architectural features

3.3 Data sources and preparation

The database consisted of digital plans, land use maps, road and alley network data, building height and age data, available aerial and video images, field observations, and facade and landmark photographs. The movement network was cleaned by removing duplicate lines, closing unintended gaps, and verifying connectivity at intersections, then converted to a format suitable for analysis in DepthmapX. The analysis relied on axes and sections representing actual movement possibilities, excluding lines that did not represent a general route.

Building data were used to interpret spatial results, not to replace them. Building height, age, condition, and use are morphological and functional variables, while integration and connectivity are network variables. Linking the two layers allowed for the differentiation between a spatially strong axis that is subject to morphological pressure and a spatially weak axis that possesses historical value warranting stimulating intervention.

Figure 5 shows the spatial distribution of the principal landmarks and buildings of heritage value within the study area, highlighting their concentration along and around the main historic urban axes.



Figure 5. Distribution of the most important landmarks and buildings of value in the study area
Source: Prepared by the researchers.

The expert data were derived from the original questionnaire of the dissertation entitled “Urban Injection as a Strategy for Balancing Preservation and Development in the Historic Rusafa Center – Baghdad.” Twenty-six questionnaires were valid, and participants were distributed

according to their academic qualifications as follows: 21 PhD holders (80.8%), four Master's degree holders (15.4%), and one Bachelor's degree holder (3.8%). Responses were collected electronically using a five-point Likert scale. In this research, means and standard deviations were directly verified from the response frequencies published in the dissertation tables.

Figure 6 provides a field photograph of Al-Zawraa Cinema on Al-Rashid Street, illustrating the current condition of one of the study area’s significant cultural landmarks.



Figure 6. Al-Zawraa Cinema building on Al-Rashid Street
Source: Researchers' photography.

3.4 Spatial structure indicators

Four main indicators were used. The first is overall integration, which measures the relative position of each axis within the entire network. The second is connectivity, which measures the number of direct links. The third is spatial clarity, which represents the statistical relationship between connectivity and integration and is measured by the coefficient of determination. The fourth indicator is spatial intensity, which expresses the concentration of relationships and potential movement within the network according to the outputs of the spatial analysis used in the dissertation. It was used to explain the gradient between the main axes and internal regions, without equating it to the actual movement count on-site.

Table 2 summarizes the operational structure of the proposed model, including the selected indicators, data sources, measurement and normalization methods, classification thresholds, identified spatial dysfunctions, and corresponding intervention types.

Table 2. The operational structure of the model

Indicator	Data Source	Measurement and Normalization Method	Classification Threshold	Indication of Spatial Dysfunction	Associated Intervention
Global Integration	Axial network analysed in DepthmapX	Integration value followed by linear normalization	Low, moderate, high	Spatial isolation or excessive pressure on the axis	Catalytic intervention for low values, integrative intervention for moderate values, and reinforcing intervention for high values
Connectivity	Number of direct spatial connections	Connectivity value followed by normalization	Low, moderate, high	Poor permeability or concentration of movement	Opening spatial links, reorganizing intersections, and improving movement routes
Spatial Intelligibility	Relationship between connectivity and global integration	Coefficient of determination between the two variables	Below 0.50: low to moderate; 0.50 or above: better intelligibility	Difficulty in understanding and navigating the urban fabric	Wayfinding signage, lighting, small-scale landmarks, and visual organization

Spatial Intensity	Spatial network model analysed in DepthmapX	Spatial intensity value followed by comparison across urban axes	Low, moderate, high	Weak potential vitality or concentration of spatial pressure	Activating land uses or regulating movement and urban activities
Historical and Symbolic Value	Building survey and expert assessment	Five-point scale supported by qualitative description	Low, moderate, high	Loss of cultural meaning or inappropriate use	Adaptive reuse and catalytic urban injection
Morphological Quality	Building heights, façades, masses, and voids	Field assessment checklist	Incoherent, transitional, coherent	Disruption of the urban scene and skyline	Height and façade controls and sequential rehabilitation

To make the indicators comparable, linear normalization is used for positive values:

Normalized Value = (Original Value - Lowest Value) ÷ (Highest Value - Lowest Value), resulting in values between 0 and 1. These are then divided into three operational categories: low performance (0 to <0.33), medium performance (0.33 to <0.67), and high performance (0.67 to 1.00).

Statistical triads can be used instead of equal bounds if the distribution of values is biased, provided the researcher declares and maintains the chosen method in all maps and tables.

3.5 Questionnaire and expert sample

The questionnaire included twenty-six experts and specialists in relevant urban, cultural, and social fields. The sample was selected purposively because the aim was to obtain

professional judgment, not to statistically represent the population of Baghdad. The original instrument consisted of twelve closed-ended statements and two open-ended questions. Five statements were chosen that directly relate to the criteria of the current model: the first question addressed the revitalization of walkways and squares; the second, cultural and social activities; the fifth, restoration using traditional materials and modern techniques; the sixth, the integration of modern architectural elements; and the tenth, the preservation of historical buildings with spiritual and symbolic significance.

The mean, standard deviation, and 95% confidence interval were recalculated for each criterion from the published frequencies, as shown in Table 3. The order of frequencies within each row is: strongly agree, agree, somewhat agree, slightly agree, and strongly disagree.

Table 3. Descriptive statistics and response distributions for the expert-assessment criteria

Criterion and Question Number	Score Frequencies (5/4/3/2/1)	Mean	Standard Deviation	95% Confidence Interval	Response Intensity
Activation of Pathways and Spaces – Q1	7/10/7/2/0	3.846	0.925	3.473–4.220	76.9%
Social Activities – Q2	6/16/2/2/0	4.000	0.800	3.677–4.323	80.0%
Traditional and Contemporary Restoration – Q5	6/15/4/1/0	4.000	0.748	3.698–4.302	80.0%
Integration of Modern Architecture – Q6	0/8/13/5/0	3.115	0.711	2.828–3.403	62.3%
Preservation of Symbolic Buildings – Q10	11/15/0/0/0	4.423	0.504	4.220–4.627	88.5%

3.6 Integrating indicators and guiding intervention

The integration process consists of five steps. First, the spatial indicators are printed within a unified range. Second, the heritage, morphological, and social value of each axis or location is determined. Third, direct weights derived from expert averages are applied. Fourth, a composite index of performance and priority is calculated. Fifth, the score is not automatically converted into a decision but is interpreted in conjunction with the type of dysfunction and the heritage value to determine the appropriate intervention.

The sum of the five averages was 19.3846. Dividing the average of each criterion by this sum yielded the weights shown in Table 4, all of which are then summed to 1.0000.

Table 5 shows the matrix of reciprocal ratios derived from the weights, where each cell is calculated by dividing the row weight by the column weight.

The matrix reached a maximum eigenvalue of 5.000, and the consistency index and coherence ratio approached 0.000 using a random index of 1.12 for a matrix of five criteria. This result is expected because the matrix was derived algebraically from a single weighting vector and does not represent a test of

the consistency of independent pairwise comparisons.

Table 4. Relative weights of the expert-assessment criteria

Code	Criterion	Mean	Relative Weight	Percentage
C1	Activation of Pathways and Spaces	3.846	0.1984	19.84%
C2	Social Activities	4.000	0.2063	20.63%
C3	Traditional and Contemporary Restoration	4.000	0.2063	20.63%
C4	Integration of Modern Architecture	3.115	0.1607	16.07%
C5	Preservation of Symbolic Buildings	4.423	0.2282	22.82%

The composite site score can be expressed as: Site score = Sum of (Relative weight of criterion × Site value printed in criterion). However, two sites may achieve the same score for different reasons; one may have high heritage value and poor

connectivity, while the other has low value and high functional pressure. Therefore, a qualitative rule was added to prevent reducing the decision to the overall score. If the historical value is high, the priority is protection and reuse, even if spatial performance is average. If integration is high with clear functional pressure, the intervention is regulatory and reinforcement-oriented. If poor connectivity is combined with low activity and a lack of features, the intervention is motivational and communicative.

Table 5. Reciprocal ratio matrix derived from the normalized criterion weights

Criterion	C1	C2	C3	C4	C5
C1	1.000	0.962	0.962	1.235	0.870
C2	1.040	1.000	1.000	1.284	0.904
C3	1.040	1.000	1.000	1.284	0.904
C4	0.810	0.779	0.779	1.000	0.704
C5	1.150	1.106	1.106	1.420	1.000

3.7 Validation and sensitivity analysis

Verification was based on three feasible levels with the available data. The descriptive level was verified by recalculating means, deviations, and confidence intervals from the response frequencies. Spatial verification compared maps with land-use observations and the condition of the axes. Comparative verification tested the model's ability to explain the differences between Al-Rashid Street, transition axes, and internal alleyways.

Sensitivity analysis of the weights was conducted by changing one criterion at a time and then renormalizing them so that the sum of the weights remained equal to one. The tests included increasing the symbolic value weight by 10%, increasing the paths weight by 10%, decreasing the modern architectural integration weight by 20%, and increasing the social weight by 10%. Thresholds for change in ranking between similar criteria were also calculated. This analysis does not test the ranking of sites because a complete quantitative matrix of sites is not available for all five criteria; rather, it tests the stability of the intervention pattern priorities extracted from the questionnaire.

4. RESULTS AND DISCUSSION

4.1 Comprehensive integration results

The comprehensive integration map revealed a clear gradation in the performance of the traffic network. High values were concentrated on Al-Rashid Street, Al-Khulafa Street, and their connecting axes, which aligns with their role as arteries for traffic, commercial activities, and services. Conversely, values decreased in secondary streets and internal alleyways, revealing their relative isolation and the difficulty of traffic flow between them and the main axes.

Figure 7 illustrates the spatial distribution of comprehensive integration values across the study area, highlighting the contrast between the highly integrated main axes and the relatively isolated internal streets and alleyways.

A high value does not necessarily mean that the axis does not require intervention; high integration can be a source of pressure, congestion, advertising density, and unregulated land use. Therefore, the high values on Al-Rashid Street are interpreted as a spatial capacity that should be preserved and

managed, not as a perfect, ideal state. Appropriate interventions include pedestrian traffic management, sidewalk improvement, restoring facade continuity, regulating advertising, and highlighting landmarks at intersections.

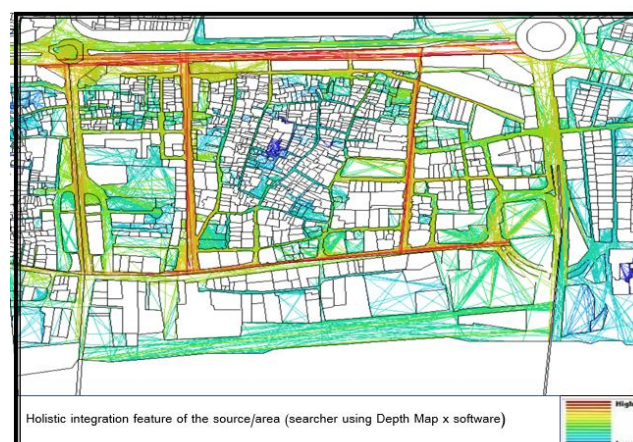


Figure 7. Comprehensive integration map of the study area using DepthmapX

Source: Prepared by the researchers.

Low values in the alleyways do not necessitate widening them or altering their historical character. Narrowness and winding can be part of their morphological and environmental value. The most appropriate interventions include improving lighting and orientation, removing obstacles, revitalizing land uses, and connecting some discontinuous paths when this does not harm the fabric or historical properties.

4.2 Connectivity results

The main axes recorded the highest connectivity values, while the number of direct connections in the inner alleyways decreased. The comparison revealed that some hubs, while well-located within the overall network, suffer from poor local connectivity at specific points. This explains the bottlenecks or interruptions in pedestrian movement from the hub to the inner perimeter.

Figure 8 shows the spatial distribution of connectivity values within the study area, indicating the stronger direct connections along the main axes and the weaker local connectivity within the internal alley network.

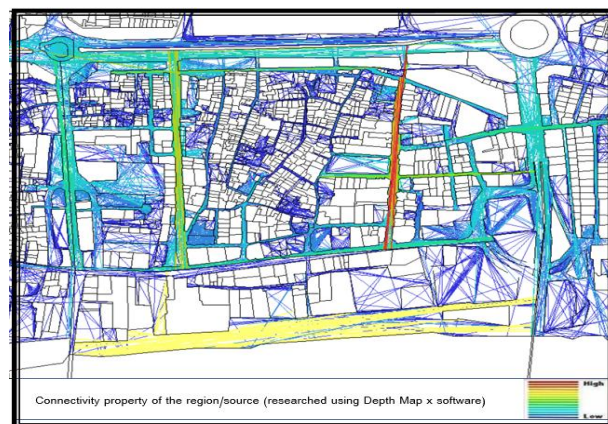


Figure 8. Connectivity map of the study area using DepthmapX

Source: Researchers.

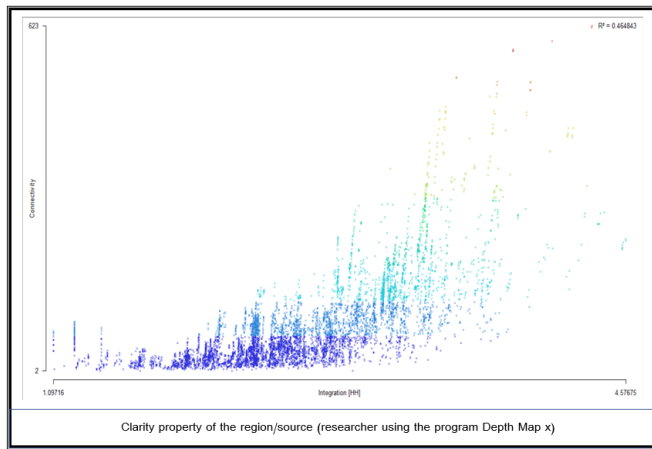


Figure 9. The relationship between integration and connectivity in measuring spatial clarity

Source: Prepared by the researchers.

The results support the concept of precise connectivity injection. Instead of creating wide new streets, specific nodes can be addressed by reorganizing intersections, opening existing blocked passageways, clarifying alleyway entrances, or improving visual continuity between alleyways and markets. Such interventions require a property survey, structural condition assessment, and heritage evaluation

before implementation, as increased permeability is not an absolute goal if it leads to loss of privacy or the destruction of valuable urban fabric.

Figure 9 illustrates the relationship between integration and connectivity used to assess spatial intelligibility, with a coefficient of determination of approximately 0.46.

4.3 Spatial clarity results

The coefficient of determination between integration and connectivity was approximately 0.46. This indicates a moderately positive relationship; that is, the user can infer some features of the overall structure from their local connections, but this ability does not encompass the entire system. Main axes exhibit greater clarity due to the continuity of facades, the presence of landmarks, and the flow of movement, while internal alleyways become more difficult to read due to meandering, multiple break points, poor signage, and varying facades.

The terms spatial clarity or comprehensibility should be used consistently and not confused with vision or spatial intelligence. Clarity here is a statistical relationship between a local and a comprehensive indicator, not merely an impressionistic assessment. Field observation can explain a decrease in clarity, but it does not replace calculation.

Table 6 illustrates the clarity scale and its associated interventions.

Table 6. Spatial intelligibility levels, identified dysfunctions, and proposed interventions

Axis or Location	Intelligibility Level	Main Characteristics	Identified Dysfunction	Proposed Intervention
Al-Khulafa Street toward Al-Wathba Square	High	Clear spatial sequence, continuous frontages, and prominent landmarks	Visual and movement pressure	Reinforce landmarks and organize intersections and directional signage
Al-Rasheed Street	High	Historical continuity and a strong commercial presence	Visual clutter and deterioration of some façades	Rehabilitate façades and regulate advertisements and wayfinding elements
Sayyid Sultan Ali Street	Moderate	A transitional axis connecting primary and secondary streets	Partial discontinuities	Improve route continuity and connect transition points
Aqd Sayyid Sultan Ali	Moderate	Fragmented spatial pattern and relatively weak landmarks	Wayfinding difficulty	Improve lighting and signage and restore reference points
Hafiz Al-Qadi Street	Low	Morphological irregularity and weak visual identity	Limited spatial perception and connectivity	Introduce small-scale landmarks, regulate façades, and improve lighting
Internal Alleys and Streets	Very low	Narrowness, curvature, discontinuity, and limited activity	Spatial isolation and poor legibility	Establish wayfinding nodes, introduce selective connections, and activate land uses

4.4 Spatial intensity results

The highest spatial intensity values were concentrated on Al-Rashid Street (1.034), Al-Khulafa Street towards Al-Wathba Square (1.020), and Sayed Sultan Ali Street in Al-Shourja (0.995). The value decreased in Akd Sayed Sultan Ali (0.610), and the lowest value among the detailed axes was recorded on Hafez Al-Qadi Street (0.570).

These values reflect a gradient from the main axes with high potential traffic to the less integrated pathways within the network. Intensity does not represent a direct count of pedestrians or vehicles, but rather a structural indicator that should be verified in the future with field traffic measurements.

Figure 10 illustrates the spatial distribution of intensity values across the study area, showing higher values along the principal urban axes and lower values within the less integrated internal streets and alleyways.

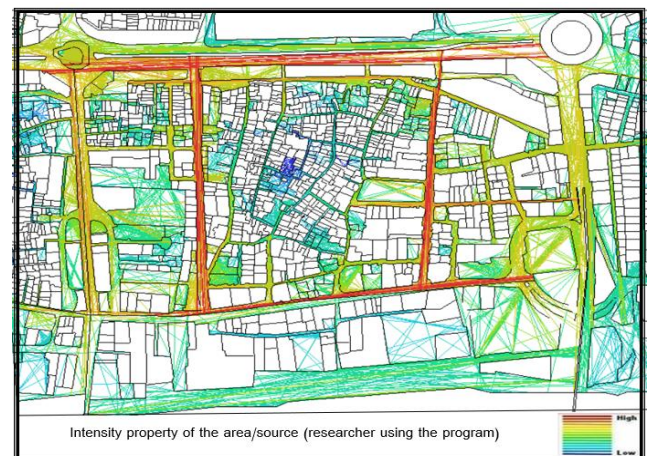


Figure 10. Spatial intensity map of the study area

Source: Prepared by the researchers.

The results indicate that Rashid and Khulafa Streets require enhancement and regulatory interventions: improving pedestrian flow, regulating parking and loading, managing activities, rehabilitating facades, and highlighting historical buildings. Sayyid Sultan Ali Street requires an integrated intervention that connects intersections with adjacent passageways and revitalizes local uses. The roof and less densely populated alleyways require a stimulating intervention that does not aim to increase traffic indefinitely, but rather to provide an appropriate level of activity that improves safety and usability without compromising the historical scale.

4.5 Expert evaluation results

Recalculation of the response frequencies showed that preserving symbolic buildings was the highest priority, with a mean of 4.423 out of 5 and a standard deviation of 0.504. All 26 participants selected either “strongly agree” (11) or “agree” (15), representing the strongest consensus across the five items. Social activities and restoration each received an

average of 4.000, followed by the revitalization of pathways and spaces with an average of 3,846. The integration of modern architecture, however, received a lower average of 3,115, reflecting a clear professional caution against introducing new elements that might disrupt the overall harmony.

Table 7 summarizes the averages, deviations, and direct weights for the five criteria.

The exact overall mean for the five items was 3.8769 out of 5, or 77.54% when the mean was linearly converted to a percentage. This result differs from stating that model acceptance was 83%, because the latter figure was not linked in the original manuscript to a specific equation or response distribution. The current result can be traced to 130 actual responses, representing five items multiplied by 26 participants.

Table 8 shows the results of the sensitivity analysis after adjusting for one weight and renormalization. Columns C1 to C5 represent the criteria defined in Table 4.

Table 7. Expert-assessment results and interpretation of the five criteria

Criterion	Mean out of 5	Standard Deviation	Weight	Interpretation
Preservation of Symbolic Buildings	4.423	0.504	22.82%	Very high priority assigned to identity and cultural value
Social Activities	4.000	0.800	20.63%	Clear support for activating public spaces and social interaction
Traditional and Contemporary Restoration	4.000	0.748	20.63%	Professional acceptance of controlled rehabilitation
Activation of Pathways and Spaces	3.846	0.925	19.84%	Strong support, conditional on protecting the historic fabric
Integration of Modern Architecture	3.115	0.711	16.07%	Moderate acceptance accompanied by concern about visual distortion
Overall Level of the Five Criteria	3.877	—	100.00%	High overall acceptance of the integrated model

Table 8. Sensitivity analysis of criterion weights under alternative scenarios

Scenario	C1	C2	C3	C4	C5
Baseline	19.84%	20.63%	20.63%	16.07%	22.82%
Preservation +10%	19.40%	20.17%	20.17%	15.71%	24.54%
Pathway Activation +10%	21.40%	20.23%	20.23%	15.76%	22.37%
Modern Architecture –20%	20.50%	21.32%	21.32%	13.28%	23.58%
Social Activities +10%	19.44%	22.24%	20.22%	15.75%	22.36%

In the main scenarios, the preservation of symbolic buildings remained the top priority, while the integration of modern architecture remained the lowest. The ranking of the intermediate criteria changed when the weight of pathways or the social activity weight increased by 10%, a change that was expected given the convergence of their averages. Threshold analysis showed that the weight of pathways needed to increase by only 4.0% to surpass the weights of social activity and restoration, and that the weight of symbolic preservation only lost its top ranking if it decreased by approximately 9.6%, while the weight of modern architecture integration needed to increase by approximately 23.5% to equal the weight of pathways. Thus, the model exhibits clear stability at both ends of the ranking and limited sensitivity in the middle, a more accurate result than the common claim that the model is invariable under all changes.

The results also reveal that symbolic value is not a secondary element added after spatial analysis, but rather a criterion capable of modifying the decision. A cinema building might be in the mid-performing axis, but its cultural value and

deteriorating functional condition warrant priority for stimulating intervention and reuse. Conversely, a commercial axis might be highly integrated, but its priority should be managing pressure and improving the public space rather than adding new activity.

4.6 A tiered model for urban injection orientation

Based on the findings, the research proposes three performance levels. The first level includes high-performance spatial sites, which do not require movement stimulation as much as they need capacity protection and pressure regulation. The second level includes transitional areas that possess some strengths but suffer from interruptions or weaknesses in orientation and functionality. The third level includes low-performance sites that suffer from isolation, building deterioration, or a lack of activity and landmarks.

The first level is associated with reinforcement interventions, such as sidewalk rehabilitation, advertising regulation, traffic management, facade restoration, skyline

protection, and landmark enhancement. The second level is associated with integrative interventions, such as improving connectivity between axes, revitalizing land uses, reorganizing nodes, and adding small public spaces. The third level is associated with stimulating interventions, such as reusing a symbolic building, opening selective pathways, improving lighting and security, and introducing cultural or community

activities.

Figure 11 summarizes the conceptual flow of the proposed model, linking spatial indicators and heritage-related criteria to performance levels and the corresponding urban injection strategies.

Table 9 illustrates the relationship between the problem, the location, and the type of intervention.

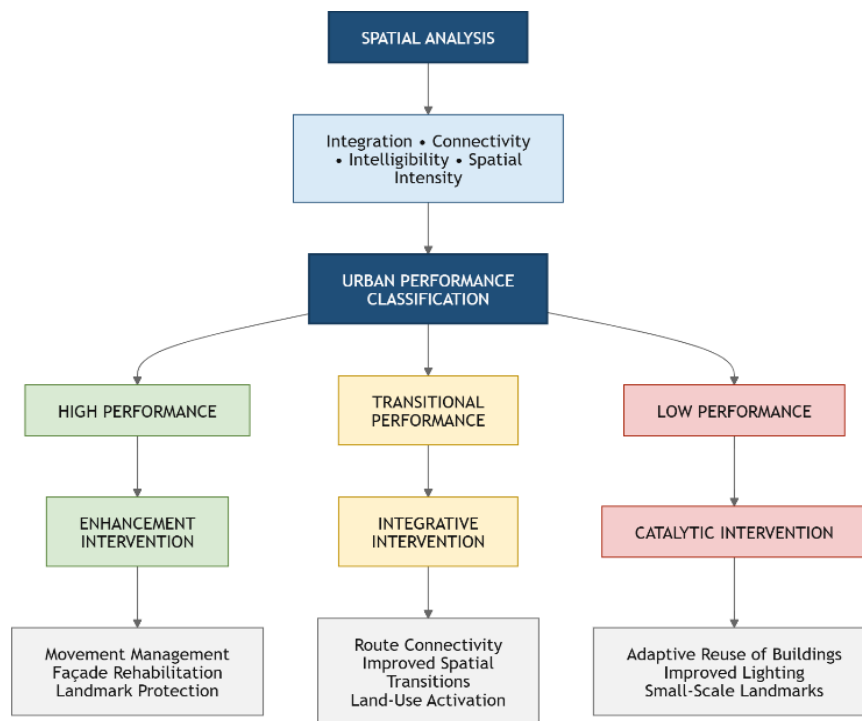


Figure 11. Conceptual flow from spatial indicators to performance levels and urban injection strategies

Source: Prepared by the authors.

Table 9. Proposed urban injection interventions according to identified problems and implementation timeframes

Identified Problem	Typical Locations	Type of Urban Injection	Short-Term Action	Medium-Term Action
Movement pressure and visual clutter	Al-Rasheed and Al-Khulafa Streets	Regulatory enhancement	Regulate advertisements and parking and improve pedestrian movement	Implement an integrated façade rehabilitation and movement-management program
Route discontinuity	Sayyid Sultan Ali intersections and internal alleys	Connective-integrative	Install wayfinding signs and lighting and remove physical obstacles	Introduce selective connections following heritage-impact assessment
Weak functional value of landmarks	Cinemas and abandoned buildings	Cultural catalytic	Provide emergency protection and introduce a temporary-use program	Implement cultural or civic adaptive reuse
Inconsistent building heights and façades	Transitional axes	Morphological	Halt violations and document existing façades	Develop design guidelines and controls for building heights and materials
Limited social activity	Internal squares and passageways	Socio-functional	Introduce temporary events and urban furniture	Establish community centers and organized local markets
Poor environmental comfort	Exposed streets and residual spaces	Environmental	Provide temporary shading and drinking water and improve cleanliness	Introduce suitable vegetation, permanent shading structures, and climate-responsive design

4.7 From analysis to decision

The model's main value lies in making the transition from diagnosis to decision clear. When an axis exhibits high integration, high connectivity, and high spatial intensity, further activity is not automatically recommended, but rather an intervention that protects performance and minimizes negative impacts. When an alley exhibits low integration and connectivity but contains a symbolic building, it is not

classified as a low-priority area, because its cultural value raises the need for a stimulating intervention. When morphological value is high and visibility is low, the intervention focuses on orientation and lighting without widening the fabric.

This logic reduces the risk of using composite grading as an absolute judgment. Numerical ranking is useful for resource allocation, but it must remain subject to clear protection rules. The study proposes an exclusion rule that prevents the

selection of any intervention involving the removal of a building of value or a change to a historical scale before a detailed assessment. It also proposes a priority rule that gives deteriorating symbolic buildings high executive weight, because their loss is irreversible.

4.8 Theoretical, methodological, and applied contribution

The theoretical contribution lies in reframing urban injection within a hierarchical system. The concept is no longer synonymous with a small, visually appealing intervention, but rather with a relationship between a specific diagnosis, an appropriate intervention, an expected outcome, and a follow-up indicator. The research also demonstrates that the size of the intervention does not solely determine its impact; its location within the network, its symbolic value, and its relevance to activities determine its potential for dissemination.

The methodological contribution lies in the separation of three types of evidence: measured spatial values, described field values, and expert judgments. This separation prevents confusion between the five-way mean and pairwise comparisons, or between the integration map and visual quality assessment. The research also presents a verifiable computational path that begins with the frequency of expert responses, progresses to means, deviations, and confidence intervals, and then to direct weights and sensitivity analysis. This transparency allows for the replication of calculations or the substitution of weights when applying the model in a different context.

The practical contribution lies in translating the results into a package of actions specific to the Rusafa area. Main axes need organization and reinforcement, transitional areas need connection, deteriorated symbolic buildings need reuse, and isolated alleyways need security interventions, guidance, and local activity. This package can be implemented in phases, starting with low-cost and reversible interventions, then moving to deeper rehabilitation projects after assessing the impact of the first phase.

4.9 Relationship with the historic urban landscape

The model aligns with the historic urban landscape approach because it does not separate the building from its network or the community from the physical space. It also integrates knowledge, planning, and participatory tools, and accepts that the historic center is a dynamic entity. However, the use of indicators should not become a closed, technical management process; decisions regarding reuse and the organization of activities and public spaces must involve residents, shop owners, religious and cultural authorities, municipalities, and heritage bodies.

5. STUDY LIMITATIONS

The results are subject to several limitations. First, the model was applied to a single case, and therefore the numerical limitations cannot be directly generalized to all historic centers. Second, the expert sample is purposive and limited to 26 participants, suitable for professional exploration but not representative of all residents and users. Third, assessments of cultural value and morphological risk are influenced by human judgment, even with the use of a structured scorecard.

Fourth, spatial composition analysis expresses structural potential for movement and does not measure actual movement unless corroborated by counting pedestrians and vehicles at multiple times. Fifth, the message presents the frequency of responses for each question but does not present the individual matrix linking each participant's responses across questions; therefore, Cronbach's alpha or item correlation coefficients cannot be calculated from the available file. Sixth, the reciprocal matrix in the research is derived from direct weights and not an independent pairwise judgment matrix; thus, the zero-consistency index does not provide additional empirical evidence. Seventh, the sensitivity analysis tests the order of intervention criteria, not the order of locations, because quantitative location data are incomplete across all five criteria. Finally, usage and movement patterns may change seasonally or as a result of security and commercial measures, necessitating data updates before implementation.

These limitations do not diminish the model's usefulness but do define the scope of its claims. The results provide a decision-support tool, not a definitive prescription. Implementation decisions still require structural, legal, financial, and social assessments of each location, and temporary interventions must be tested before being implemented.

6. CONCLUSIONS AND RECOMMENDATIONS

The analysis demonstrated that Old Rusafa does not function as a homogeneous urban fabric, but rather consists of high-performance axes, transitional zones, and alleyways with low connectivity and visibility. Spatial power is concentrated in Rashid and Khulafa Streets, while isolation is evident in the inner reaches. A visibility index of approximately 0.46 indicates a moderate relationship between local perception and the overall structure, justifying interventions related to orientation, lighting, and the restoration of visual landmarks.

Expert assessments confirmed that symbolic buildings hold the highest priority, with a weight of 22.82%, followed by social activities and restoration, each with a weight of 20.63%, while the integration of modern architecture ranked last at 16.07%. This implies that interventions should not begin with the desire to add a new form, but rather with protecting existing value, restoring its function, and connecting it to the urban network.

The research concluded that the most effective urban injection is that which matches the type of intervention to the nature of the problem. High-performance axes require reinforcement and organization, transitional zones require integration, and low-traffic areas require stimulation. Furthermore, the decision should not be based on a single composite indicator, but rather on a shared understanding of spatial performance, heritage value, morphological condition, and social acceptance.

The study recommends developing a phased program beginning with three packages. The first package includes rapid and reversible measures: regulating advertising, improving lighting and orientation, removing obstacles, protecting deteriorating symbolic buildings, and operating some spaces with temporary events. The second package includes medium-term projects: rehabilitating successive facades, repurposing abandoned cinemas and administrative buildings, improving sidewalks and arcades, and creating

small shaded spaces. The third package includes long-term institutional tools: an urban design guide, a spatial monitoring system, a conservation fund, and a permanent participation mechanism.

The study also recommends conducting a re-survey of actual traffic flow on different days and at different times, linking it to spatial composition values, and administering a survey of residents, business owners, and experts. The current version includes the frequencies of expert responses, means, deviations, confidence intervals, direct weights, reciprocal matrix, computational consistency values, and sensitivity scenario results. However, calculating Cronbach's alpha for the original instrument remains contingent upon the availability of individual response files and cannot be derived from pooled frequencies. The study also recommends conducting a re-survey of actual traffic flow on different days and at different times, linking it to spatial composition values, and administering a survey of residents, business owners, and experts. The current version includes the frequencies of expert responses, means, deviations, confidence intervals, direct weights, reciprocal matrix, computational consistency values, and sensitivity scenario results. However, calculating Cronbach's alpha for the original instrument remains contingent upon the availability of individual response files and cannot be derived from pooled frequencies.

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