



American Journal of Urban Planning and Smart City (AJUPSC)

VOLUME 1 ISSUE 1 (2025)



PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

Redesigning Roads in Muscat: Integrating Engineering Standards with the Principles of Integrated Humanization

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Article Information

Received: August 13, 2025

Accepted: September 16, 2025

Published: October 14, 2025

Keywords

Integrated Humanization, Urban Humanization, Greater Muscat Structure Plan, Gulf Urbanism, Walkability

ABSTRACT

This article builds directly on Integrated Humanization: A Gulf-Centric Urban Paradigm (Saad, M. A. A. (2025). American Journal of Urban Planning and Smart City, 1(1), 1–6), where the author introduced Integrated Humanization (IH) as a Gulf-centric mobility paradigm. This paper examines the limitations of imported road engineering standards in the Gulf, primarily AASHTO and British Standards, and advocates for a Gulf-specific framework rooted in Oman Vision 2040 and the Greater Muscat Structure Plan (GMSP). Integrated Humanization is defined by five pillars: urban planning, urban humanization, public transport integration, road engineering, and micro-mobility. By analyzing Oman's five existing road classifications, as outlined in the Oman Road Design Manual and Standard Specifications for Road and Bridge Construction (MTCIT, 2019), and the innovations proposed in the GMSP, the study highlights the need to recalibrate right-of-way (ROW) allocations to include shaded pedestrian paths, micro-mobility lanes, and climatically adaptive infrastructure, leading to reduced reliance on private vehicles, improved public health, enhanced viability of public transport, and lower carbon emissions. Ultimately, the paper concludes that road engineering in Oman must evolve beyond lane widths and design speeds, embedding Integrated Humanization as a guiding principle for sustainable Gulf cities.

INTRODUCTION

Road networks in the Gulf have historically been shaped by imported engineering standards, primarily the American Association of State Highway and Transportation Officials (AASHTO, 2018) and the Design Manual for Roads and Bridges (DMRB, 2020) from the UK. These frameworks were designed for temperate climates and car-oriented societies, emphasizing traffic flow, vehicular capacity, and speed. While effective in ensuring vehicular efficiency, they have produced environments in Gulf cities that are hostile to pedestrians, micro-mobility users, and climatically responsive design.

In Oman, the reliance on imported codes has limited the ability of road engineering to respond to local environmental and cultural conditions. The Oman Road Design Manual and Standard Specifications for Road and Bridge Construction (MTCIT, 2019) provides a comprehensive technical baseline for roadway design. It defines five hierarchical road classes—arterials, major collectors, minor collectors, local streets, and service streets. While this manual offers clarity and structure, its orientation remains largely vehicular, emphasizing geometric design, capacity, and safety according to imported models such as AASHTO and British Standards (MTCIT, 2019). This creates a policy–practice gap: Oman Vision 2040 and the Greater Muscat Structure Plan articulate ambitious goals for livability, sustainability, and reduced car dependency. However, the engineering codes currently in force translate these aspirations into designs that continue to privilege cars over people.

For example, the persistence of 3.65 m standard lane widths across most street types reflects imported safety assumptions rather than the realities of Muscat's residential neighborhoods, where narrower lanes could safely accommodate lower speeds while freeing ROW for shaded walkways and micro-mobility. As Oman advances toward its Vision 2040, it is imperative to rethink road engineering not only as a technical exercise but also as a strategic tool for sustainable urbanism. Integrated Humanization (IH) addresses this gap by reframing engineering practice within the Gulf's socio-climatic realities. Rather than discarding Oman's existing manuals, IH proposes an overlay framework: reinterpreting the five road classifications not as static categories but as flexible templates where shaded corridors, dedicated micro-mobility lanes, and transit integration become standard inclusions. By embedding IH principles into everyday road projects, Oman can ensure that Vision 2040's sustainability aspirations and the GMSP's multimodal networks move beyond diagrams and policy documents to become tangible, lived realities for residents. This approach turns high-level strategy into practical design, ensuring that Muscat's roadways evolve from vehicle conduits into climate-adapted, people-centered lifelines.

LITERATURE REVIEW

Imported Road Engineering Standards in the Gulf

Road engineering in the Gulf has historically relied on imported frameworks, primarily the American Association of State Highway and Transportation

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Officials (AASHTO, 2018) and the UK's Design Manual for Roads and Bridges (DMRB, 2020). These standards emphasize lane width, horizontal and vertical alignment, sight distances, and design speed, reflecting priorities of mid-20th century automobile societies in North America and Europe. While these codes have been widely recognized for their technical rigor and safety outcomes, they were originally designed for temperate climates and socio-economic contexts where private cars dominated mobility, fuel was abundant, and pedestrian movement was a marginal concern.

Applied directly to the Arabian Gulf, these standards have produced wide arterials (3.65 m per lane), grade-separated interchanges, and vehicle-centric rights-of-way (ROWs) that prioritize high-speed traffic flow. However, they do not account for the thermal stress of hot-arid environments, nor for the cultural and behavioral patterns of Gulf societies where car dependency is reinforced by climate, income levels, and planning legacies. Consequently, streets designed under these imported models are often hostile to pedestrians, micro-mobility users, and public realm functions (Shaaban & Muley, 2018). This mismatch illustrates a broader critique: while AASHTO and DMRB succeed in technical efficiency, they fail to deliver livability, inclusivity, or climate responsiveness when transplanted into the Gulf.

Oman's National Road Guidelines

To address localized needs, Oman has issued its own Oman Road Design Manual and Standard Specifications for Road and Bridge Construction (MTCIT, 2019). This document introduces five primary road classifications—arterial roads, major collectors, minor collectors, local streets, and service streets—each with a defined functional role. Arterials are designed to provide regional connectivity and carry long-distance traffic; collectors distribute this flow into neighborhoods; and service/local roads provide fine-grained access. Unlike AASHTO's more universal approach, the Omani manual acknowledges contextual differentiation. However, in practice, many of the adopted dimensions (e.g., lane widths, intersection geometries) remain aligned with imported standards. For example, local streets frequently maintain 3.65 m lanes, even though traffic volumes and design speeds are much lower, thereby wasting ROW capacity that could otherwise be allocated to shaded sidewalks, micro-mobility lanes, or landscaping. Here lies the opportunity: Oman's five-tier system is not inherently flawed—it provides a structured framework into which Integrated Humanization (IH) can be embedded. If lane widths and design speeds are recalibrated for local conditions, these classifications can be reinterpreted to support multimodal and climate-sensitive streets.

Greater Muscat Structure Plan (GMSP)

The Greater Muscat Structure Plan (GMSP), prepared by the Ministry of Housing and Urban Planning in collaboration with MIC-HUB (2022), represents Oman's

most ambitious attempt to modernize its metropolitan road and mobility system. Covering approximately 1,360 km², the plan envisions a livable, productive, connected, green, and inclusive Muscat by 2040.

Key innovations include:

- Arterial corridors redesigned as transit boulevards, with Bus Rapid Transit (BRT) lanes, wide shaded sidewalks, and linear green buffers.
- Local streets redesigned with reduced lane widths (≈ 3.0 m), integrated 2.0 m micro-mobility lanes, and shaded pedestrian paths.
- Service roads reframed as community spines, prioritizing slow speeds, pedestrian movement, and shaded arcades.
- Systematic tree planting and canopy requirements embedded into ROW standards, making shade a design obligation rather than an optional amenity.

The GMSP thus represents a departure from traditional engineering codes by explicitly embedding climate adaptation, public transport, and livability goals into road design. However, its success hinges on operationalizing these visions within the technical standards currently applied by municipalities and contractors.

Climate-Responsive Mobility and Thermal Comfort

Thermal comfort is a decisive factor in the success of walkability and micro-mobility in hot-arid cities. Studies consistently demonstrate that mean radiant temperature (T_{mrt}), not just air temperature, determines whether people will walk or cycle outdoors (Middel *et al.*, 2016). Without shade, outdoor movement becomes physiologically stressful, especially in summer when ground surfaces exceed 50°C.

Strategies that have shown effectiveness include:

- Vegetation and tree canopies, which lower surface and globe temperatures by up to 10°C while creating shaded corridors (Alharthi *et al.*, 2025).
- Photovoltaic canopies, which not only provide shade but also generate renewable energy for lighting or micro-mobility charging (Santamouris, 2016).
- Cool pavements and permeable surfaces, which reduce heat absorption and improve drainage.
- Arcades and permeable canopies, which maintain ventilation while reducing direct solar radiation (Hamdan & Oliveira, 2019).

In Muscat and other Gulf cities, outdoor comfort dictates behavior. Regardless of sidewalk width or paving quality, residents avoid walking if exposed to intense heat. Therefore, climate-responsive infrastructure is not optional but fundamental to Integrated Humanization.

Comparative Insights from Gulf Cities

While Oman represents a distinctive case, the challenges of reconciling imported road engineering standards with climatic and cultural realities are shared across the Gulf region. For instance, Riyadh's Public Transport Program, aligned with Saudi Vision 2030, emphasizes metro and BRT corridors but continues to grapple with first- and last-mile

access in sprawling, low-density neighborhoods (Shaaban & Muley, 2018). Similarly, Doha’s urban transformations for the FIFA World Cup 2022 showcased world-class metro infrastructure, yet studies note persistent cultural resistance to walking in hot-humid conditions, especially for trips under 2 km (Pojani & Stead, 2017). These cases highlight the structural difficulty of shifting mobility culture when road engineering and neighborhood design remain car-dominated.

Oman’s approach, particularly through the Greater Muscat Structure Plan (GMSP), thus occupies a middle ground: it acknowledges global best practices while seeking to adapt them to local conditions. Integrated Humanization, as advanced in this paper, offers a theoretical framework that Gulf cities can collectively adopt to bridge the gap between ambitious transit infrastructure and everyday human-scale accessibility.

Socio-Cultural Dimensions of Car Dependency

Beyond climatic constraints, Gulf cities face entrenched cultural reliance on the private car. Research indicates that even very short trips—under 1 km—are often undertaken by car in Muscat, Riyadh, and Doha (Shaaban & Muley, 2018; Al-Harthy, 2020). This behavior is reinforced by road design standards that privilege speed and vehicular throughput over inclusivity and

comfort. Without deliberate interventions to normalize walking, cycling, and micro-mobility, infrastructure projects risk underutilization. Integrated Humanization acknowledges this cultural layer by framing micro-mobility and shaded pedestrian spaces not only as technical solutions but also as behavioral transition tools that gradually shift social norms toward shared and sustainable modes of mobility.

Transition to Comparative Framework

The literature therefore reveals a three-stage evolution in Gulf urban mobility paradigms:

1. Imported standards (AASHTO, DMRB): Vehicle-focused, climate-insensitive.
2. Oman’s national guidelines (ORDM 2019): Formalized classifications but still vehicular in emphasis.
3. Strategic visions (Vision 2040, GMSP): Acknowledging sustainability and multimodality.
4. Integrated Humanization (proposed): Embedding climate-responsive, socio-cultural, and human-centered design.

To synthesize these insights, Table 1 presents a comparative overview of how Oman’s evolving standards—and Gulf experiences more broadly—progress from imported codes toward Integrated Humanization as a Gulf-specific paradigm.

Table 1: Evolution of Road Engineering and Urban Design Paradigms in Oman and the Gulf

Phase	Framework / Reference	Core Characteristics	Limitations in the Gulf Context	Transition Toward Integrated Humanization
1	Imported Standards (AASHTO, DMRB)	Focus on vehicular throughput, lane width ≥ 3.65 m, high-speed design, car-centric mobility	Climate-insensitive, neglects pedestrians and micro-mobility, encourages sprawl	Highlights the need for local adaptation
2	Oman Road Design Manual and Standard Specifications for Road and Bridge Construction (MTCIT, 2019)	Five-tier classification (arterial, major collector, minor collector, local, service streets); codified design criteria	Still vehicular in emphasis, limited shading or micro-mobility provisions	Provides a formal baseline for redefinition
3	Strategic Visions (Oman Vision 2040, GMSP)	Emphasis on sustainability, livability, mass transit (BRT, metro), green corridors	Risk of underperformance without first/last-mile integration	Opens policy space for human-centered frameworks
4	Integrated Humanization (proposed)	Five interdependent domains: urban planning, urban humanization, public transport, road engineering, micro-mobility; climate-adapted ROW	Requires pilot testing and cultural adaptation	Establishes a Gulf-specific grammar for sustainable, human-centered cities

Integrated Humanization (IH) as an Emerging Concept

Integrated Humanization (IH), introduced by Saad (2025), is a Gulf-centric paradigm designed to overcome the climate and cultural misfits of imported road engineering codes. Conceptually, IH reframes streets as thermal-adaptive, multi-modal public spaces rather than purely vehicular conduits. Unlike Western and East Asian frameworks, IH treats shaded pedestrian access, micro-mobility, and last-mile connectivity as engineering requirements, not optional amenities. While the idea of humanizing cities has been widely discussed in global literature, no operational framework yet addresses the Gulf's extreme climate and entrenched car dependency. This study fills that gap by translating IH from a conceptual vision into actionable design principles and pilot-ready standards.

Gaps in Existing Research

Despite progress, several gaps remain:

- Over-technical focus: Gulf road engineering studies remain dominated by capacity analysis, neglecting human comfort, equity, or climate resilience (Banister, 2008; Shaaban & Muley, 2018).
- Weak integration with policy visions: While Oman Vision 2040 stresses sustainability and livability, few engineering documents translate these into measurable design standards.
- Limited empirical pilots: To date, there is a scarcity of pilot projects in Muscat or elsewhere in the Gulf that test integrated, climate-adaptive street designs. Most remain at the conceptual or policy level.
- Social and cultural adaptation: Micro-mobility adoption faces resistance due to entrenched car culture, yet few studies have explored behavioral incentives in Gulf contexts.

These gaps reinforce the need for a new engineering paradigm—Integrated Humanization—that can bridge technical rigor with social, cultural, and climatic realities.

MATERIALS AND METHODS

This research adopts a qualitative and exploratory approach, designed to bridge the gap between imported engineering codes and Gulf-specific needs for sustainable urbanism. The methodology integrates policy analysis, literature synthesis, conceptual framework building, and case-based reasoning to ensure that findings are both academically robust and practically applicable to Oman's urban development context.

Policy Analysis

The first methodological step consisted of analyzing Oman's national and metropolitan planning frameworks, particularly:

- Oman Vision 2040 (Ministry of National Economy, 2020), which outlines national objectives for sustainability, livability, and reduced car dependency.
- Oman National Spatial Strategy (ONSS) (MoHUP, 2021), which defines the spatial hierarchy of cities, road

networks, and multi-modal transport integration.

- Greater Muscat Structure Plan (GMSP) (MoHUP & MIC-HUB, 2022), which provides metropolitan-scale strategies for transport corridors, transit-oriented development, and human-scale streets.
- Oman Road Design Manual and Standard Specifications for Road and Bridge Construction (MTCIT, 2019), which currently governs design standards for road classifications, cross-sections, and technical specifications. The analysis compared these policy frameworks to international standards (AASHTO, 2018; DMRB, 2020) and identified critical gaps—particularly in integrating micro-mobility, shading, and pedestrian-first ROW reallocations.

Literature Synthesis

An extensive literature review was conducted to contextualize Oman's challenges within global debates. Sources included:

- Urban humanization & livability: Gehl (2010), Newman & Kenworthy (2015).
- Climate-responsive urban design: Santamouris (2016), Middel *et al.* (2016), Alharthi *et al.* (2025), Al-Hajri *et al.* (2025).
- Transport accessibility & last-mile issues: Curtis & Scheurer (2017), Litman (2021), Shaheen & Cohen (2020).
- Road engineering practices: AASHTO (2018), DMRB (2020), MTCIT (2019).
- Gulf-specific critiques: Al-Kindi (2021), Al-Rawas & Khan (2019), Shaaban & Muley (2018).

The synthesis highlighted key transferable lessons (e.g., multimodal integration, shading strategies, micro-mobility adoption) and revealed unique Gulf constraints (extreme climate, cultural car dependency, fragmented governance).

Conceptual Framework Development

Building on the emerging concept outlined in Section 1.8, and informed by the literature synthesis and policy analysis, the Integrated Humanization (IH) framework was developed to function as a system of mutually reinforcing domains. Instead of presenting road engineering, public transport, or micro-mobility in isolation, IH integrates them into one adaptive framework.

The contribution here is not only the identification of five domains—urban planning, urban humanization, public transport, road engineering, and micro-mobility—but the recognition of synergy between them. For example:

- Public transport requires micro-mobility for last-mile access.
- Micro-mobility thrives only when shaded, humanized urban design is present.
- Road engineering must shift from capacity-focused standards toward ROW redistribution that supports these links.

Thus, IH is framed not as a checklist of interventions but as a systems paradigm that ensures each domain amplifies the effectiveness of the others. This systemic approach

provides the theoretical bridge between Oman’s strategic visions (Vision 2040, GMSP) and the practical design shifts outlined later in this paper.

Case-Based Reasoning: Muscat as a Laboratory

Muscat was chosen as the case city for applying IH due to:

- Its scale and ambition (1,360 km² metropolitan area with metro/BRT proposals).
- Its pressing challenges: rapid car dependency, urban sprawl, and weak pedestrian infrastructure.
- Its policy readiness: both Vision 2040 and the GMSP explicitly endorse integrated mobility and livability goals. By situating IH within Muscat, the research translates abstract concepts into tangible interventions, such as lane narrowing, shaded pedestrian corridors, micro-mobility hubs, and integrated ticketing systems.

Research Validity and Rigor

To ensure rigor, the study triangulates across three domains:

- Policy documents (Vision 2040, ONSS, GMSP, Oman Road Design Manual).
- Peer-reviewed literature (climate-responsive urbanism, transport integration, micro-mobility adoption).
- International benchmarks (AASHTO, DMRB, WHO guidelines).

This triangulation provides internal validity (consistency across sources) and external validity (comparability to international best practices).

Limitations

As a conceptual and policy-oriented paper, this study has several limitations:

- It does not provide quantitative simulations such as traffic flow models, heat index measurements, or economic cost–benefit analyses.
- The proposed pilot project is hypothetical and requires future empirical testing to validate its assumptions.
- Cultural adaptation of micro-mobility remains uncertain until tested in real-world Gulf neighborhoods,

where entrenched car dependency may resist behavioral change.

- The framework focuses primarily on Muscat as a case study, which may limit generalizability to other Gulf cities without contextual adaptation.

These limitations do not undermine the value of the research but highlight areas for future work, such as empirical pilots, quantitative modeling, and behavioral studies that test Integrated Humanization under real urban conditions.

RESULTS AND DISCUSSION

Comparative Overview of Road Engineering Standards and the Integrated Humanization (IH) Framework

To contextualize the proposed framework of Integrated Humanization (IH), it is important to compare existing road engineering standards applied in Oman with the international benchmarks that have historically influenced them. While AASHTO (2018) and the UK’s DMRB (2020) emphasize vehicular efficiency, throughput, and safety, Oman’s Road Design Manual and Standard Specifications for Road and Bridge Construction (MTCIT, 2019) attempts to localize these principles by introducing a five-tier classification system. However, this manual still inherits much of the car-centric orientation of its source models.

The proposed Integrated Humanization framework moves beyond these paradigms by embedding climate adaptation, multi-modal safety, and livability at the core of design standards. Unlike imported codes, IH treats shaded walkways, thermal-comfort nodes, and micro-mobility corridors as essential engineering provisions rather than optional amenities. This positions IH as a systemic recalibration of Gulf road engineering, transforming ROW allocations from purely vehicular channels into balanced, human-centered mobility corridors. Table 2 summarizes this shift by contrasting AASHTO and DMRB with Oman’s current manual and the proposed IH code.

Table 2: Comparative Overview of Road Engineering Standards and Integrated Humanization (IH) Framework

Dimension	AASHTO (2018)	DMRB (2020)	Oman Road Design Manual & Standard Specifications (MTCIT, 2019)	Integrated Humanization (Proposed)
Design Orientation	Vehicular mobility, capacity, flow efficiency	Safety, network hierarchy, traffic throughput	Local adaptation of international codes with five road classifications	Human-centered, climate-responsive, multi-modal
Lane Width Standards	Standard 3.65 m for most classifications	Similar to AASHTO, with minor context-based variations	3.65 m for arterial, reduced widths for local/service roads	Reduction to ~3.0 m in local/collector roads to free ROW for micro-mobility and pedestrians

Climate Adaptation	Limited (assumes temperate climates)	Minimal attention to hot-arid conditions	Partial: some provisions for shading and landscaping	Central: shaded walkways, thermal comfort nodes, photovoltaic canopies
Pedestrian & Public Realm	Secondary to vehicle throughput	Safety-focused but limited pedestrian integration	Recognizes walkways but lacks systemic emphasis	Core priority: shaded sidewalks, plazas, greenery, inclusivity
Public Transport Integration	Considered in highway-urban interfaces	Supports transit corridors but not systematically embedded	Reference to transit connections in GMSP but not a design driver	Explicit integration with BRT/Metro, ROW allocation for feeders
Micro-Mobility	Not addressed	Not addressed	Absent in technical codes	Protected 2.0 m micro-mobility lanes (scooters, e-bikes, buggies)
Right-of-Way (ROW) Management	Primarily vehicle allocation	Hierarchical network design	Vehicle-dominant with some pedestrian allocation	Balanced ROW: vehicles, transit, pedestrians, micro-mobility, greenery
Cultural/Regional Fit	US/Europe car-oriented context	UK/Europe safety and flow context	Adapted but still imports global templates	Designed for Gulf climate, culture, and Vision 2040 goals

The comparative overview in Table 2 highlights a fundamental gap between existing engineering manuals and the requirements of climate-adaptive, people-centered design. While AASHTO and the DMRB emphasize vehicular efficiency, and Oman’s 2019 Road Design Manual introduces localized classifications, none of these frameworks fully account for the composite needs of Gulf cities—namely thermal resilience, last-mile micro-mobility, and integrated public transport access. The Greater Muscat Structure Plan moves further by embedding shading and multi-modal priorities, yet it remains a high-level planning tool rather than a binding engineering code.

This underscores why Integrated Humanization (IH) is not merely an add-on to existing standards but a systemic recalibration: it treats shading, micro-mobility, and public transport readiness as engineering requirements, not optional amenities. By positioning human comfort and climate adaptation alongside traffic flow and safety, IH closes the operational gap between vision documents and street-level implementation. In doing so, it transforms road engineering from a discipline of vehicle throughput into one of multi-modal, climate-responsive, and socially inclusive mobility—a shift that Oman’s future infrastructure projects cannot achieve through legacy standards alone.

Operationalizing Integrated Humanization (IH) for Omani Road Engineering

Having established the conceptual rationale for IH (Sections 1.8–1.9), this section translates the framework into enforceable design specifications aligned with Oman’s five road classes and the targets of Vision 2040 and the Greater Muscat Structure Plan (GMSP). The goal is to move from vision to curb-level criteria that can be embedded alongside the Oman Road Design

Manual and Standard Specifications for Road and Bridge Construction (MTCIT, 2019).

Core Operational Dimensions

(A) Speed & Lanes: Target ≤40 km/h on local/collector streets; reduce vehicle lane width to ≈3.0 m where appropriate; add friction elements (tight curb radii, raised crossings) to enforce operating speeds.

(B) Protected Micromobility: Provide a continuous 2.0 m protected lane for e-scooters/e-bikes/buggies, with intersection continuity, conflict-free crossings, and dedicated parking/charging at neighborhood mobility hubs.

(C) Thermal-Comfort Package: Hybrid shade combining clustered trees (species and spacing per irrigation context) and permeable canopies/arcades; shaded segments every 25–40 m and rest nodes every 250–300 m; cool/reflective & permeable pavements for sidewalks and micro-lanes.

(D) Transit Integration: Define each street’s feeder role to BRT/Metro; co-locate hubs with stops/stations; enable fare bundling (micro + bus/metro) and real-time information; minimize walk/ride exposure time in peak heat.

(E) Safety & Equity. Daylighting at intersections, protected junction treatments, tactile wayfinding, and gender-/age-inclusive design.

(F) ROW Redistribution: Reallocate existing right-of-way from purely vehicular space toward shaded sidewalks and protected micromobility; prioritize curb management (loading, micromobility corrals) over excess travel lanes.

(G) Intersection & Crossing Treatments: Reduce turning radii; provide marked, priority crossings for neighborhood EVs/buggies designed for 25–35 km/h; ensure sight triangles via setback planting.

(H) Transit-Ready Street Design: Embed BRT/metro feeder functions into every class: local streets connect to

neighborhood hubs; arterials incorporate dedicated bus lanes and enhanced stops.

(I) **Materials & Surfaces:** Adopt cool pavements and permeable surfaces to reduce heat absorption and improve drainage; use reflective coatings on sidewalks/micro-lanes; consider photovoltaic structures for shade + power.

(J) **Monitoring & KPIs:** Track mode shift (<3 km), Tmrt reduction, access within 8–10 minutes to high-frequency transit, 85th-percentile speeds, and equity uptake, as specified for the pilot (Section 1.25).

Implementation note. These provisions intentionally avoid repeating the five-pillar concept; they apply it as specifications and street-scale standards to be encoded with MTCIT (2019) details and GMSP cross-sections.

Wadi-Aligned Blue–Green Corridors

In Muscat’s hydro-morphology, wadis constitute latent linear spines that can simultaneously host flood conveyance, shade infrastructure, and low-speed micro-mobility. Where right-of-way is constrained, parallel wadi easements can accommodate 2.0 m protected micro-mobility lanes, clustered native tree belts (with episodic irrigation), and permeable/cool pavements that both lower Tmrt and preserve infiltration. Coupled with photovoltaic canopies at crossings and hub nodes, wadi-aligned corridors deliver triple value: drainage safety, thermal comfort, and last-mile access. This dovetails with the GMSP’s green–blue ambitions.

In practice, wadi-aligned alignments complement the 1.17 toolkit, unlocking shaded, low-speed spines where conventional ROW is constrained and strengthening network continuity across flood-sensitive areas.

Design note: at arterial crossings, use raised, daylighted

sections and setback planting to protect flood pathways while maintaining micro-mobility continuity.

Why Integration Matters

Treating these domains separately has historically led to fragmented outcomes:

- Urban planning without transport integration reinforces sprawl.
- Public transport without micro-mobility fails to solve the last-mile problem.
- Road engineering without humanization produces unsafe, heat-exposed streets.
- Humanization without planning remains symbolic.

IH addresses these failures by creating a holistic ecosystem, where improvements in one domain reinforce the others. This aligns directly with Oman Vision 2040 and the Greater Muscat Structure Plan (GMSP), both of which emphasize integrated mobility, livability, and climate responsiveness.

Engineering Shifts Under IH

While previous sections highlighted the need to embed IH principles within Oman’s five existing road classifications, this section focuses on the engineering-level transformations required to operationalize the framework. Unlike imported standards such as AASHTO (2018) or DMRB (2020), which prioritize throughput and design speed, the IH approach reconceptualizes engineering design to balance efficiency, comfort, and inclusivity.

The key transformations are summarized in Table 3, which illustrates how traditional road engineering elements evolve under the IH framework and the outcomes expected from these changes.

Table 3: Key Engineering Shifts Under Integrated Humanization Framework

Traditional Road Engineering (Imported Standards)	Integrated Humanization (Proposed Gulf Framework)	Expected Outcomes
Lane width fixed at 3.65 m	Lane width reduced to 3.0 m, ROW redistributed	More space for micro-mobility + traffic calming
Focus on vehicle throughput & speed	Multi-modal priority: pedestrians, micro-mobility, transit	Reduced car dependency + improved safety
Minimal shading, heat-blind design	Hybrid shading: trees + permeable canopies	Better thermal comfort + livability
Roads as transport conduits only	Roads as multifunctional public spaces	Social inclusion + healthier communities
Disconnected from public transport	Feeder role to BRT/metro integrated in ROW design	Increased viability of mass transit

Linking Engineering Shifts to Policy

These engineering transformations are not isolated technical adjustments but represent policy-relevant innovations. Narrowing lanes to 3.0 m, integrating micro-mobility corridors, and embedding hybrid shading strategies all resonate with the National Planning Standards (MoHUP, 2021) and the sustainability principles of Oman Vision 2040 (2020). By adopting these changes, Muscat can

create a road network that supports sustainable mobility, equitable access, and climate adaptation simultaneously.

Impacts of IH on Urban Systems

The proposed engineering and design shifts under Integrated Humanization extend beyond road geometry—they reshape the entire urban system. Their impacts can be categorized across three interlinked domains:

Urban Climate (Thermal Comfort)

Hybrid shading (trees, canopies, arcades) combined with reflective and permeable pavements reduces surface temperatures and improves outdoor thermal comfort (Santamouris, 2016; Middel *et al.*, 2016). This adaptation is essential for Gulf cities, where radiant heat is the most significant barrier to walkability and non-car mobility.

Public Transport (BRT/Metro Viability)

The success of Muscat's proposed metro and BRT depends on first/last-mile access. Without IH, these systems risk being underutilized. Shaded micro-mobility corridors and neighborhood-scale retrofits provide a practical solution to link homes and workplaces to stations (Curtis & Scheurer, 2017; MIC-HUB, 2022).

Public Health

Encouraging short trips by walking, scooters, and bicycles integrates physical activity into daily routines. This reduces sedentary lifestyles, lowers obesity rates, and mitigates diseases associated with inactivity (WHO, 2020).

Pilot Project as Proof-of-Concept

To operationalize IH, a 12-month pilot project in a Muscat neighborhood is proposed. This pilot reduces financial and political risks while producing measurable data to validate the framework.

Scope of the Pilot Project:

- Conversion of 1.5–2.0 km of residential streets with narrowed lanes (3.0 m) and protected 2.0 m micro-mobility corridors.
- Hybrid shading package: clustered trees and permeable canopies, with shaded rest stops every 250–300 m.
- Deployment of 30–50 shared e-scooters/e-bikes and 10–15 neighborhood electric buggies, integrated with bus and metro fares.
- Establishment of a local mobility hub providing charging, parking, and seamless ticketing.

Key Performance Indicators (KPIs)

- Mode shift: percentage of short trips (<3 km) shifted from cars to micro-mobility.
- Thermal comfort: reductions in mean radiant temperature (T_{mrt}) along pilot routes.
- Accessibility: percentage of households within 8–10 minutes of a high-frequency bus or metro stop.
- Equity: participation rates among women, youth, and older adults.

Governance

The pilot must align with Oman's National Planning Standards (MoHUP, 2021) and be incorporated into the program architecture of Oman Vision 2040, ensuring scalability and institutional embedding.

Costs, Co-Benefits, and Risks

Costs

The largest cost component is shading infrastructure

(trees, canopies, photovoltaic covers). Road narrowing and resurfacing are significantly cheaper than constructing grade-separated transit systems. Micro-mobility fleet operations remain modest relative to bus services and can be concessioned to private operators.

Co-Benefits

- Improved air quality and reduced urban heat island effect.
- Lower household transport costs through reduced car dependency.
- Activation of the public realm, encouraging social interaction and inclusivity.

Risks & Mitigation

- Sidewalk clutter and conflicts: risk of scooters or buggies encroaching on pedestrian zones → mitigated by dedicated parking corrals, fleet caps, and geofencing.
- Tokenistic shading: insufficient shading could undermine thermal performance → mitigated by micro-climate simulation and evidence-based shading design (Hamdan & Oliveira, 2019; Middel *et al.*, 2016).

The pilot, cost structure, co-benefits, and risk mitigations together provide a low-regret pathway to mainstream IH within Muscat's street program—setting the stage for the concluding implications.

CONCLUSION

This study argues that road engineering in Muscat—and Gulf cities more broadly—must undergo a paradigm shift. Imported frameworks such as AASHTO (2018) and DMRB (2020) prioritize vehicular flow and speed but neglect the region's climate, cultural, and sustainability needs. By contrast, Integrated Humanization (IH) offers a Gulf-specific framework unifying five dimensions: urban planning, humanization, public transport, road engineering, and micro-mobility.

IH reclassifies Oman's road categories to redistribute right-of-way, balancing vehicles with shaded pedestrian networks, thermal comfort, and last-mile micro-mobility. It embeds climate-resilient design—hybrid shading, reflective pavements, narrow lanes—that directly address Muscat's heat and livability challenges.

Far from abstract, IH operationalizes policy imperatives in Oman Vision 2040 and the Greater Muscat Structure Plan, translating them into curb-level interventions. The proposed pilot project demonstrates a risk-managed path by testing lane narrowing, shaded corridors, micro-mobility fleets, and integration with BRT/metro stations. These pilots generate evidence on mode shift, comfort, safety, and equity—building trust and ensuring metro/BRT investments succeed.

Ultimately, the study concludes that Muscat's road engineering must evolve from being vehicle-centric to becoming human-centric and climate-adapted. Integrated Humanization offers a “Gulf grammar” for sustainable streets: one that shortens trips, shades the public realm, integrates micro-mobility, and supports public transport.

If adopted, it will not only improve livability and reduce carbon emissions but also position Oman as a regional leader in defining climate-responsive urbanism for arid regions.

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