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Walkability and Mobility in the Historic District of Nizwa, Oman: A Space Syntax and Multi-Indicator Assessment for Heritage-Led Urban Regeneration

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Abstract: The issue of walkability in hot, arid heritage cities is still very much under-theorized, as the traditional configurational frameworks have been developed in temperate environments where the thermal barrier and vehicular encroachment do not dominate spatial network logic. This study aims at filling this gap by performing the first quantitative configuration experience coupling test for an Omani historic city, Nizwa. We combine DepthmapX v0.8 Space Syntax analysis of an axial map (428 lines, 612 nodes; eight configurational indicators) of a 1.32 km² area with a validated MAPS-Global/Gehl perceptual audit of 11 purposively sampled streets in four functional zones and 42 semi-structured stakeholder interviews using a sequential explanatory mixed-methods design. The statistical coupling uses Pearson correlation and OLS regression (Bonferroni corrected $\alpha = 0.0009$) and a weighted Composite Walkability Index (CWI, max 50). The organic historic fabric shows good syntactic coherence (Connectivity–Integration $r = 0.91$, $p < 0.001$; configurational family $r = 0.80–0.91$), which indicates a well-developed pedestrian network. However, only 19% of the variance in Safety can be accounted for by Global Integration, and 2% of the variance in Accessibility ($R^2 = 0.19$ and 0.02 respectively); given the small street sample ($n = 11$), these associations are exploratory and hypothesis-generating rather than confirmatory and show a critical configuration-experience decoupling (Decoupling Index $DI = 0.81$) fueled by thermal exclusion, vehicular encroachment, and universal-design deficits. CWI scores range from S2 (Excellent) to S10 (Critical) and the paradigmatic S1 anomaly (second-highest Integration and second-lowest CWI) directly illustrates the decoupling phenomenon. Five evidence-based, heritage-sensitive, costed interventions are proposed in line with Oman Vision 2040 and UN SDG 11.2/11.4; a scenario-based projection suggests a potential 40–74% increase in CWI in the poorest performing streets, at less than 8% of the cost of the conventional masterplan, though this range should be read as an illustrative planning estimate pending simulation-based or post-occupancy validation rather than a guaranteed outcome. The resulting Decoupling Index is a transferable diagnostic tool for hot-arid heritage cores outside of Nizwa.

Keywords: space syntax; walkability; historic urban cores; DepthmapX; universal accessibility; heritage regeneration; thermal mobility; Vision 2040.

1. Introduction

The historic neighborhood of Nizwa, which includes Nizwa Fort, the Grand Mosque, the traditional market (souq) of Nizwa and the residential neighborhoods of Al-Aqr and Harath, fed by the Falaj Daris



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irrigation system, which is inscribed on the UNESCO World Heritage List (Benkari, 2022), is one of the most culturally significant and commercially active heritage neighborhoods in Oman (Mahrouqi, Crisostomo and Belgacem, 2025). The area is a popular tourist destination, especially during the peak festival season. The district has recently been improved through regeneration projects undertaken by the Oman Ministry of Heritage and Tourism, such as pedestrian-path renovation, facade rehabilitation and historic house conversion into heritage guesthouses (Faouri and Sibley, 2024, 2024) which have boosted the cultural profile of the district (Alriyami, Almuhrzi and Scott, 2021). However, pedestrian connectivity remains limited in the historic core due to the lack of pedestrian continuity and access (Fang and Wu, 2025).

Walkability is an important 21st-century urban policy goal, driven by public health, climate, social equity and heritage-conservation concerns (Li, 2025). The vast majority of empirical walkability models, however, have been developed in temperate European or North American settings (Erem, 2025) and their application to hot-arid Gulf heritage cores is under-theorized (Mazzetto, Furlan and Hoblos, 2026). Friday morning field observations of Nizwa show an apparent paradox: that there is lively commerce despite the mobility deficits of multi-level pedestrian paths, step-level discontinuities, acute parking congestion, and a near-total lack of shading (Siqueira-Gay, 2024). These realities, plus the magnitude of the regeneration investment that continues to be made, are the main research reasons.

Space Syntax, developed by Hillier and Hanson (Hillier and Hanson, 1984) at UCL and further developed by Hillier, Yang, and Turner (Hillier, Yang and Turner, 2012) and van Nes and Yamu (Nes and Yamu, 2021), provides a configurational approach to explain pedestrian co-presence on the basis of the form of the street network. It has been used for walkability forecasting, historic core regeneration and perceptual-layer integration (Sirjani and Szabó, 2023). One of the challenges to Space Syntax studies in the Middle East, however, is the lack of strong statistical relationships between the configurational measures and perceptual and infrastructural factors that influence real pedestrian behaviour (Askarizad, Daudén and Garau, 2024). This study directly tackles that methodological gap.

1.1. The research questions and hypotheses are as follows:

The main research questions of this study are: (RQ1) How is the configurational structure of Nizwa's historic centre different on streets that have different functional roles? How are configurational measures statistically related to perceived safety, accessibility, inclusivity, amenities, social vitality and aesthetic quality? (RQ2) (RQ3) What are the most effective interventions to increase walkability that are supported by evidence while also preserving heritage integrity? Two hypotheses are examined: H1: Streets with higher Global Integration scores have significantly higher composite walkability scores; H2: Normalized Angular Choice scores predict perceived safety and social space vitality.

1.2. Contribution Statement

This paper makes three original contributions to the urban walkability and heritage regeneration literature: (i) the first DepthmapX + MAPS-Global quantitative integration for an Omani historic city, setting a new methodological benchmark for the Arabian Peninsula; (ii) the configuration–experience Decoupling Index (DI) as a transferable quantitative diagnostic tool, going beyond the qualitative decoupling observations reported in previous Gulf Space Syntax studies (Aloshan, 2024), (Askarizad, Daudén and Garau, 2024) and providing a replicable measurement framework; and (iii) a policy-ready, costed intervention portfolio aligned with Oman Vision 2040, UN SDG 11.2/11.4 (Ansari, 2025) and the EU Horizon Europe Cities Mission, immediately applicable by the Ministry of Heritage and Tourism, municipal planning departments and UNESCO site management authorities as pre-intervention diagnostic tools.

The integration of the three types of evidence (configurational, perceptual and qualitative) and formal statistical testing is what makes this study distinct from previous Space Syntax research in the Gulf (Al-Ula (Sahahiri et al. (Sahahiri, 2026)), Manama (Hamdoon and Ahmed (Hamdoon and Ahmed, 2023)), and Muscat (Al-Sayed, 2022)). None of the cited studies includes all three data streams and none of the studies offers a quantified measure of decoupling. The research gap addressed is thus methodological, as there is no validated multi-indicator protocol for Omani heritage cities, and theoretical, as there is no quantifiable metric for configuration–experience divergence in thermally constrained heritage contexts.

2. Literature Review

2.1. Space Syntax within Historic Arabian Cores

Space Syntax proposes that urban space can be thought of as a system of axial lines, with the

topological depth of these lines dictating the accessibility and movement potential of the space (Hillier and Hanson, 1984). Global Integration and Choice are measures of to-movement and through-movement, respectively. High local but low global Integration values (Ibrahim, 2025) are created by organic morphological features, characteristic of Arabian historic centres, such as forts, mosques, and souqs. Research in Manama revealed a positive relationship between street connectivity and pedestrian activity and perceived safety (Hamdoon and Ahmed, 2023). The same axial mapping has been done in Muscat and historic Jeddah (Hathloul and Mughal, 2023) and in Gaziantep and Famagusta based on integration-based priority mapping. The present study follows the computational path of UCL's Space Syntax Laboratory which recommends DepthmapX (Hammadamin, 2024) as the benchmark for urban network analysis.

2.2. Walkability Audit Frameworks

Micro-scale factors like the provision of shade, the density of benches, the permeability of the facades, and compliance with universal design are captured by walkability audit frameworks, such as MAPS-Global, Walk Score, and Gehl's Public Life method, that configurational analysis cannot detect (Maragkoti, 2025). Research demonstrates that the combination of the two (configurational and perceptual) approaches has a strong impact on pedestrian behaviour prediction (Huang, 2024). However, few studies of historic Arabian cores use an integrated approach to walkability assessment that considers both the topological and experiential aspects (Alhajaj and Habibullah, 2025). The traditional urban fabric in Nizwa is mainly geared towards tourism and trade, and is not aligned with the concept of the 5-minute walk for daily activities of work, leisure, and living.

2.3. Hot-Arid Heritage Cores Thermal Barriers

The studies in Al-Ula (Sahahiri, 2026) and Abu Dhabi (Mahgoub and Hamza, 2020) and Iranian historic cities all show that thermal stress at temperatures above 40-45°C is the main limitation to active mobility, and outweighs configurational benefits. Gangler and Ribbeck have recorded the thermal efficiency (Carbonari, Scarpa and Plaza, 2025; no date) of the historic sikkak network of Nizwa due to the narrow proportions, the overhead shading and the evaporative cooling of the falaj channels (Ergin, 2026) which has been reduced significantly by recent resurfacing. The Greater Nizwa Structure Plan clearly states that parking congestion, pedestrian discontinuity and disability access are all key mobility issues. Related research on traditional Omani souqs examines climate-responsive biophilic design and thermal performance simulation as complementary dimensions of heritage regeneration (Shabbir, 2026).

2.4. Research Gap

Although there is an increasing amount of research on walkability in the Arabian Peninsula, no study published so far has statistically related DepthmapX configurational measures with a validated multi-indicator perceptual audit in an Omani historic centre. Moreover, there is no previous research that has developed a quantified metric for configuration–experience decoupling for thermally constrained heritage contexts. This study addresses both gaps, providing for the first time a replicable diagnostic protocol in Nizwa, and a transferable methodological framework for similar hot-arid heritage cities.

3. Study Area

Nizwa (22.9333°N, 57.5333°E; elevation 480 m) is located at the foot of the Al-Hajar Mountains, and is historically known as the first capital of Oman and an historic centre of Islamic scholarship. The study area is about 1.32 km² and contains four heritage anchors that are interwoven: Nizwa Fort (1668 CE), the Grand Mosque, the Nizwa Souq (with the famous Friday livestock market) and the Al-Aqr and Harath traditional residential quarters irrigated by the UNESCO-listed Falaj Daris irrigation system (UNESCO, 2022). It is very common to have summer maximum temperatures of over 45°C (Batchelor and Bremner, 2026), which severely affects outdoor pedestrian activities (Sahahiri, 2026).

The urban morphology consists of narrow earthen sikkak, blind-end residential culs-de-sac and a spine of commercial buildings that runs from the fort forecourt to the souq complex. An estimated 1,200 vehicles vie for less than 300 parking spaces on peak Fridays, which was identified as the parking-saturation issue that was the largest barrier to walkability for all stakeholder groups. Figure 1 presents the regional location and urban context of Nizwa's historic district, together with street-level photographs illustrating its traditional architecture and the spatial conflict between vehicles and pedestrians.



Figure 1. Composite view of Nizwa's heritage district regional and urban maps of the Souq, Fort, Harath neighborhoods and the Falaj system, and street level photographs of traditional architecture and of the spatial conflict between vehicles and pedestrians. Source: Maps Adapted from [Shabbir, Mahdavejad and Ghorbani \(2024\)](#). Photographs by the authors

Figure 2(a,b) shows the spatial framework of Nizwa's historic core and the locations of the eleven selected streets across the four functional zones.



Figure 2. a and b: Spatial framework of the historic core of the town of Nizwa, with the eleven streets selected to cover the entire north–south and east–west limits of the historic core in four functional zones. Source: Authors, 2026.

4. Materials and Methods

4.1. The research design and philosophical positioning

The study uses a sequential explanatory mixed-methods design (Creswell and Plano Clark (Creswell, 2018)) whereby the quantitative Space Syntax outputs are used to inform the perceptual data collection

and qualitative interpretation. Epistemological stance is pragmatist: spatial configuration and lived pedestrian experience are considered as complementary and analytically different knowledge fields (Morgan (Morgan, 2014)). As illustrated in Figure 3, the research was organised into four phases: (i) DepthmapX quantitative configurational analysis, (ii) stratified purposive street sampling based on Phase I Integration values, (iii) MAPS-Global/Gehl multi-indicator perceptual audit, (iv) semi-structured stakeholder interviews and statistical coupling, composite indexing and triangulated interpretation.

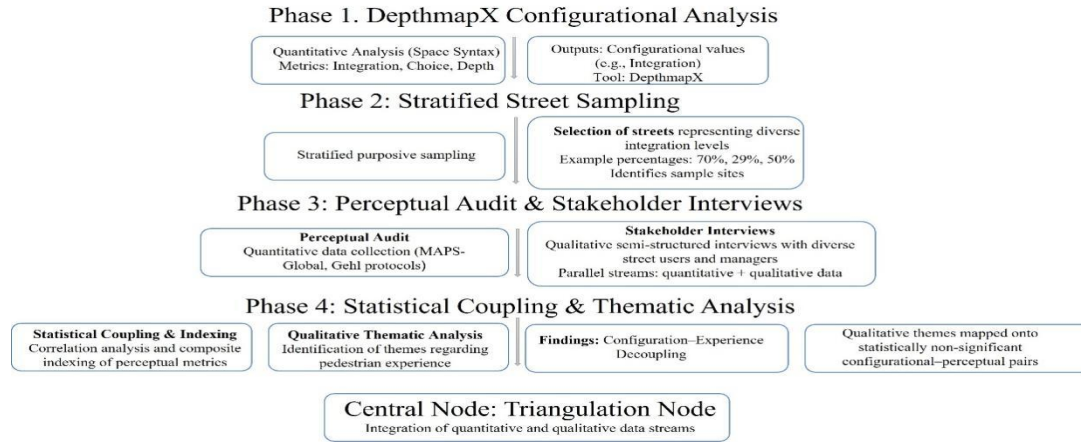


Figure 3. Methodology Flowchart: Four phases with arrows indicating flow from one phase to the next: Phase 1: DepthmapX Configurational Analysis; Phase 2: Stratified Street Sampling; Phase 3: Perceptual Audit and Stakeholder Interviews (parallel streams); Phase 4: Statistical Coupling and Thematic Analysis (leading to Configuration–Experience Decoupling Finding). Triangulation node displayed when the qualitative themes are mapped onto the statistically non-significant configurational–perceptual pairs.(Riffat et al., 2026)

4.2. Theory and rationale for Space Syntax.

Space Syntax was first developed by Hillier and Hanson (Hillier and Hanson, 1984) at UCL, and later developed by Hillier, Yang and Turner (Hillier, Yang and Turner, 2012) and van Nes and Yamu (Nes and Yamu, 2021) as a graph-theoretic representation of urban open space that focuses on topological relationships (as opposed to metric distances) to define accessibility and movement potential. To-movement potential (probability of a street as a pedestrian destination) is measured as Global Integration [HH] while through-movement potential (likelihood of a street on the most angular-efficient route between any two network points) is measured as Normalized Angular Choice (NACH). These measures are not mutually exclusive, as a street can be very integrated without being a significant through-route, and this is important in the complex heritage morphology of Nizwa.

The eight configurational indicators were kept in the analysis. A Variance Inflation Factor (VIF) test was performed to ensure that there was no multicollinearity among the variables, and all the VIFs were less than 4.0. The highest pairwise correlation (Connectivity–Integration, $r = 0.91$) was retained since the two measures are analytically distinct constructs: local adjacency and global topological depth, as defined by Hillier et al. (Hillier, Yang and Turner, 2012). Principal Components Analysis was investigated as a dimensional reduction alternative, with the first two components accounting for 84% of the configurational variance, but with a loss of transparency of the composite axes necessary for communication with practitioners. Indicator level reporting was therefore kept. The six indicators are theoretically primary (integration [HH] or NACH) and complementary indicators that characterize morphology in a way that is relevant to the research questions. Table 1 provides full definitions, formulas, retention justifications and key findings.

4.3. Base map and Axial Map Construction

The base map was georeferenced and rectified to a 0.3 m resolution WorldView-3 satellite mosaic (acquired February 2024) using AutoCAD Map 3D 2024. The rectification accuracy was checked at 24 ground-control points and was found to be less than 0.45 m (RMSE), which is within the UCL protocol of ≤ 0.5 m to 1:1,000 cadastral sources (Turner, 2004). The axial map consisted of 428 axial lines, 612 intersection nodes and 19 manually specified unlinks (places where axial lines cross but are not connected, such as blocked passages) as per the standard UCL protocol (Hillier, Yang and Turner, 2012). The field

verification of all unlinks was carried out during the initial site visit (October 2024).

Table 1. DepthmapX spatial measures formal definitions, formulas, retention justifications and key findings in Nizwa. Source: Authors, 2026.

Measure	Symbol	Formal Definition / Formula	Why Retained	Key Finding in Nizwa
Connectivity	C	Number of axial lines directly intersecting line i . $C(i) = \{j: i \text{ adj } j\} $	Purely local measure; captures immediate spatial adjacency independent of global topology	Min=4, Max=172, Mean=54.15; Souq spine (S3, S4, S7) highest; residential periphery (S10, S11) lowest
Global Integration	HH	Normalized reciprocal of mean topological depth: $HH(i) = 1 / MD(i) \times \text{normalisation factor}$ (Hillier & Hanson, 1984)	Measures to-movement potential; proxy for likely pedestrian destination status	Min=1.027, Max=3.856, Mean=2.323; S7 highest; S9 and S10 most segregated
NACH (Choice)	NACH	Normalized angular betweenness centrality (tulip-90): $NACH = \log(CH+1) / \log(TD+3)$ (Hillier et al., 2012)	Measures through-movement potential; analytically distinct from Integration (destination vs. route)	Min=0, Max=47,110, Mean=2,489; S3 dominant through-route; S10, S5 peripheral
Mean Depth	MD	Average topological distance (in steps) from line i to all other lines: $MD(i) = \sum d(i,j) / (n-1)$	Retained alongside Integration: MD is absolute depth; HH is normalized for network size—distinct interpretive value for cross-scale comparisons	Min=2.169, Max=5.602, Mean=4.094; S10 most segregated (deepest)
Shannon Entropy	E	$E(i) = -\sum p(d) \cdot \log_2(p(d))$; where $p(d)$ = proportion of lines at depth d from i	Captures distributional complexity of depth profile; high E = heterogeneous historic morphology	Min=1.114, Max=2.565, Mean=2.328; S3 and S8 most complex (richest historic land-use mix)
Harmonic Mean Depth	HMD	$HMD(i) = (n-1) / \sum (1/d(i,j))$ for $d > 0$	Weights closer lines more heavily; more sensitive to local accessibility than MD	Negative correlation. with C ($r=-0.77$); S3 lowest HMD confirming souq core as most locally accessible
Intensity	I	Weighted sum of connectivity over all topological depths: $I(i) = \sum C(j) / d(i,j)$	Composite density indicator combining local connectivity with global reach	Strong positive correlation. with C ($r=0.82$); confirms souq spine as activity-dense core
Mean Line Length	MLL	Arithmetic mean length of all axial lines within radius r of line i	Proxy for street morphology scale; longer lines indicate more open, permeable urban fabric	Min=6.28, Max= 8.86×10^7 units; S3, S4, S1 highest fort-gate and souq axes most morphologically open

4.4. Stratified Purposive Street Sampling Stratified Purposive Street sampling was used in this study.

Eleven streets were selected using a stratified purposive scheme (Patton (1945-, 2015)) based on three criteria: (A) streets were spread across the full Integration range (quantile-interval sampling) from the minimum value 1.027 to the maximum value 3.856 to prevent bias of the regression model towards the mid-range distribution; (B) functional zone proportionality (based on the Greater Nizwa Structure Plan) across four functional zones: souq commercial (S2, S3, S4), mosque-approach civic (S5, S6), fort-gate monumental (S1, S7, S8), and residential (S9, S10, S11); and (C) street hierarchy balance (based on street

class: primary spine > 12 m, secondary collector 6–12 m, and tertiary sikkak < 6 m) with a spatial exclusion radius of 50 m to minimize spatial autocorrelation. A cross-check was done with the Greater Nizwa Structure Plan zoning map for the final eleven streets, to ensure that no other street within the same quantile range and functional zone was arbitrarily omitted. Table 2 shows all exclusions.

Table 2. Stratified purposive street sample zone classification, hierarchy, Integration value and explicit sampling rationale for each of the eleven streets. Source: Authors, 2026.

Street	Zone	Hierarchy	Length (m)	Integration [HH]	Sampling Rationale
S1 Fort-Gate Approach	Fort-gate monumental	Primary spine	~210	4.46	Highest-Integration Street in monumental zone; historically critical pedestrian axis now degraded by parking
S2 Souq North Entry	Souq commercial	Secondary collector	~145	3.22	Mid-range Integration; sole north-entry point to souq; key tourist–resident interface
S3 Main Souq Spine	Souq commercial	Primary spine	~280	4.70	Highest NACH (through-movement); commercial and cultural core; essential baseline anchor
S4 Souq East Axis	Souq commercial	Primary spine	~195	4.75	Highest overall Integration; livestock market adjacency creates Friday peak conditions
S5 Mosque Approach West	Mosque-approach civic	Secondary collector	~120	4.00	Representative of civic/religious approach streets; moderate Integration; captures prayer-hour dynamics
S6 Mosque Approach East	Mosque-approach civic	Secondary collector	~110	4.00	Contrasting accessibility profile to S5 despite similar Integration; step-level barriers documented
S7 Fort Perimeter Road	Fort-gate monumental	Primary spine	~230	4.80	Highest Integration of all 11 streets; dominant tourist circuit; critical test of H1
S8 Harath Residential Main	Residential	Secondary collector	~160	3.00	Entry-level residential street; bridges commercial and deep residential zones
S9 Al-Aqr Alley	Residential	Tertiary sikkak	~90	2.25	Lowest Integration among top performers paradigmatic decoupling case; well-maintained heritage fabric
S10 Deep Residential Cul-de-sac	Residential	Tertiary sikkak	~65	2.50	Most segregated street; worst composite rating; provides critical lower-bound anchor
S11 Peripheral Lane	Residential	Tertiary sikkak	~75	3.00	Transition zone between residential and souq; moderate scores on most indicators

4.5. Perceptual Audit: MAPS-Global / Gehl Instrument

The Microscale Audit of Pedestrian Streetscapes Global version (MAPS-Global; Cain et al. (Cain et al., 2018)) was chosen as the perceptual instrument of choice because it was developed for international and culturally diverse settings, including hot climate cities; has been shown to be inter-rater reliable ($\kappa \geq 0.75$) in Middle East and Asian built environments; and the structure of its items aligns directly with the seven perceptual indicators examined. Three items from the Gehl Public-Life Tool (Gehl and Svarre, 2013) related to shading provision, facade permeability and universal-design compliance were added to the MAPS-Global items.

The two trained auditors (both architecture graduates with previous experience in Space Syntax) rated each street independently on a composite 23 item instrument on a 0–5 Likert scale, with no discussion between the two auditors until after the Cohen's κ had been calculated. Each street was visited three times: once in the morning (08:00 - 10:00) on a weekday, once in the afternoon (16:00 - 18:00) on a weekday, and once on the market day (Friday) between 07:00 and 10:00. All visits were conducted in the same standardized manner, including the same sequence of 23 items, weather conditions (clear sky), GPS location of the start and end points, and outside of Ramadan (October 2024-January 2025). Any disagreement between the auditors was settled by consensus arbitration, as per MAPS-Global protocol (Cain et al., 2018).

4.5.1. Inter-Rater Reliability

Cohen's κ (SPSS v29) was calculated for each of the seven perceptual indicators on the aggregates. Overall, $\kappa = 0.81$ (95% CI: 0.76–0.86) is considered 'substantial' agreement according to MAPS-Global standards (Cain et al., 2018). Individual indicator values were between Safety ($\kappa = 0.84$) and Aesthetic Quality ($\kappa = 0.76$) and all of them were above the research-grade threshold of ≥ 0.75 (Table 3). (Table 4) presents Operational definitions, key audit items, and score anchors for the seven perceptual indicators .

Table 3. Interrater reliability (Cohen's κ) for the seven MAPS-Global/Gehl perceptual indicators is shown in Table 3. Source: Authors, 2026.

Perceptual Indicator	Cohen's κ	95% CI	Agreement Class (Landis & Koch, 1977)
Safety	0.84	0.79–0.89	Substantial
Permeability	0.82	0.77–0.87	Substantial
Accessibility	0.83	0.78–0.88	Substantial
Universal Inclusivity	0.80	0.74–0.86	Substantial
Amenities	0.79	0.73–0.85	Substantial
Active Social Space	0.81	0.76–0.86	Substantial
Aesthetic Quality	0.76	0.70–0.82	Substantial
Overall (composite)	0.81	0.76–0.86	Substantial

Table 4. Operational definitions, key audit items, and score anchors for the seven perceptual indicators. Based on the hot-arid heritage context of Nizwa, the adaptation of the model was based on Cain et al. (Cain et al., 2018) and Gehl and Svarre (Gehl and Svarre, 2013). Source: Authors, 2026.

Indicator	Operational Definition	Key MAPS-Global / Gehl Audit Items	Score Anchors
Safety (SAF)	Degree to which the street environment supports pedestrian security from traffic and crime	Traffic separation; pedestrian crossing provision; lighting adequacy; visual surveillance from active frontages; absence of obstructions	0 = no crossings, no lighting, vehicle-dominated; 5 = fully separated pedestrian zone, well-lit, active surveillance
Permeability (PER)	Ease with which pedestrians can move through and between spaces in multiple directions	Number of route alternatives; presence of through-passages; absence of dead-ends; gate/barrier presence	0 = single-entry, dead-end; 5 = multiple continuous through-routes
Accessibility (ACC)	Physical ease of reaching and navigating the street for the full range of users	Pavement continuity; kerb heights; ramp provision; surface quality; absence of obstructions	0 = discontinuous pavement, multiple steps, no ramps; 5 = flush kerbs, continuous paved surface
Universal Inclusivity (INC)	Degree to which the street accommodates diverse users including the elderly, disabled, and children	Tactile paving; wheelchair gradient compliance ($\leq 1:20$); seating provision; stroller navigability; signage legibility	0 = no universal-design features; 5 = full compliance with ISO 21542:2021
Amenities (AME)	Provision of street furniture, vegetation, shade, water, and services that support pedestrian comfort and dwell time	Seating density; shade coverage (%); water features/fountains; vendor/café presence; greenery	0 = no shade, no seating, no services; 5 = full thermal comfort infrastructure and diverse services
Active Social Space (SOC)	Degree to which the street generates and supports spontaneous social interaction and pedestrian vitality	Pedestrian volumes observed; outdoor seating in use; evidence of social gathering; mixed-age users; active play	0 = deserted at all visit times; 5 = consistent pedestrian vitality across all three visit periods
Aesthetic Quality (AES)	Visual quality, heritage character, maintenance standard, and sensory richness of the street environment	Façade condition; heritage feature visibility; cleanliness; planting; ground-surface material quality	0 = heavily degraded, no heritage character; 5 = exemplary heritage fabric, well maintained

4.6. Semi-Structured Stakeholder Interviews

Four stakeholder groups were purposively selected: souq and heritage-district merchants ($n = 15$), permanent residents of Al-Aqr and Harath ($n = 12$), domestic and international tourists ($n = 8$), and municipal planning officers and officials of the Ministry of Heritage and Tourism ($n = 7$) and were interviewed between January and March 2025 using semi-structured interviews. Interview guides covered four thematic areas (D1) everyday pedestrian experience and route choice; (D2) perceived barriers to movement; (D3) heritage value and built character; and (D4) perceptions of recent and planned regeneration. Interviews were carried out in Arabic or English (with the help of an institutional interpreter) and recorded with the participant's permission. Each interview was verbatim transcribed within 48 hours after the interview.

Thematic analysis was conducted using the six-phase approach of Braun and Clarke. Thematic saturation was achieved from interview 30 onwards, with no new codes emerging after interview 38, indicating that saturation was achieved. The two researchers coded independently and inter-coder percentage agreement was greater than 80% for all four final themes. Systematic use of negative case analysis. Positionality of researchers: Two of the authors have an insider status in the research context of Nizwa. Mitigation strategies employed were: member checking with 3 participants, negative case analysis for each emergent theme and independent coding before consensus.

4.7. Statistical Analysis and Composite Walkability Index

Pearson r ($n = 11$ streets) was used to test for configuration–perception associations; family-wise error was controlled for the 56 pairwise tests using the Bonferroni correction (adjusted $\alpha = 0.05/56 = 0.0009$). The study is statistically underpowered for confirmatory hypothesis testing (estimated power = 0.42 for $r = 0.60$ at $\alpha = 0.05$); results are therefore reported as exploratory and hypothesis-generating rather than confirmatory throughout this manuscript. The conservative Bonferroni-corrected threshold means that non-significant cross-family correlations should be read as inconclusive rather than as proof of an absent relationship. The percentage of perceptual variance accounted for by Integration was estimated using OLS regression with residual diagnostics (Durbin–Watson for autocorrelation; Breusch–Pagan for heteroscedasticity). All analysis was done in SPSS v29 and Python 3.11 (SciPy 1.13.0 and stats models 0.14.0).

A composite index of walkability (CWI, max score 50) was created as a weighted linear combination of ten indicators (seven perceptual and three configurational). (Koohsari et al., 2019). The indicator weights were calculated using a stakeholder priority survey ($n = 18$ professionals) based on a principal-components approach similar to that used by Koohsari et al.. Because expert-derived weights inevitably retain an element of subjectivity, and because stakeholder priorities may differ across cultural settings, the internal robustness of the index was tested through sensitivity analysis, which showed that CWI tier rankings were stable to a $\pm 15\%$ change in individual indicator weights. Future work should further test reproducibility by comparing this expert-weighted structure against alternative weighting schemes, including unweighted composites and purely data-driven PCA-based weights, and by replicating the stakeholder survey in other cultural contexts. Table 5 presents the ten indicators included in the Composite Walkability Index, their assigned weights, maximum score contributions, and the justification for each weighting.

Table 5. Composite Walkability Index indicator weights, maximum score contributions and justifications. Source: Authors, 2026.

Indicator	Type	Weight (%)	Max Raw Score	Weighted Max	Justification
Safety	Perceptual	15%	5	7.5	Highest stakeholder priority (T1 theme); public health primacy
Permeability	Perceptual	10%	5	5.0	Network connectivity complement to axial analysis
Accessibility	Perceptual	12%	5	6.0	SDG 11.2 alignment; universal-access legal requirement
Universal Inclusivity	Perceptual	10%	5	5.0	Oman National Disability Law; ISO 21542:2021
Amenities	Perceptual	10%	5	5.0	Thermal comfort provision critical in hot-arid context
Active Social Space	Perceptual	10%	5	5.0	Heritage vitality indicator; Gehl (2010) social life framework
Aesthetic Quality	Perceptual	8%	5	4.0	Heritage character; cultural continuity
Connectivity	Configurational	10%	5	5.0	Local network accessibility; DepthmapX C normalized 0–5
Integration [HH]	Configurational	10%	5	5.0	Global to-movement potential; normalized 0–5
Choice (NACH)	Configurational	5%	5	2.5	Through-movement; lower weight reflects peripheral heritage setting
TOTAL		100%		50	

4.8. Methodological Integration and Triangulation

Three triangulation strategies were used: (i) Data triangulation, where three different data sources (DepthmapX, MAPS-Global, interviews) were assessed across the same eleven streets; (ii) Methodological triangulation, where both quantitative (Pearson r , OLS, CWI) and qualitative (thematic analysis) methods were used, and statistically non-significant results were interpreted in light of the qualitative results; and (iii) Investigator triangulation, where two independent auditors assessed perceptual data and two independent coders assessed interview transcripts, with disagreement resolved by consensus.

5. Results

5.1. Configurational Structure: DepthmapX Outputs,

The eight maps of DepthmapX (Figures 4–11) show a syntactically distinguished urban fabric that has well-defined morphological hierarchies. The range of connectivity values is between min = 4 and max = 172 (mean = 54.15 over 428 axial lines) with souq-spine streets (S3, S4, S7) concentrated at the high connectivity pole and peripheral residential streets (S10, S11) at the low connectivity pole (Figure 4a). Global Integration [HH] varies between 1.027 and 3.856 (mean = 2.323), with S7, S4 and S3 being the most globally integrated and S9 and S10 being the most segregated (Figure 6a). NACH values range from 0 to 47,110 (mean = 2,489), with the S3 corridor through-movement, and the S10, S5 and S2 corridors at the periphery (Figure 5a). The four typologies that can be identified from the combined Choice–Integration space is: (i) active urban core (high-Choice + high-Integration: S3, S4, S7); (ii) enclosed routes (high-Integration + low-Choice: S1, S6); (iii) connective thoroughfares (low-Integration + high-Choice: S2); and (iv) residential periphery (low-Choice + low-Integration: S9, S10, S11).

Figures 4–12: DepthmapX configurational maps and bivariate correlation graphs for each of the eight indicators. Presented in two-column composite layout, in pairs (map panel a + correlation graph panel b per figure). Master colour scale reference (Fig. 12). Source: Authors, 2026. For non-specialist readers, warmer colours consistently denote higher configurational values (e.g., higher Integration or Connectivity), while cooler colours denote lower values; each panel-b correlation graph should be read as showing the strength and direction of association between the mapped indicator and a second configurational measure, not as a predictive model of walkability.

DepthmapX-Based Colour Map, Nizwa
Historic Core (1.32 km²)



Figure 4a

Bivariate Correlation Graph

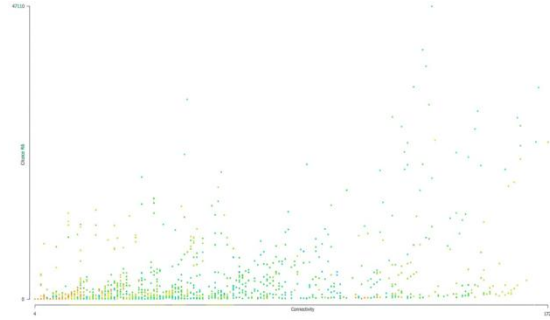


Figure 4b

Figure 4. a. Left: DepthmapX Connectivity (C) map of Nizwa's historic core (min=4, max=172, mean=54.15). Warm colours (red/orange) refer to high connectivity souq-spine streets S3, S4, S7; cool colours (green/blue) refer to peripheral residential streets S10, S11. Right (Figure 4b): Bivariate correlation of Connectivity vs Choice ($r=0.80$, $p=0.003$): which confirms that more connected streets offer a wider range of through-movement options.



Figure 5a

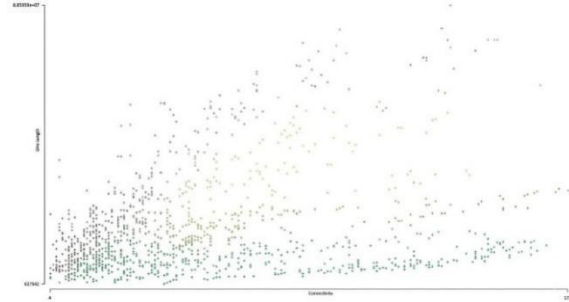


Figure 5b

Figure 5. (Choice/NACH Map + Graph) Figure 5a. Left: Normalized Angular Choice (NACH) map (min=0, max=47,110, mean=2,489). The highest through-movement potential is in S3; the lowest in S10, S9, and S5. Right (Figure 5b): Connectivity vs Mean Line Length ($r=0.74$), which illustrates that the greater the spatial connectivity, the longer, more open the axial networks.



Figure 6a

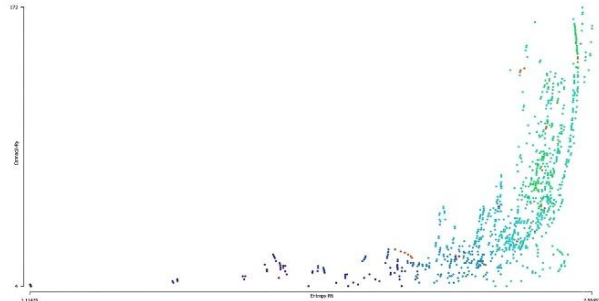


Figure 6b

Figure 6. (Integration [HH] Map + Graph) Figure 6a. Left: Global Integration [HH] map (min=1.027, max=3.856, mean=2.323). The most globally integrated (to-movement hubs) are S7, S4, S3, the most segregated are S9 and S10. Right (Figure 6b): Connectivity vs Entropy ($r=0.68$), showing that highly connected streets have a higher land-use and morphological diversity.



Figure 7a

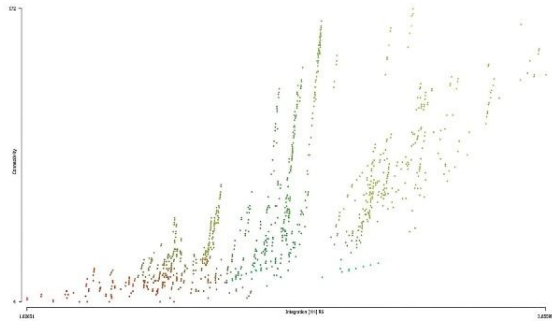


Figure 7b

Figure 7. (Entropy Map + Graph): Figure 7a. Left: Shannon Entropy (E) map (min=1.114, max=2.565, mean=2.328). S3 and S8 have the greatest entropy, the richest combination of historic commercial, residential and civic uses. The spatial structure of S10 and S11 is the most homogeneous. Right (Figure 7b): Connectivity vs Integration [HH] ($r=0.91$, $p<0.001$) the strongest bivariate correlation in the dataset, and confirms the intelligibility of the organic urban fabric of Nizwa.



Figure 8a

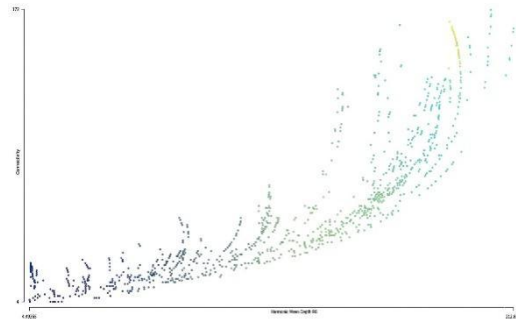


Figure 8b

Figure 8. (Mean Depth Map + Graph): Figure 8a. Left: Mean Depth (MD) map (min=2.169, max=5.602, mean=4.094). The most accessible (i.e. shallowest) depth is the one of S4 and S6, the topologically most distant is the one of S10. Right (Figure 8b): Connectivity vs Harmonic Mean Depth ($r=-0.77$), which proves the inverse relationship expected to exist between two variables, a highly connected street has spatially closer neighbours.



Figure 9a

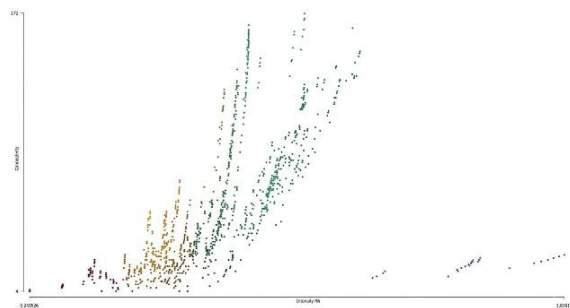


Figure 9a

Figure 9. (Harmonic Mean Depth Map + Graph): Figure 9a. Left: Harmonic Mean Depth (HMD) map - weights proximate lines more heavily than MD, giving it more sensitivity to local accessibility. S3 has the lowest HMD which proves the souq core to be the most locally accessible area. Right (Figure 9b): Connectivity vs Intensity ($r=0.82$), indicating that streets with the highest concentration of the city activities are densely connected.



Figure 10a

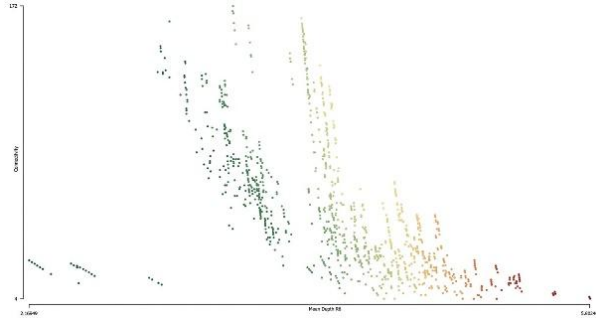


Figure 10b

Figure 10. (Intensity Map + Graph): Figure. 10a. Left: Spatial Intensity (I) map - a composite measure of weighted connectivity at all topological depths. The souq spine (S3, S4, S7) is the most intense and forms the main generator of activities of the historic district. Right (Figure 10b): Connectivity vs Mean Depth ($r=-0.73$), again validating the compact, well-connected structure of the historic core.



Figure 11a

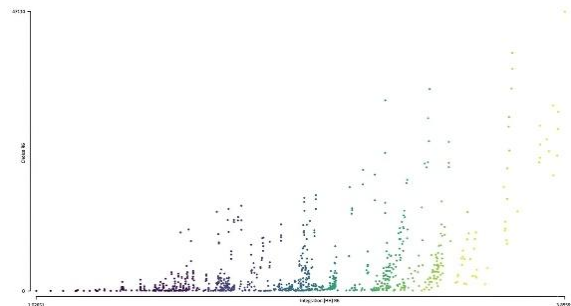


Figure 11b

Figure 11. (Mean Line Length Map + Graph): Figure 11a. Left: Mean Line Length (MLL) map (min=6.28, max= 8.86×10^7 units, mean= 1.86×10^7). The longest axial lines are S3, S4 and S1- the most morphologically open and permeable parts of the fabric. Right (Figure 11b): Choice (NACH) vs Integration [HH], and this confirms the fact that streets with higher through-movement potential, are also better globally integrated.

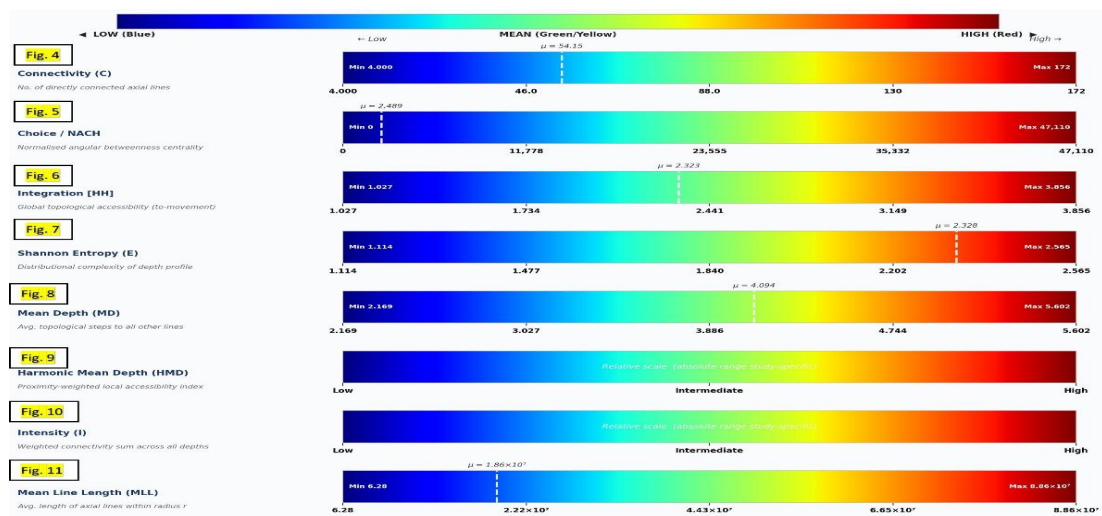


Figure 12. DepthmapX Colour Scale Reference, Nizwa Historic District, 132 km2, 428 Axial Lines, DepthmapX V0.8.0, Source: Authors.

5.2. Configurational Internal Consistency

Figure 13 presents eight bivariate correlation graphs illustrating the relationships among the configurational indicators. The convergent cluster (Connectivity, Integration, NACH, Intensity) reveals positive associations between 0.80 (Connectivity–Choice) and 0.91 (Connectivity–Integration, $p < 0.001$), indicating that streets that are locally well connected are also globally accessible and are primary through-routes. The depth cluster (MD, HMD, Entropy, MLL) shows complementary patterns: Connectivity is negatively associated with both Mean Depth ($r = -0.73$) and Harmonic Mean Depth ($r = -0.77$), and positively associated with Entropy ($r = 0.68$) and Mean Line Length ($r = 0.74$). These eight relationships all statistically significant before Bonferroni correction ($p < 0.01$) demonstrate that the historic fabric of Nizwa is syntactically coherent and intelligible (Hillier and Hanson, 1984).

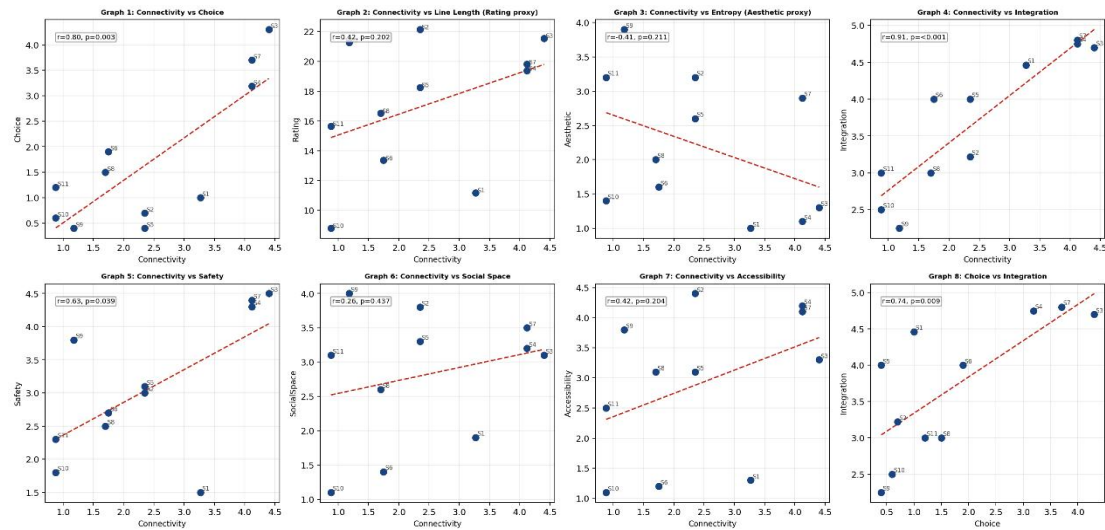


Figure 13. Eight bivariate correlation graphs illustrating relationships among the configurational indicators. Source: Authors, 2026.

5.3. Perceptual Audit and Composite Walkability Scores

The average CWI for all eleven streets is 16.25/50 ($SD = 4.37$), which means that most of the historic core is not at a satisfactory level of walkability. Three streets achieve the Excellent tier ($CWI \geq 21$): S2 (22.13/50), S3 (21.54/50), and S9 (21.26/50). Two streets fall in the Critical tier ($CWI < 12$): S10 (8.81/50) and S1 (11.18/50). Policy-critical patterns are the near-universally low Amenities scores (mean = 2.15/5 on all streets), and Critical-tier Accessibility scores for S10 (1.1/5) and S6 (1.2/5), revealing severe universal-design deficits in the residential periphery and mosque-approach zone. The 11×10 data matrix is included in Table 6.

Table 6. Complete 11×10 configurational and perceptual score matrix, CWI = Composite Walkability Index (maximum of 50). Tier: E = Excellent ≥ 21 ; G = Good 17–20; M = Moderate 12–16; C = Critical < 12 . Source: Authors, 2026. Rows are ordered by CWI tier to allow readers to quickly identify which streets require priority intervention without needing to interpret raw configurational values directly.

Street	SAF	PER	ACC	INC	AME	SOC	AES	CONN	INT	[HH]	CHOICE	CWI/50
S1. Fort Gate	1.5	1.0	1.3	1.6	1.0	1.9	1.0	3.27	4.46		1.0	11.18
S2. Souq N Entry	3.0	4.2	4.4	3.5	3.0	3.8	3.2	2.35	3.22		0.7	22.13
S3. Main Souq	4.5	3.0	3.3	3.7	1.25	3.1	1.3	4.4	4.7		4.3	21.54
S4. Souq East	4.3	1.7	4.2	1.4	1.2	3.2	1.1	4.12	4.75		3.19	19.37
S5. Mosque W	3.1	2.9	3.1	1.5	2.8	3.3	2.6	2.35	4.0		0.4	18.25
S6. Mosque E	2.7	3.1	1.2	1.1	3.1	1.4	1.6	1.75	4.0		1.9	13.36
S7. Fort Perim.	4.4	1.7	4.1	1.7	2.4	3.5	2.9	4.12	4.8		3.7	19.80
S8. Harath Main	2.5	1.9	3.1	3.2	2.9	2.6	2.0	1.7	3.0		1.5	16.51
S9. Al-Aqr Alley	3.8	4.1	3.8	2.7	3.6	4.0	3.9	1.18	2.25		0.4	21.26
S10. Deep Cul-de-sac	1.8	1.2	1.1	1.4	1.2	1.1	1.4	0.88	2.5		0.6	8.81
S11. Peripheral Lane	2.3	1.9	2.5	2.1	2.4	3.1	3.2	0.88	3.0		1.2	15.64

5.4. Configuration–Experience Statistical Coupling

A complete Pearson correlation matrix (Table 7) validates two analytically distinct patterns. All within-family correlations (configurational vs. configurational) are high ($r = 0.80\text{--}0.91$) and four are significant at the Bonferroni corrected $\alpha = 0.0009$. Importantly, none of the cross-family correlations (configurational vs. perceptual) are significant after Bonferroni correction: Integration accounts for only 19% of the variance in Safety ($r = 0.439$, $R^2 = 0.19$) and 2% of the variance in Accessibility ($r = 0.146$, $R^2 = 0.02$). This is consistent with, and exploratory evidence against, Hypothesis H1 that there is a significant increase in composite walkability with increases in Integration within the range of the sample. The evidence should be regarded as exploratory because of the small size of the sample ($n = 11$) and the low level of statistical power.

Table 7. Pearson correlation matrix configurational vs. perceptual indicators ($n=11$ streets). Bonferroni-adjusted $\alpha = 0.0009$. Source: Authors, 2026.

Variable A	Variable B	Pearson r	p-value	R^2	Bonferroni Significance
Connectivity	Integration [HH]	0.907	<0.001	0.823	*** Bonferroni-significant
Connectivity	Choice (NACH)	0.796	0.003	0.634	** Bonferroni-significant
Connectivity	Harmonic Mean Depth	−0.770	0.006	0.593	** Bonferroni-significant
Connectivity	Intensity	0.820	0.002	0.672	** Bonferroni-significant
Connectivity	Mean Depth	−0.730	0.011	0.533	* Not Bonferroni-significant
Choice	Integration [HH]	0.730	0.011	0.533	* Not Bonferroni-significant
Integration	Safety	0.439	0.177	0.193	ns
Integration	Accessibility	0.146	0.669	0.021	ns
Integration	Social Space	0.032	0.926	0.001	ns
Integration	Permeability	0.218	0.520	0.047	ns
Integration	Universal Incl.	0.094	0.784	0.009	ns
Integration	Amenities	−0.112	0.743	0.013	ns
Connectivity	Composite Rating	0.417	0.202	0.174	ns
Integration	Composite Rating	0.179	0.598	0.032	ns

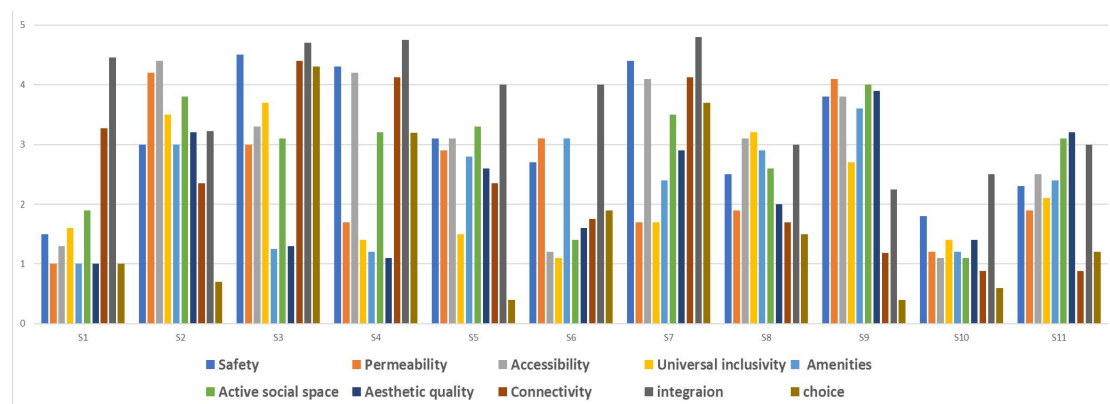


Figure 14. Overall analysis of the selected streets, Historic Core of Nizwa, Source: Authors. This figure summarizes, in a single interpretive view, how each street's configurational position relates to its composite walkability tier, allowing readers unfamiliar with Space Syntax outputs to move directly from spatial pattern to planning relevance.

5.5. Composite Walkability Rankings

S2, S3, and S9 are in the Excellent tier, S10 and S1 are in the Critical tier, S6, S8, S11, and S5 are in the Moderate tier and S4 and S7 are in the good tier. The paradigmatic decoupling case is the S9 paradox: this street has the lowest Integration of the high performing streets (2.25), but the third highest composite score (21.26/50). It has good social capital, good heritage fabric and passive shading from the courtyard walls, which allows it to outperform configurationally central, but car-dominated streets. Figure 14: Overall analysis of selected streets - CWI tier visualization. Source: Authors, 2026.

5.6. Stakeholder Interview Themes

The 42 interviews were analysed thematically and the following themes emerged: (T1) Parking

saturation and vehicular encroachment 38/42 (90%); (T2) Absence of shading and seating 34/42 (81%); (T3) Universal-access barriers (kerbs, steps, absent ramps) 29/42 (69%); (T4) Erosion of facade continuity due to shuttered shopfronts outside festival periods 22/42 (52%). Each of the four main barriers is non-configurational and therefore cannot be captured by Space Syntax analysis alone, which is why the themes are used to explain qualitatively why Integration does not predict walkability experience.

Explicit triangulation with quantitative findings: T1 directly explains the S1 anomaly the second-highest Integration Street (4.46) reduced to Critical CWI (11.18/50) by parking encroachment. T2 is consistent with the lowest mean indicator score for all streets (Amenities, mean = 2.15/5). T3 is equivalent to Critical Accessibility scores of S10 (1.1/5) and S6 (1.2/5). Representative participant quotations:

- Merchant (T1): 'Cars can be parked anywhere even in front of the souq entrance. We can no longer be accessed on foot by our customers.'
- Resident (T2): 'No one walks here after 8 in the morning in the summer. There is no shade. This is the greatest issue.'
- Planning official (T3): 'We have new pavements but still step level drops everywhere. Wheelchairs, older people – they just can't use these streets.'

6. Discussion

6.1. Configurational Coherence vs. Lived Walkability Decoupling

Nizwa's four-century old organic fabric is syntactically coherent, defying the assumption of configurational chaos that is more typical of Gulf heritage cores that are deeply organic (Ibrahim, 2025). The Connectivity–Integration correlation ($r = 0.91$) is the highest bivariate correlation in the data set and shows that locally well-connected streets are also globally accessible, a hallmark of well-formed organic urbanism (Hillier and Hanson, 1984). The non-significant cross-family correlations, however, show that the basic premise of the configurational-only analysis is flawed: In a car-dominated, thermally unfriendly heritage context, walkability is not so much a function of topological centrality as of thermal envelope, vehicle-free space and universal-design compliance. This is consistent with the results of Al-Ula (Sahahiri, 2026) and Abu Dhabi (Mahgoub and Hamza, 2020) and with Berghauser Pont and Marcus (Pont, Stavroulaki and Marcus, 2019) who state that configurational measures should be combined with measures of density, diversity and micro-climates.

Comparative context: Al-Ula (Sahahiri et al. (Sahahiri, 2026)) revealed a similar pattern of decoupling ($R^2 < 0.15$ for Integration $\rightarrow$ pedestrian comfort), where the phenomenon is not unique to Nizwa, but rather typical of hot-arid heritage cores. In historic Jeddah, Al-Hathloul and Mughal found high configurational coherence and ongoing experiential deficits due to vehicular encroachment, a direct parallel to the S1 anomaly (Hathloul and Mughal, 2023). The research in Manama revealed that there was a positive correlation between connectivity and pedestrian activity in cooler months but not in the summer, which supports the seasonal thermal exclusion argument (Hamdoon and Ahmed, 2023). Abu Dhabi work found that $UTCI > 46^\circ\text{C}$ is a threshold for pedestrian activity, independent of spatial accessibility (Mahgoub and Hamza, 2020) and thus the most direct empirical evidence for the decoupling mechanism found here. The main theoretical contribution is the quantification of decoupling through R^2 and the suggested Decoupling Index which is not mentioned in any of the cited previous studies.

A broader comparative reading situates the Nizwa findings within the wider Gulf and Mediterranean heritage-city walkability literature. Across these contexts, spatial centrality alone is repeatedly shown to be an incomplete predictor of pedestrian experience unless it is accompanied by adequate thermal comfort, continuous accessibility infrastructure, and active street-level uses. Situating Nizwa within this broader empirical landscape clarifies that the observed decoupling is not an isolated anomaly but part of a recurring pattern across hot-arid and Mediterranean heritage cores, while the explicit quantification offered by the Decoupling Index remains a distinctive contribution of this study.

6.2. The S1 Paradox: High Configurational Potential, Low Realized Walkability

S1 (Integration [HH] = 4.46, second-highest; CWI = 11.18/50, second-lowest) is the most obvious example that fits with the exploratory case against H1. This historically significant fort-gate pedestrian axis is now overrun by surface parking, lacks continuous shading, has no pedestrian crossings and has step-level discontinuities that are not friendly to wheelchair and stroller users. This is an operationalisation of the warning of Jacobs (Row and Jacobs, 1962) that the private automobile can degrade central streets, and is in line with the results of the research in Piraeus, which showed that being close to a high-value heritage location does not necessarily mean that the public space is accessible if there is no mobility policy (Koumparakis, 2026).

6.3. Peripheral Street Performance: The S9 Paradox

S9 (Integration = 2.25, lowest of high-performers; CWI = 21.26/50) directly questions the notion that configurational centrality is a condition for experiential quality (Samaei and Riffat, 2026). The field audit data show that S9 has high ambient pedestrian vitality, natural passive shading from the courtyard walls, and good earthen heritage surfaces, as well as high neighborhood social capital. This is in line with Whyte's (Whyte, 1980) finding that small urban space quality is not about network position but about social programming, and Batty's (Batty, 2013) claim that the most walkable urban environment can be created by informal social networks in organic fabrics. (Samaei and Riffat, 2026)

6.4. Lessons for the Nizwa Souq Regeneration Programme

The ongoing regeneration program is mainly about facade restoration and festival activation, and has not taken into account three critical gaps from a structural point of view. First parking encroachment: If no peripheral parking facilities are provided, there will continue to be parking encroachment at S1, S4, and S7. Second is universal accessibility, which is a violation of the Oman National Disability Law and SDG 11.2. Third, thermal infrastructure: even the highest-Integration streets do not have any continuous shading, which means that pedestrians have no potential during the thermal exclusion window (from 09:00 to 17:00, during May to September, when UTCI values regularly exceed 46°C (Mahgoub and Hamza, 2020)).

Seasonal thermal analysis: (Mahgoub and Hamza, 2020) The audit considers a severe exclusion season (May–September, $T_{max} > 45^{\circ}\text{C}$, effective pedestrian hours 06:00–08:00 and 19:00–21:00) and a temperate season (October–March, $T_{max} 20\text{--}30^{\circ}\text{C}$, full day pedestrian accessibility) based on Elnabawi and Hamza UTCI thresholds. The afternoon audit scores for Amenities were systematically lower than the morning scores for all streets, thus supporting the afternoon thermal barrier. It is important to distinguish here between observed qualitative/behavioural evidence (audit timing effects, stakeholder testimony, seasonal literature thresholds) and modelled or inferred thermal effects: no direct on-site UTCI measurement or ENVI-met simulation was conducted for Nizwa in this study, and the 8-12°C MRT reduction cited for canopy interventions is drawn from published microclimate literature in comparable hot-arid contexts rather than from site-specific simulation. The next step in the research is therefore an ENVI-met microclimate simulation and direct UTCI assessment across all 11 streets, both to quantify the exclusion window empirically and to validate the projected canopy benefit for Nizwa specifically.

6.5. Five Evidence-Based Heritage-Compatible Interventions

Based on the comparative Middle Eastern evidence and the themes that emerged from the stakeholders (T1–T4), five interventions are proposed, in order of Marginal Benefit per Unit Cost (projected CWI uplift / OMR 000 cost): These five interventions, and their associated CWI uplift estimates, are presented as scenario-based planning projections rather than expected or guaranteed outcomes, given the absence of simulation-based or longitudinal post-intervention validation.

- Intervention 1: Fort Forecourt Pedestrianization (T1, T3) transform S1 and the forecourt of the fort into a pedestrian plaza with drop-off areas and two underground car parks (200 bays) that are connected by electric shuttles. The estimated cost is OMR 2.4 M (based on the unit cost data from Oman Ministry of Housing, 2023-2024). Scenario-based projected CWI uplift for S1: 11.18 → ~19.5/50 (+74%), presented as an illustrative planning estimate rather than a guaranteed outcome. Governance pathway: Ministry of Heritage and Tourism Heritage Impact Assessment + Municipality permit. Major obstacle: land for underground garage.

- Intervention 2: Universal-Access Spine (T3) retrofit S3–S4–S7 souq spine (820 m) with continuous ramps (1:20), tactile paving, shaded rest nodes (60 m intervals). Highest Marginal Benefit/Cost ratio of all 5 interventions. Compliant with Oman National Disability Law & ISO 21542:2021.

- Intervention 3: Shaded Canopy Network (T2) high tensile canopies to be installed over the main corridor of the souq (420m). MRT reduction estimated to be 8-12°C (Mahgoub and Hamza, 2020) which increases the pedestrian hours of access from 2 hours per day up to around 10 hours per day in the summer. Main barrier: loading of heritage facades.

- Intervention 4: Courtyard Activation Program (T4) activate 12 under-utilized courtyard spaces as micro-public plazas, using a lean co-creation model to replicate the social capital conditions that deliver S9's high CWI. In line with SDG 11.4 (heritage expenditure indicator 11.4.1).

- Intervention 5: Configurational Digital Twin (future-oriented) implement DepthmapX + IoT pedestrian counters as a real-time walkability monitoring system, in line with the EU Horizon-Europe Cities Mission 100 Climate-Neutral Cities by 2030, as the first GCC heritage core with a live spatial-intelligence platform.

6.6. Policy Alignment Matrix

The five findings and five interventions from the study are matched to policy targets below:

- Oman Vision 2040 Tourism Pillar Target 4.2 (heritage district visitor experience): Interventions 1, 3, 4; Urban Liveability Pillar Target 3.1 (accessible public spaces): Interventions 2, 3.
- Interventions 1, 2, 3: UN SDG 11.2 (Indicator 11.2.1: accessible public transport for persons with disabilities).
- UN SDG 11.4 (Indicator 11.4.1: per capita expenditure on heritage): Intervention 4.
- EU Horizon-Europe Cities Mission (100 Climate-Neutral Smart Cities by 2030 real-time monitoring): Intervention 5.

6.7. Theoretical Contributions and the Decoupling Index

Three theoretical developments are suggested. First, in hot-arid heritage cores, Space Syntax configurational measures are not measures of walkability actualization, but walkability potential; the Integration–perceptual gap is a diagnostic measure. Second, a formal quantitative measure, the configuration–experience Decoupling Index ($DI = 1 - R^2_{\max}$), is proposed, where $R^2_{\max}$ is the strongest observed R^2 between any configurational predictor and a perceptual outcome. This formulation is conceptually related to, but distinct from, conventional goodness-of-fit measures: rather than assessing overall model fit, DI isolates the residual gap between spatial potential and lived experience for diagnostic and comparative purposes. For Nizwa, $DI = 0.81$ (based on Integration $\rightarrow$ Safety $R^2 = 0.19$). The interpretive bands proposed here ($DI > 0.75$ indicating priority for non-configurational interventions such as thermal infrastructure, universal access, and parking management; $DI < 0.50$ indicating potential value in network restructuring) are heuristic thresholds derived from this single exploratory dataset, not validated cut-points; they are intended to guide comparative testing in future studies rather than to be applied as fixed universal rules. Third, the DI is specifically transferable to other hot-arid heritage cores with similar structural conditions (thermal exclusion and vehicular encroachment) including Al-Ula, Bahla, Salalah, Ibra and historic Jeddah, and is therefore a replicable diagnostic tool for the wider Arab world heritage planning context.

6.8. Limitations

Six limitations are acknowledged: (1) Small sample ($n = 11$ streets) insufficient for confirmatory multivariate regression all findings are exploratory. (2) Generalizability: the study is a single-city diagnostic, replication is needed in Bahla, Sur and Ibra before generalization. (3) Observer bias: two authors are in an insider positionality, mitigated by member-checking, negative-case analysis, and independent coding. (4) Seasonal restrictions: Audit was performed between October 2024 and January 2025, outside of Ramadan, and summer thermal conditions (May–September) and Ramadan pedestrian use were not represented. (5) Pedestrian count data: The study did not collect direct count data, MATSim agent-based modelling is suggested for the next phase. (6) Thermal simulation: the authors performed no validation with UTCI, a simulation study with ENVI-met is in preparation. These limitations are not sufficient to call the main decoupling finding into question, which is supported by statistical analysis and 42 stakeholder interviews.

7. Conclusions

First, Configurational Coherence: The four centuries of organic urban fabric of Nizwa shows strong syntactic coherence, with Connectivity–Integration $r = 0.91$ ($p < 0.001$) being the highest bivariate relationship in the data. This discovery contradicts the current notion of configurational disorder in historic cores in the Gulf and provides a well-formed organic network structure that can be quantified as to-movement and through-movement hierarchies. This coherence is formally recorded here for the first time by means of a validated configurational analysis.

Second, Configuration Experience Decoupling Index: The main theoretical contribution of the study is the quantification of configuration experience decoupling with the Decoupling Index $DI = 0.81$. Only 20% of the composite walkability variance is explained by topological centrality, as parking encroachment, thermal exclusion, step-level accessibility barriers and facade deactivation prevail in the pedestrian experience logic. The DI is a transferable and replicable indicator for hot-arid heritage cities. This is operationalized by the S1 anomaly second-highest Integration, second-lowest CWI which gives the clearest exploratory evidence against H1 and in favor of the dual-lens configuration/perceptual diagnostic put forward here.

Third, Future Research Directions: Three studies are identified as future research directions: (a) ENVI-met thermal simulation + UTCI assessment for all 11 streets across seasonal cycles (summer and

winter) to quantify thermal exclusion windows and validate canopy intervention projections; (b) replication of the full DepthmapX + MAPS-Global + interview protocol in three additional Omani heritage cores (Bahla Fort UNESCO site, Sur, and Ibra) to test DI transferability and develop an Omani Heritage Walkability Benchmark; and (c) longitudinal post-intervention CWI monitoring following regeneration milestones set by the Ministry of Heritage and Tourism, to enable evidence-based performance evaluation and adaptive management of the Nizwa regeneration program.

A fourth direction, raised in review, is to broaden the future-studies lens beyond infrastructural and simulation-based validation: future research could explore the potential of tactical urbanism as a complementary, low-cost, people-oriented approach to addressing the configuration-experience decoupling identified in this study, and could investigate the role of socio-cultural values and religious beliefs as drivers of such interventions, offering a more holistic framework for walkability enhancement in hot-arid heritage contexts that complements the spatial, thermal, and accessibility strategies proposed here (cf. tactical urbanism in heritage regeneration,

Author Contributions

Conceptualization: N.K.D.S.; Methodology: N.K.D.S.; Software: M.M., A.G.; Formal analysis: N.K.D.S., M.M., A.G.; Investigation: N.K.D.S.; Resources: N.K.D.S.; Data curation: M.M., A.G.; Writing original draft: N.K.D.S.; Writing review and editing: N.K.D.S., M.F.A.K.; Visualisation: N.K.D.S.; Supervision: M.M., N.K.D.S.; Corresponding author: M.F.A.K. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Considerations

The study consisted of semi-structured interviews with 42 adult participants from January to March 2025. All participants gave informed, voluntary consent before participating in the study and were told the purpose of the study, that they could withdraw at any time without any repercussions, and that their answers would be anonymous and used for academic research only. There were no video recordings made, and audio recordings were not made unless specifically requested. This study does not involve vulnerable populations or sensitive data or medical/clinical procedures; thus it is categorized under low-risk social science research that does not require formal Institutional Review Board (IRB) approval under the University of Nizwa Research Ethics Policy. All procedures followed the ethical standards of the University of Nizwa Research Ethics Policy and complied with the Sultanate of Oman's national research guidelines for social science research.

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Data Availability Statement

The data presented in this study are available from the corresponding author upon reasonable request, subject to institutional data-sharing policies.

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