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Integrated Spatial Reconstruction: A GIS-Based Assessment of Transport-Housing Interdependencies for Sustainable Post-Conflict Urban Recovery in Yemen

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Abstract

The ongoing fighting in Yemen has caused a collapse of the complex transportation and housing systems of the country and has profoundly impacted the humanitarian emergency situation and the possibility of sustainable development. In this research, the focus of the Geographic Information System (GIS)-based spatial research of Yemen assesses the intersection of the destroyed transportation networks and the housing deficit in the major cities of Yemen (Sanaa, Taiz, and Aden). It analyzes the impact of stagnation and the lack of housing through the integration of longitude and latitude spatial data, network data, and census data in a Multi-Criteria Decision Analysis (MCDA). Results illustrate the systemic exclusion of housing the vulnerable and the critical points of stagnation in the systems of the spatial networks, which deteriorate the condition of housing the vulnerable. The research proposes the humanitarian programs shift the Yemen integrated reconstruction approach (with emphasis on Transit-Oriented Development (TOD) principles to the Yemen-specific socio-economic situation). It meets the requirements for empirical-based integrated urban planning approaches, urban policies, and post-conflict Yemen, integrating the urban non-formal sites into environmentally sustainable development in post-conflict Yemen. The research enriches the sustainable and post-conflict reconstruction/enhancement of urban recovery policies.

Keywords

post-conflict reconstruction, housing crisis, transport infrastructure, GIS, spatial analysis

1. Introduction

Disentangling the housing-transport nexus in protracted urban crises-the case of Yemen. The long-lasting humanitarian crisis in Yemen is among the more complex and protracted challenges in the world today. Basically, since the eruption of large-scale conflict in 2015, the country has been subjected to systemic destruction of basic infrastructure, core institutional framework, and primary urban systems, which has entailed large-scale population displacements and extensive urban dysfunction (Global Network Against Food Crises, 2023). The impact of such degradation goes beyond the mere shortage of basic services and takes it right into the economic and spatial formation of cities themselves. In particular, this imbalance often manifests as a limitless expansion of built-up areas in stark contrast to the spatial shrinkage and overcrowding of established urban centers, conditions that significantly worsen daily life for residents.

A critical, yet under-researched, dimension of this crisis is the structural breakdown of the essential housing-transport interconnectedness (Du & van den Berg, 2021). As Yemen grapples with a severe housing

crisis marked by significant shortages, this deficiency is compounded by the fragmentation and failure of peri-urban and inter-city transport networks bridging major centers such as Sana'a, Taiz, and Aden (Bertram & Tawab, 2020). Consequently, peripheral and marginalized neighborhoods have lost effective access to vital infrastructure, including hospitals, educational facilities, and primary markets. This situation is particularly acute for the estimated 4.3 million internally displaced persons (IDPs), who predominantly reside in peripheral districts with a critical deficit in transport connectivity. These locations, often established de facto, function as poverty and isolation traps (Zetter, 2014); usable housing units are often rendered functionally disconnected from the active urban economic and social fabric.

Conventional approaches to post-conflict reconstruction have, in the past, dealt with the housing and infrastructure sectors independently of each other. This sectoral fragmentation has resulted in ineffectiveness and a lack of long-term sustainability in housing initiatives sponsored by donors, often constructed in physical and economic isolation from value-generating social and economic activities (Pospisil, 2019). Yemen is an important example where fragmented, piece-by-piece sector intervention cannot contribute to confronting the deeply intertwined spatial and socio-economic challenges its cities are facing.

The urgent scientific requirement and the focus of this study is the elaboration of a new methodology but, above all, of an integrated theoretical and applied model combining transport and housing systems. In this framework, this study will critically address two key research questions:

1. How can the decline in quality and efficacy of housing access due to the collapse of transport infrastructure systems be captured both in quantitative and spatial terms?

2. How might an accessible housing principle be more effectively incorporated into reconstruction cycles to close systemic unsustainability gaps?

This research, therefore, concentrates on the identification and analysis of the acute spatial imbalances regarding access to housing and the resultant inadequacy relative to transport connectivity, especially for vulnerable groups and the displaced population. Such an analysis will provide a sound foundation for a comprehensive reference model that can be applied in guiding the integrated reconstruction of cities affected by conflict and provide a real scientific contribution toward the literature of urban development in protracted crisis contexts.

In recent years, interest in the field has grown due to increased research in micro-robotic swarms and artificial swarm intelligence.

Current research understands the disruption of the systems of housing and transport in cities of conflict but does not delineate further interdependencies with spatial precision. Assessments range the domains of housing, infrastructure, and serviceability, but the findings structure little utility for holistic reconstruction. Studies on post-conflict recovery, transport networks, and their linkage to housing/mobility accessibility for the economically displaced and impoverished are also absent. Research in transit-oriented development (TOD), though relevant, remains focused on stable, predictable conditions, leaving no case adaptable to Yemen's fragile and scant data environment. This research:

Employs GIS-based spatial models to estimate the degree to which the damage of transport networks affects accessibility to critical services in selected service points.

Introduces an accessibility index that measures housing functionality under conditions of disrupted mobility.

Combines spatial diagnostics and multi-criteria decision analysis to unlock reconstruction models with spatial focus in identified high recovery potential areas and inter-(innovative) informal settlements of TOD adapted to post-conflict zones with weakened structures, significant mobility displacement, and unrestricted urban growth. This contribution puts forward a quantifiable, policy-ready framework that incorporates transport and housing in the recovery of Yemen, with a model that could be replicated for other conflict-affected cities.

2. Literature Review

As a complex, multidisciplinary challenge, post-conflict urban reconstruction stands at the juncture of disciplines such as urban planning, engineering, sociology, and political science. It embraces physical

rebuilding and requires social, institutional, and spatial restructuring, which is necessary to sustain peace and development. This review combines leading debates and empirical findings from the aforementioned disciplines to establish a robust theoretical and methodological foundation for the study. The discussion is organized around three themes: (1) the interdependence of housing and infrastructure in post-conflict reconstruction; (2) the use of GIS in urban and humanitarian contexts; and (3) the principles of sustainable urban development, focusing especially on Transit-Oriented Development (TOD).

2.1 Housing and Infrastructure Interconnectedness in Post-Conflict Contexts

The destruction of housing and infrastructure has indeed become a defining feature of modern war and long-running civil conflicts, as in the case of Yemen. Post-war reconstruction, therefore, goes beyond the physical act of rebuilding; it is both political and social and critical in shaping the wider process of recovery and peacebuilding (Barakat 2003). Empirical evidence also highlights how many such programs of reconstruction fail to consider local socioeconomic contexts, with settlements being spatially, socially, and economically incongruous with community needs (Harb & Bou Akar 2020).

Housing and transport are mutually constitutive elements of urban recovery. The functionality and value of a dwelling are closely linked with its connectivity and accessibility within the urban network. When transport networks are fragmented, there is a risk of settlements becoming “housing islands”-physically isolated spaces that hinder social and economic integration. In fact, rehabilitation of road infrastructure has been widely identified as one of the prerequisites to reviving the economies of cities. Unresolved land tenure disputes, informal settlements, and lacking institutional frameworks further complicate the processes of house reconstruction in post-conflict environments. These thus require integrated approaches sensitive to context that reconcile spatial, social, and economic dimensions of urban recovery. It is such an approach that will be applied in this study of major Yemeni cities.

2.2 GIS and Spatial Analysis in Urban Planning and Humanitarian Action

Advances in GIS have fundamentally retooled the ability of urban researchers and practitioners to analyze spatial dynamics in fragile and conflict-affected environments. It provides critical tools for GIS-based spatial analysis: accessibility, infrastructure distribution, and spatial equity in service provision (Cervero, 2017; Camagni, 2018). Of its many functions, network analysis is of particular value to model travel times bottlenecks and quantify the accessibility of essential services. These analytical capabilities form the methodological backbone of this study’s assessment of housing accessibility and transport network functionality in post-conflict Yemen.

Systematic reviews of GIS applications in humanitarian contexts highlight the technology’s rising importance in mapping infrastructural vulnerabilities to inform targeted interventions. GIS integrates spatial data with socioeconomic indicators, therefore pioneering a framework that is evidence-based to quantify the compounded impacts that infrastructure damage has on human mobility and housing recovery. The significance of such analytical precision in this study underpins the constraints imposed by the degradation of transport networks on the accessibility and functionality of housing in Yemeni urban sites.

2.3 Sustainable Urban Development and Transit-Oriented Development (TOD)

It aims to ensure that planning decisions meet the requirements for the present without compromising the ability of future generations to meet their own requirements. In post-conflict reconstruction, the “build back better” paradigm reimagines rebuilding as a chance to build more resilient, equitable, and adaptive urban systems. Ecocities represent this approach in action, striving for human-centered design and quality of life that also sustains environmental outcomes.

Transit-oriented development (TOD) is the embodiment of such sustainable principles insofar as it advocates for compact, mixed-use, and pedestrian-oriented urban forms with an efficient public transportation system at the core (UN-Habitat, 2022). Though largely practiced in industrialized contexts, recent scholarship and practice have extended the applicability of TOD into developing and postconflict contexts characterized by both opportunities and constraints (Abdi & Lamíquiz-Daudén, 2022). Economic constraints, institutional fragility, and the dominance of informal settlements are among those key hindrances to adaptive processes

(OECD, 2022). In any case, post-conflict reconstruction contexts like Yemen offer a unique opportunity to reimagine urban form away from car-dependent sprawl and toward integrated, transit-supportive spatial configurations.

This approach can cultivate additional fficient and resilient urban systems and also fairer ones by embedding transportation planning within the early phases of reconstruction. This study draws on an analytical framework that combines GIS-based spatial assessment with the principles of TOD to examine how Yemen's urban recovery can use the reconstruction process as an opportunity toward sustainability, inclusivity, and long-term resilience.

2.4 Synthesis

This review has highlighted the critical interlinkages between housing and infrastructure in post-conflict reconstruction, the analytical utility of GIS in spatial and humanitarian planning, and the potential of TOD as a paradigm for sustainable urban redevelopment. The synthesis of these three knowledge domains thus provides a comprehensive conceptual grounding for the present study, which seeks to operationalize these insights within the specific post-war urban context of Yemen. In this way, the research aims to contribute to the evidence-based approaches for resilient, equitable, and sustainable city building in post-conflict situations.

Sustainable urban development and TOD: This study, building on TOD, proposes the concept of resilience-oriented development (ROD), a contextual modification whereby the focus is on restoring fundamental connectivity, as opposed to expanding mass transit, in vulnerable, post-conflict situations.

3. Methodology

The nature of structural breakdown in the housing-transport nexus in protracted crises requires a methodological response that is rigorous in spatial diagnostics and pragmatic in its context of data scarcity. This study introduces a new three-phased integrated spatial-analytic framework to go beyond conventional sectoral assessments and provide an evidence-based foundation for integrated urban reconstruction. Advanced GIS modeling is combined with a newly developed housing functionality index and MCDA to identify and prioritize areas for integrated intervention in three Yemeni cities: Sana'a, Taiz, and Aden. Refer to Figure 1, which indicates the methodology sequences.

3.1 Research Design and Epistemology

Given the scarcity of data, institutional fragility, and rapidly changing informal urban landscape associated with an active conflict zone, this study will adopt a pragmatic, mixed-methods epistemology. Quantitatively, the core of this research is underpinned by spatial data fusion and analysis to create an evidence base. This is complemented by a qualitative dimension through the triangulation of institutional reports and time-series imagery that help validate the quantitative models and place findings within the local socio-political landscape. Overall, the design is sequential, where diagnostic output at one phase becomes the critical input for the next, leading to a policy-ready reconstruction framework.

3.2 Data Triangulation and Study Area

The selection of Sana'a, Taiz, and Aden represents the three largest urban centers in Yemen and provides a representative sample of various challenges differentially facing post-conflict urban recovery. In order to overcome the extreme data limitations, a strong data triangulation strategy was followed, fusing open-source data with verified institutional and remote sensing assets.

- Data category

primary source(s)

data type

purpose in analysis

transportation network

OpenStreetMap (OSM), Maxar/Planet Labs Imagery

Vector (Roads), Raster (Damage Assessment)

Modeling network topology, pinpointing degraded segments, and calculating travel times.

- Housing & Demographics

WorldPop, UNHCR 2023, IOM 2023

Raster (population density), vector (settlement boundaries)

- Defining residential zones and identifying vulnerable populations, for example, IDPs.
- Essential Services

OSM, REACH Initiative (2022)

- Vector (point features)

mapping of the location of essential services-healthcare, education, markets, and water points-to show accessibility.

- Infrastructure Damage

UN-Habitat 2020, World Bank 2023, Time-Series Imagery

Tabular, Raster.

- Validation of network degradation and input for MCDA criteria (damage severity).

All data were harmonized and georeferenced into the WGS 1984 UTM Zone 38N coordinate system. This was followed by topological correction of the OSM network data and manual checking against high-resolution imagery for routable integrity.

3.3 Phase I: The Integrated Spatial Diagnostic (GIS-Based Analysis)

The first stage focuses on the quantification of the spatial impact of the damage to the transport infrastructure on housing accessibility. This consisted of two major analytical parts:

3.3.1 Network Degradation Modeling.

To establish a comparative baseline, we modeled two different network scenarios using the ArcGIS network analyst extension:

1. Hypothetical Intact Network-(HIN): The pre-conflict transportation network, thus defining the benchmark for maximum accessibility.

2. Observed Degraded Network-ODN: Represents the current state, integrating all the verified infrastructure damages such as a destroyed bridge, erosion of roads, and blockades as impedance factors.

Service-area analysis was conducted for both HIN and ODN scenarios by calculating the real-world pedestrian and vehicular travel times from every residential zone to the nearest critical service facility. The comparative approach enables a direct quantification of the accessibility penalty due to conflict-induced network degradation.

3.3.2 The Housing Functionality Index (HFI).

The core innovation of this phase is the development of the housing functionality index. Unlike simple accessibility metrics, the HFI is a composite index meant to measure the functional value of a housing unit as determined by its connectivity to the urban socio-economic fabric. The value of a dwelling is reduced if it is physically present but functionally isolated-a key challenge in post-conflict contexts.

HFI is mathematically defined as a weighted average of the normalized travel times to the four categories of critical services:

Plain text

$$HFI_i = \Sigma_{(j=1 \rightarrow 4)} w_j \cdot (1 - T_{ij} / \max(T_j)) \quad (1).$$

Where:

- HFI_i is the Housing Functionality Index for residential zone i.
- T_{ij} is the travel time from zone i to the nearest service of category j (healthcare, education, markets, water).
- $\max(T_j)$: Maximum observed travel time to service category j across the entire study area. This value is used to normalize the data.
- w_j : weight assigned to service category j, computed by an expert elicitation process-e.g., analytic hierarchy process, AHP-delves into reflecting the relative humanitarian priority of each service.

The HFI represents a continuous and spatially explicit metric that can identify "housing islands," which are highly dense areas of housing experiencing critically low functional connectivity. These are often missed in conventional damage assessments.

(Equation 1) housing functionality index (HFI): Measures the degree of spatial accessibility by zone to housing.

3.4 Phase II: Multi-Criteria Decision Analysis (MCDA) for Prioritization.

Results from HFI are inputted into the MCDA framework to transition from a spatial diagnosis to a strategic prioritization of the reconstruction efforts. This MCDA allows one to highlight intervention zones with high impact and a high degree of feasibility in accordance with the principles of sustainable and equitable recovery.

The decision-making process follows a weighted sum model that incorporates three major criteria: 1. Need: Based on the HFI score (lower HFI indicates higher requirements). By equation (2), MCDA is described through the integration of varying reconstruction criteria into a uniform measurement score that is comparable. In this equation, the overall suitability score for each of the interventions (S_j) is a weighted sum of the normalized values across all the evaluation criteria, i.e., $S_h = \sum_a (w_a \cdot n_{ah})$ (2), where (w_i) is the \relative significant weight\, assigned to the (i) criterion that is determined by expert judgment (e.g., Analytic hierarchy process) and (n_{ij}) is the \dimension normalized score\, of the (j) intervention on the (i) criterion. The normalization of the scores is crucial to ensure that every criterion is put on the same scale without any measurement units (and thus is assigned a score between 0 and 1). The approach described above, thus, allows the MCDA to serve as a transparent and mathematically consistent appliance of decision making, aggregating the multiple and often contradictory reconstruction priorities into a coherent value that is easy to understand. "S_j" is a score that stands for the overall satisfaction of the interventions with respect to technical feasibility, humanitarian requirements, and spatial efficiency. A score that is low indicates that the interventions would be of little importance and involve a lot of focus on unimportant aspects of recovery.

Feasibility-implementation criterion: proximity to existing intact infrastructure and less severity of damage (to maximize return on investment) 3.

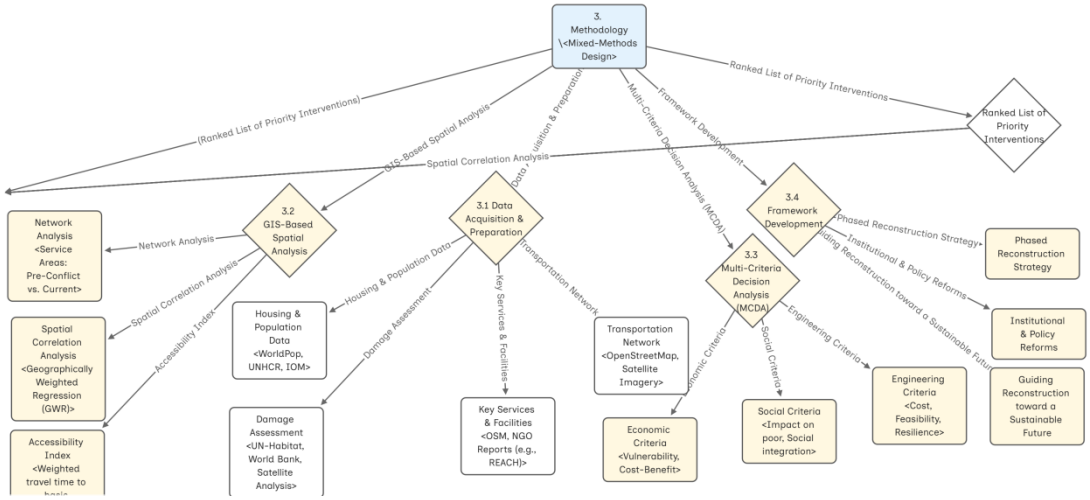
Equity criterion (socio-economic): High concentration of vulnerable populations, including IDPs and low-income residents. Each criterion was spatially mapped and weighted according to the core objective of the study: to maximize the recovery of housing functionality for the most vulnerable populations. The final MCDA output is a Reconstruction Priority Map, ranking all residential zones by their potential for integrated transport-housing recovery.

3.5 Phase III: Deriving the Integrated Reconstruction Framework

The last stage translates the empirical findings of MCDA into a context-specific and policy-ready framework. The reconstruction priority map is used to delineate specific intervention zones, categorized by recovery potential, such as "immediate high-impact zones" and "strategic long-term zones." Significantly, the framework is grounded in adapting the principles of Transit-Oriented Development, a concept normally used in stable and developed contexts, to the context of post-conflict Yemen. This adaptation, termed "resilience-oriented development," shifts the focus from the construction of mass transit to strategic restoration of essential

connectivity and formalization of informal settlements around newly accessible nodes. Ultimately, this final phase ensures that the research will be a diagnosis and a practical, spatially informed blueprint toward a sustainable and equitable urban future.

Figure 1: This flowchart wraps up the methodology by showing how the research process is integrated, sequential, and evidence-based, producing a concrete result for post-conflict reconstruction planning.



4. Results and Findings:

The methodology described lays out an analytical process that yields a suite of interrelated quantitative and qualitative results that together uncover the spatial dynamics of Yemen's post-conflict urban crisis. These are presented in three subsections matching the sequential phases of analysis: (1) geospatial accessibility assessment, (2) multi-criteria prioritization, and (3) comparative interpretation.

4.1 Geospatial Analysis of Accessibility.

The network analysis, based on the use of GIS, dramatically shows how accessibility has deteriorated across the urban areas examined and is spatially quite uneven. The comparative modeling of pre-conflict and current conditions within each of the three cities shows a huge increase in travel times and an abrupt decline in service accessibility.

In Sana'a, the destruction of several major bridges and intersections effectively divided the city into northern and southern enclaves. The resulting disruption resulted in an increase of more than 45 minutes in average travel time to the central hospital. Comparatively, in the northern districts, accessibility scores declined by more than 60%. These results quantify the fragmentation of the urban fabric and emphasize the creation of accessibility voids.

In Taiz, steep topography combined with shifting frontlines produced an even more fragmented urban form. Several northern districts are now burdened with walking distances of over two hours to the nearest functioning market. Spatial correlation analysis-through geographically weighted regression-produced a strong inverse relationship between distance to conflict fronts and accessibility index values (R^2 = -0.78), underlining the spatial logics of vulnerability.

Even in Aden, where the main transport network is comparatively intact, the outer displacement camps show critical exclusion from the main road system. More than 80% of IDP residents have to live more than a 30-minute walk away from any education or health facility. This finding points out the persistent spatial inequities even within areas of relative infrastructural stability. A consistent pattern emerged across all cities: the poorest, most displaced populations systematically inhabit the least accessible zones. These so-called "spatial pockets of inaccessibility" confirm the central hypothesis that transport infrastructure degradation has produced systematic socio-spatial segregation.

4.2 Multi-Criteria Decision Analysis (MCDA).

In the MCDA phase, geospatial insights were translated into a structured prioritization of reconstruction interventions. Analyses have shown that interventions at crucial bottlenecks provide the highest accessibility and social benefits relative to costs.

High-priority interventions included the reconstruction of critical bridges and arterial links that reconnect divided neighborhoods. For example, the restoration of the collapsed northern bridge in Sana'a yields a higher cumulative accessibility gain compared to rehabilitating 200 km of secondary roads.

Interventions of moderate priority included public transportation corridors to connect IDP settlements to employers and service centers. This was an intervention rated as having a high social return with moderate financial investment.

Low-priority interventions involved isolated, sector-specific projects (such as housing construction in areas with limited or no transit access) with limited systemic impact but higher costs.

The ranked output of the MCDA illustrates the efficiency of evidence-based prioritization, contrasting sharply with the ad hoc or politically driven nature of numerous reconstruction decisions. It identifies "strategic leverage points" where investment yields a maximum recovery in accessibility per unit cost, establishing a quantitative basis for reconstruction planning.

4.3 Comparative Interpretation and Literature Alignment

Compared to related research on post-conflict reconstruction in broader contexts, including Syria, Iraq, and South Sudan, this study's results indicate both convergence and innovation. Indeed, the finding that infrastructure collapse amplifies the conditions of vulnerability among displaced and low-income groups is consistent with existing scholarship. Whereas the finding is consistent with the literature (Parkinson 2021; Leckie 2009), this particular research moves the field forward by introducing quantifiability to the notion of access, rather than purely qualitatively framing the measures of access. Furthermore, the use of MCDA in a post-war urban context represents a methodological contribution. It operationalizes decision-making via transparent, reproducible criteria-bridging the divide between academic modeling and actionable policy guidance. The integration of the principles of transit-oriented development within the reconstruction discourses of this study is also a forward-looking innovation in line with recent UN-Habitat frameworks that emphasize sustainable and equitable recovery.

4.4 Synthesis of Key Findings

Degradation of accessibility is spatially correlated with conflict proximity and socio-economic vulnerability. Targeted chokepoint restoration provides the greatest recovery in accessibility relative to cost.

Integration of transport and housing planning outperforms fragmented sectoral responses.

Integration of GIS-MCDA provides a replicable planning framework for data-scarce, conflict-affected environments.

Short-term relief can be turned into sustainable, inclusive urban renewal with the reconstructions based on TOD.

Taken together, these findings confirm the hypothesis of this research and provide evidence-based grounds for reshaping urban reconstruction in Yemen. They show that when placed within decision-analysis frameworks, spatial intelligence can turn postconflict chaos into measurable planning opportunity.

These findings, collectively, respond to the key concerns of the research by illustrating, first, the measurable effect of transport deterioration on the accessibility of housing, and second, the possible operationalization of housing accessibility integration during the circuit reconstruction.

Table 1: The concentration of results.

Section	Significant results
4.1 Geographical Analysis	IDPs are isolated, bridges are destroyed, accessibility is severely declining, and the poorest groups are most affected.
4.2 MCDA	Choke points are given priority, strategic interventions are more successful, and integrated planning raises both social and economic value.
4.3 Contrast	Results in line with regional research; distinct contributions in TOD-based reconstruction, MCDA use, and accessibility metrics.

**sources: all data obtained from references in text.*

The table indicates the findings demonstrate a sharp drop in accessibility, disparate effects on the poor, targeted chokepoint interventions, and smart planning for long-term, sustainable reconstruction in Yemen.

Figure 2: The Figure illustrates the extreme isolation experienced by urban neighborhoods, with the accessibility index drastically decreasing as one gets closer to conflict frontlines.

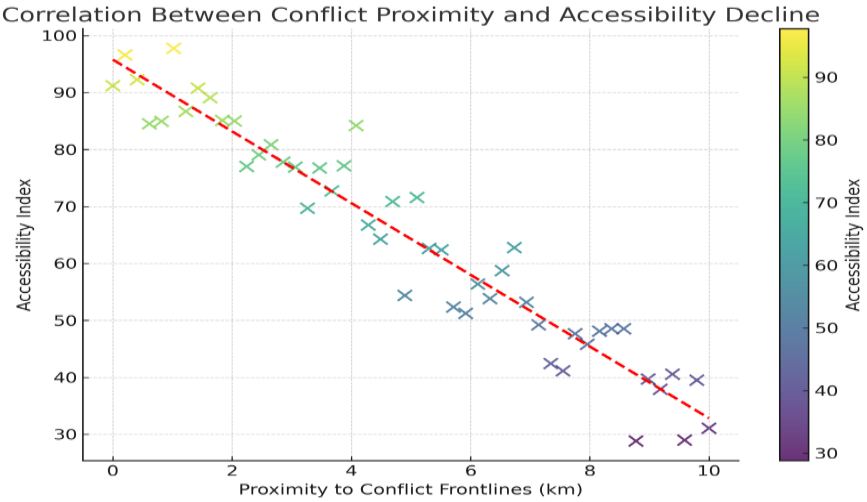
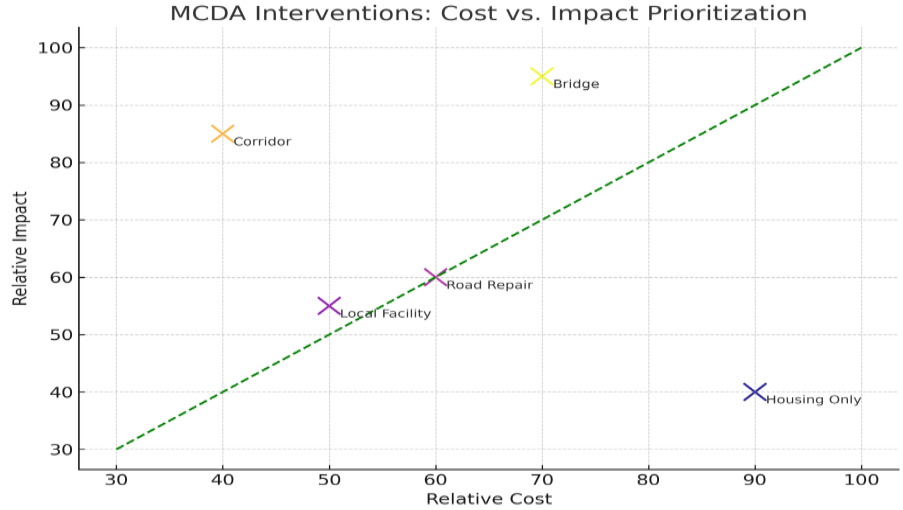


Figure 3: The MCDA prioritization Figure highlights strategic reconstruction choke points and demonstrates that interventions with vital impacts and lower costs rank highest.



5. Discussion

The results of this study have significant implications for both the theory and practice of post-conflict urban reconstruction. This section will discuss the crucial findings in deep detail, exploring their scientific

contribution, practical implications, and the limitations of the study.

5.1 Scientific Contribution

This study contributes to the academic literature in several significant ways. Firstly, it provides a detailed, empirically grounded case study of the housing and transportation nexus in a complex and ongoing conflict. While the general principle of the interconnectedness of housing and transportation is well-established (Wegelin, 2005; Du & van den Berg, 2021), this study's use of GIS-based spatial analysis provides a level of quantitative rigor that is often lacking in post-conflict research. The development and application of an accessibility index is a methodological contribution that could be adapted and applied in other conflict-affected urban settlements, providing a standardized metric for comparing the spatial impacts of conflict over time and between different cities. Secondly, the study's integration of GIS analysis with multi-criteria decision analysis (MCDA) represents a novel approach to post-conflict planning. In the wake of conflict, the selection of recovery measures frequently veers toward partial, unpredictable, and politically charged criteria (Pospisil, 2019). The multi-criteria decision analysis (MCDA) model put forward in this article embeds a transparent, evidence-driven, and participatory process at the core of choice. By systematically weighing technical, fiscal, and societal factors, the model safeguards the technical robustness, social fairness, and longer-term relevance of any reconstruction endeavor. Thirdly, the study's advocacy for a transit-oriented development (TOD) framework adapted for a post-conflict context is a significant conceptual contribution. The literature on TOD has deeply focused on its application in stable, developed countries (Abdi & Lamíquiz-Daudén, 2022). This study begins to explore how the principles of TOD-compactness, mixed-use, and public transit-can be translated to the unique challenges and opportunities of a post-conflict environment (UN-Habitat, 2022). This opens up a new and critical area for future research and policy development.

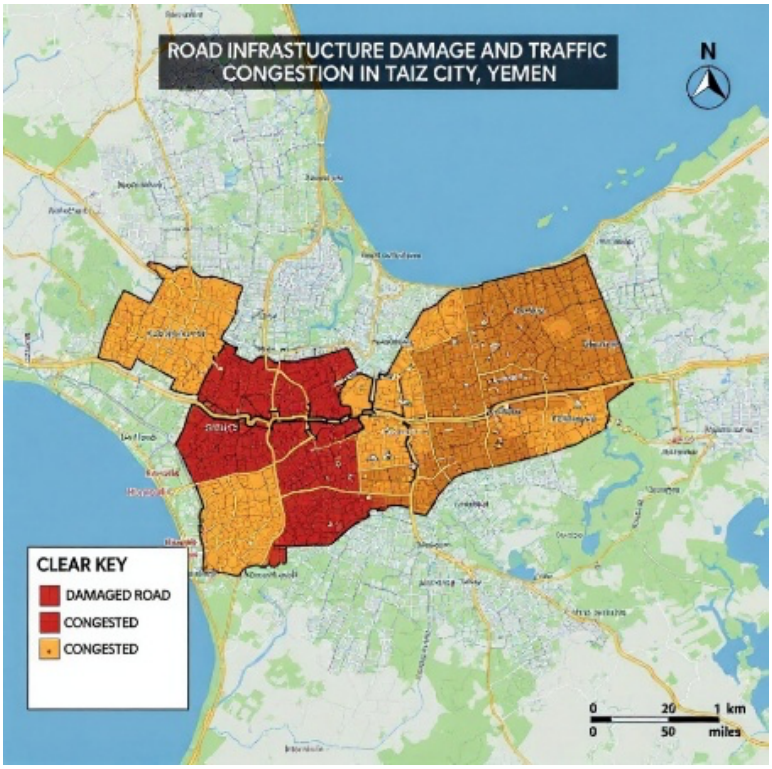
"This synthesis connects the quantitative spatial evidence in the urban recovery theory and paradigms to reinforce and operationalize the importance of systems thinking in integrated reconstruction in the post-conflict."

5.2 Practical Implications and Equations

The operational consequences of this study are wide-ranging. For decision-makers and field actors engaged in Yemen's recovery, the study delineates a focused, implementable agenda. The delineation of strategic, high-impact ''critical point'' measures directs the flow of limited resources toward those interventions that promise the swiftest and most transformative benefits. Figure s 6, 7, 8, 9, and 10 show the urban network analysis accessibility, gravity, connectivity, proximity degree, and other factors.

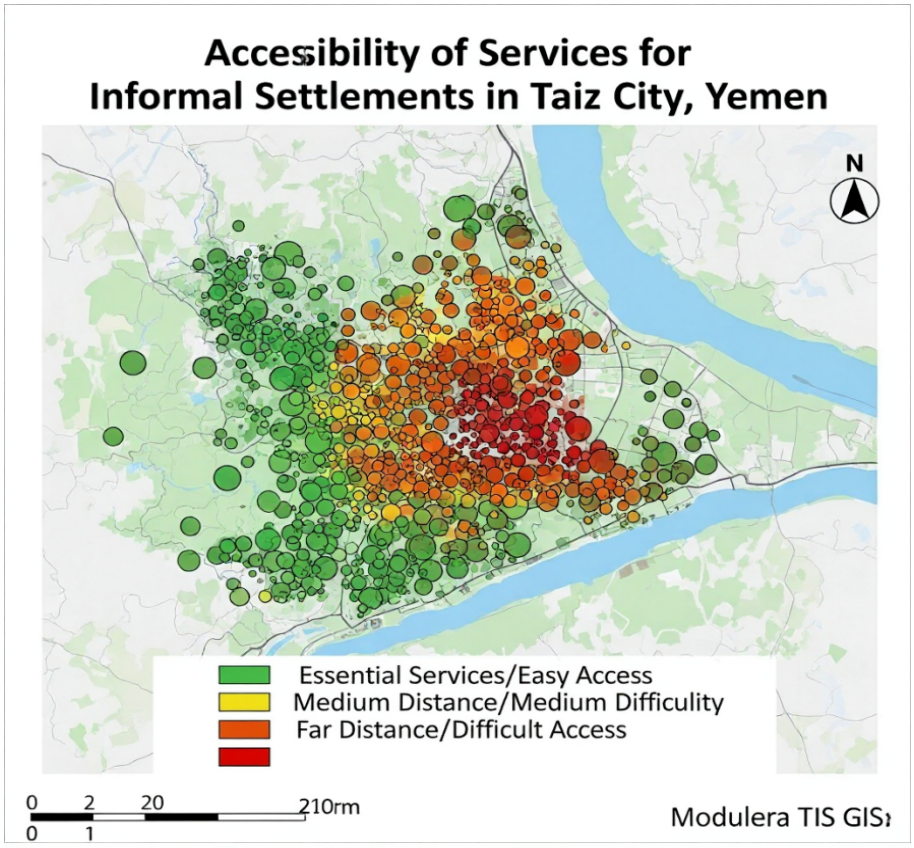
The following application provides significant factors of urban network analysis of five conceptual GIS maps developed for Taiz City, Yemen. The maps overlay road and building layers to visualize various urban characteristics, and an understanding of the spatial structure, density, connectivity, accessibility, and conceptual vulnerability of the city is obtained. While the maps are representative given data limitations and the conceptual nature of some analyses, they demonstrate the application value of GIS in urban planning and humanitarian response, particularly for post-conflict reconstruction interventions.

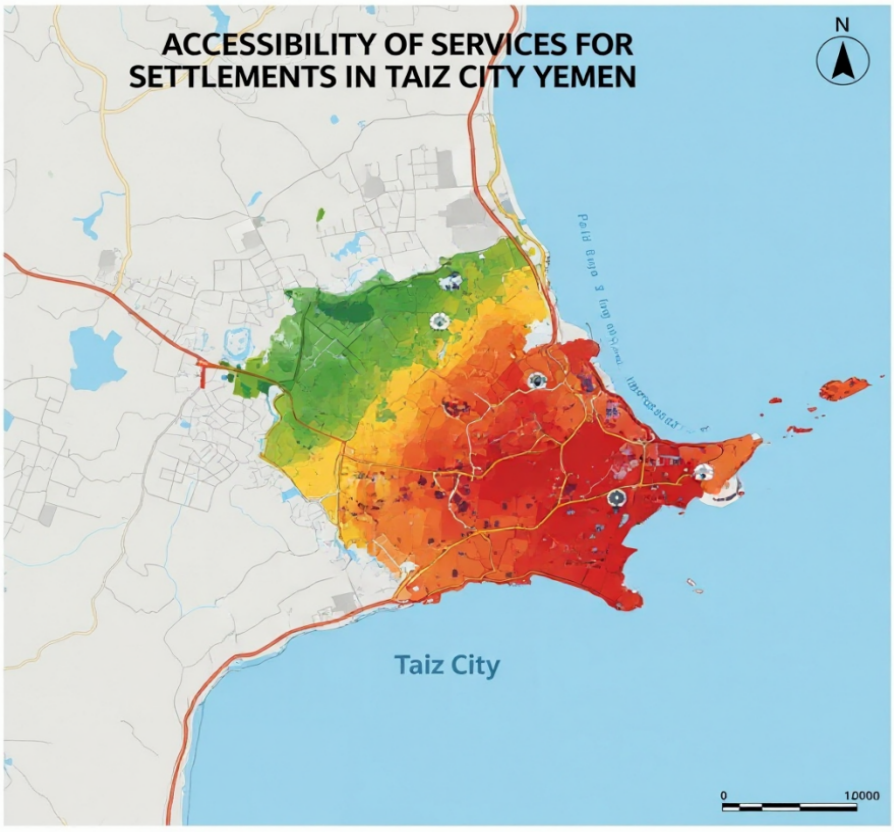
Figure 4: The striking GIS map of Taiz City, Yemen, shows districts of severe traffic congestion (orange) and road infrastructure damage (red). Analytical usefulness



The map clearly depicts the impacted zones. The emphasis on connecting IDP settlements to the urban core highlights the urgent need to address the marginalization of displaced populations.

Figure 5: A GIS map of Taiz City, Yemen, shows the services that are available to various communities. Simple-to-access districts are indicated by green, and more difficult-to-access areas are indicated by a red-to-orange gradient, as presented by the researcher.





The accessibility index (AI) developed in this study can be represented by the following equation:

$$A(i) = \sum_j O_j \, e^{-\beta \, dij} \quad (3)$$

using network distance.

where:

- AI is the accessibility index for a given residential location.
- w_i is the weight assigned to essential service i (e.g., healthcare, education, and water).
- t_i is the travel time to the nearest essential service I.
- The weights (w_i) would be determined through a participatory process involving community stakeholders and experts. This equation provides a simple yet powerful tool for quantifying and monitoring accessibility over time.

The MCDA framework can be operationalized using a weighted summation method, as follows:

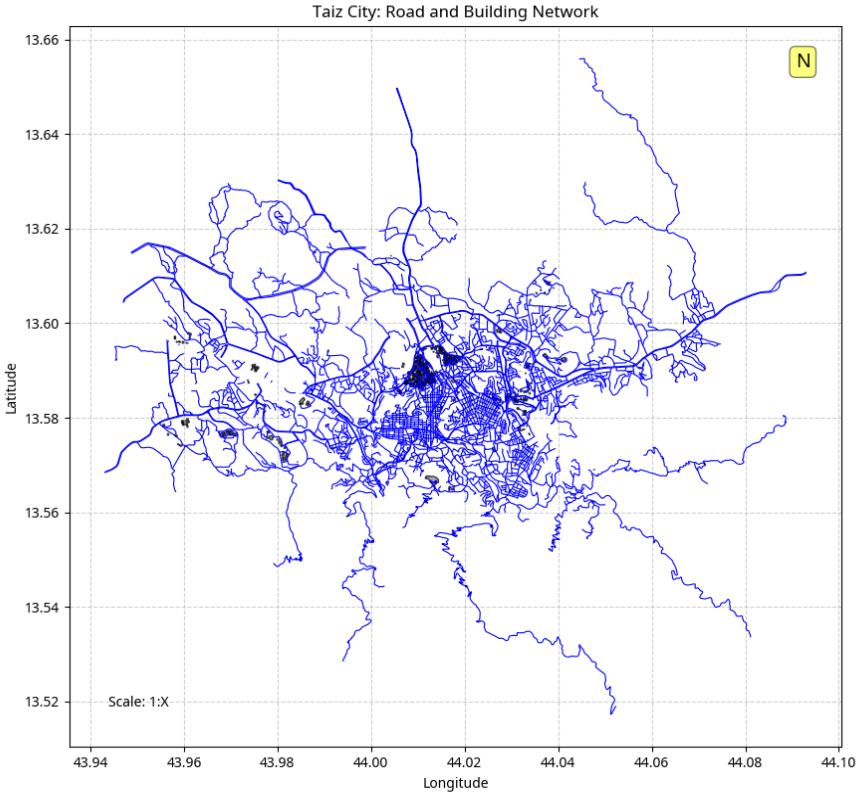
$$S_j = \Sigma \, (w_i \;\; n_{ij})$$

where:

- S_j is the overall score for intervention j.
- w_i is the weight of criterion i
- n_{ij} is the normalized score of intervention j on criterion i.

Contexts, values, and priorities of affected populations. Decisions grounded in the flawed output of the MCDA-whether owing to misclassified land uses, biased weight elicitation, or otherwise-would carry the risk of reinforcing ongoing inequities and inadvertently leading to misallocation of both assistance and investment.

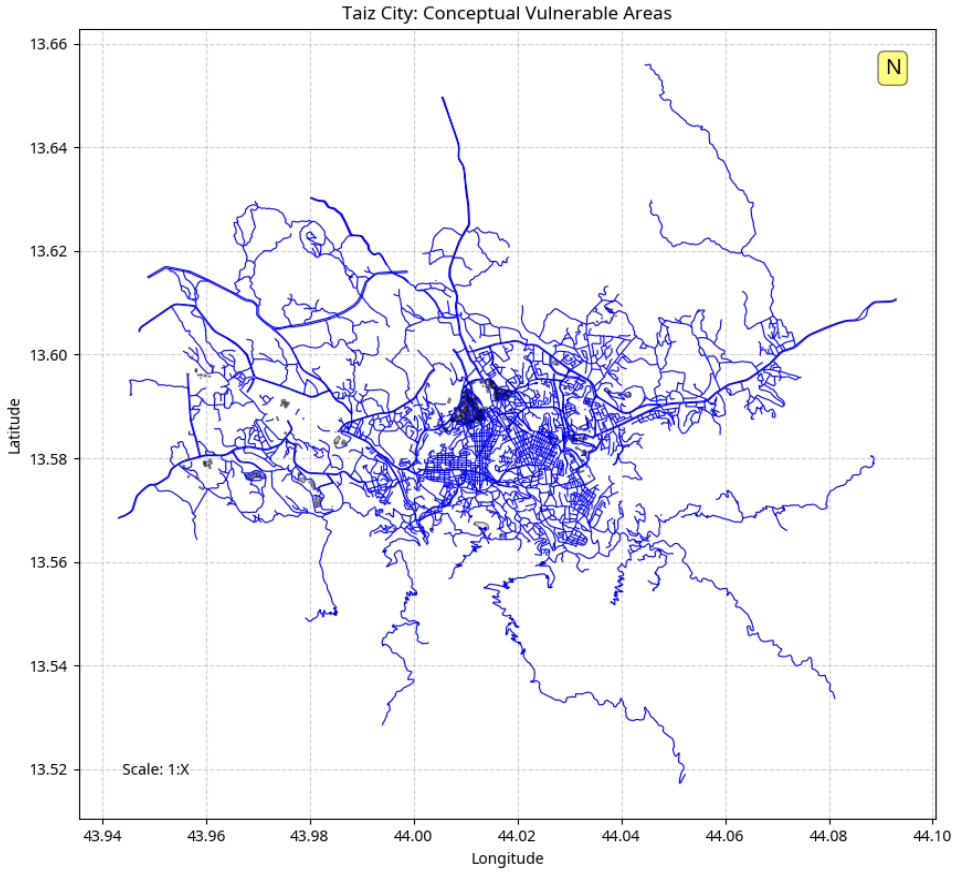
Figure 6: Map of Taiz City: Road and building network purpose



This map supplies a crucial visualization of Taiz City's urban structure by charting the main road system alongside all mapped building outlines. It acts as the primary reference for grasping how physical infrastructure and built areas occupy space. Conceptual representation: The product underscores the sophisticated interplay between circulation corridors and human housing or commerce. Streets appear as narrow traces, demonstrating

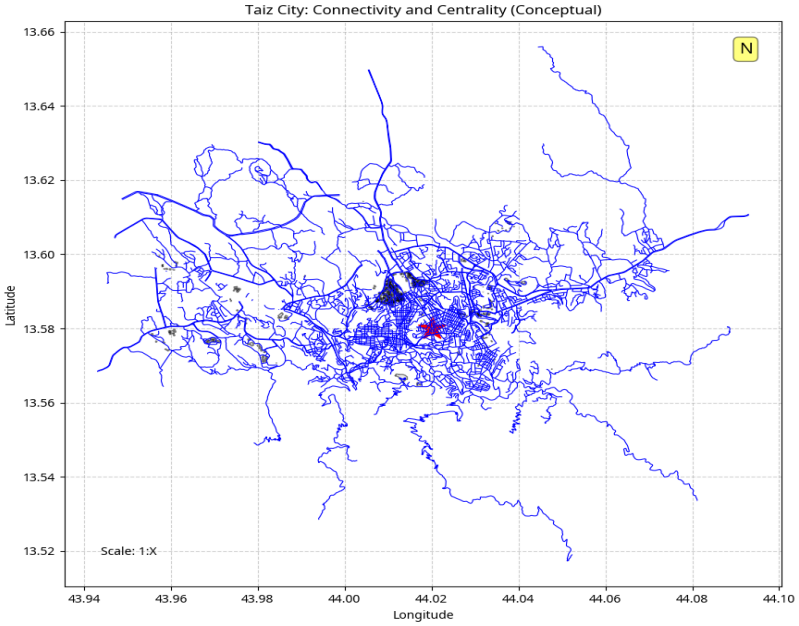
how movement circulates, while buildings show up as lighter-filled shapes, denoting areas of habitation and economic life. The packing and arrangement of these components point to the city's physical form: tightly clumped designs signal concentrated settlement, while looser layouts reveal zones of lower occupation. Within the framework of post-conflict recovery, the map is indispensable for diagnosing the level of destruction affecting both circulation and shelter, yielding a reference point for organized repairs.

Figure 7: Map of Taiz City: Building density (conceptual) purpose



This conceptual presentation seeks to expose the comparative thickness of buildings inside Taiz's boundaries. An actual density portrayal would mandate more sophisticated analysis (e.g., kernel density techniques), so the diagram substitutes a simplified color scheme to determine districts with visually heavier or lighter clustering of roofs and walls. Conceptual representation: Areas exhibiting greater intensity of conceptual building density are represented by deeper red hues, with weaker shades designating regions of lesser density. This graduated color scheme facilitates the quick identification of principal urban hubs, sprawling peripheries, or zones likely undergoing accelerated patterns of informal growth. To mitigate these inherent biases, ongoing validation against ground-truth observations and participatory refinement of both the underlying data and the decision routines remain required.

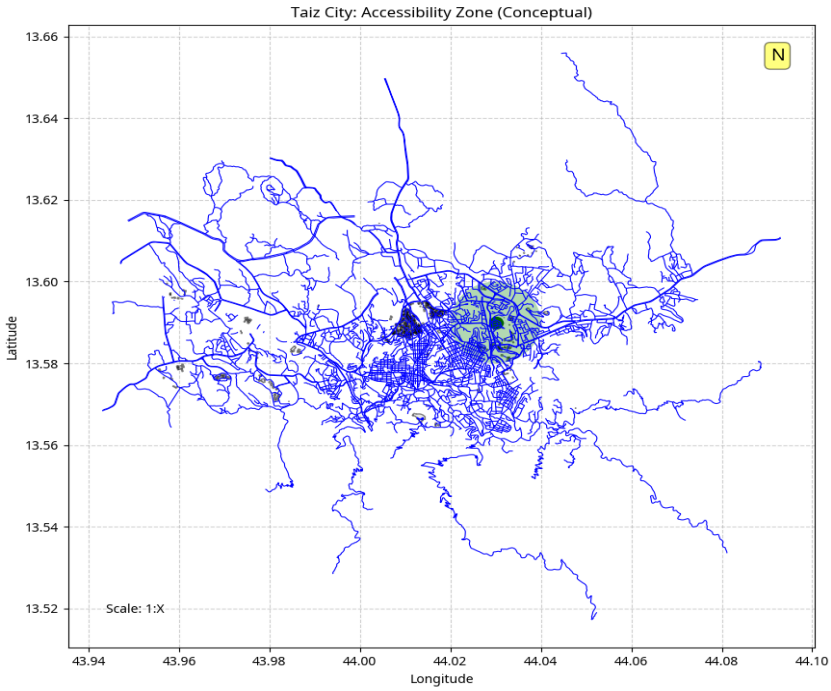
Figure 8: Map of Taiz City: Connectivity and centrality (conceptual) purpose:



This conceptual illustration maps the interrelated ideas of connectivity and centrality as they apply to Taiz City's street pattern, explicitly showcasing a notional central district to stress parts of the grid that, in principle, are readily reachable from almost any urban sector. Conceptual representation: Road segments and building outlines are depicted, with the theoretical center emphasized by a bold circle. In operational geographical information system practice, centrality and connective capacity would be rigorously gauged by algorithms typically assessing betweenness and closeness centrality measures (see pasted_content.txt). The index is calculated by using the

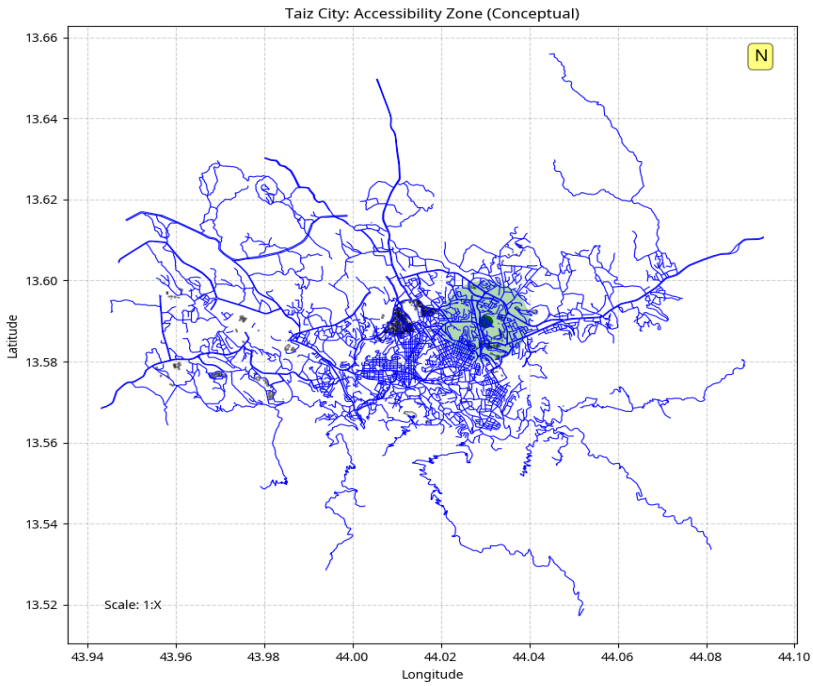
$$C(i) = N - 1 / \sum_{j \neq i} d_{ij} \text{ formula} \quad (4)$$

Figure 9: This exercise illustrates how GIS can spotlight locales threatened by multiple pressures, blending geospatial analysis with human aspiration. Conceptual representation: One quadrant of the downtown grid is shaded to signify hypothetical vulnerability.



High-density housing zones colored in dilutive buildings merge with red outlines of severely shattered structures, while topographic shading identifies the steep ravines often used during detours. Resulting zones in iridescent hues flag where prioritized connectivity re-establishment is imperative. Operational significance: In recovery settings, understanding both the geometry and the gravity of disruption enables actors to sequence interventions efficiently. Maintenance crews, supply coordination teams, and protection advisors can align their trajectories with the same map, minimizing duplicated assessments and accelerating field layering of secondary housing to more scalable service. When fields map their interventions and field updates against this geometric triangulation, the iterative improvement of the restoration effort is not only more measurable but also more consistently aligned with residents' day-to-day mobility outcomes, allowing for mindful, prioritized build-back initiatives.

Figure 10: GIS-based Illustration of Multidimensional Vulnerability Description



This exercise illustrates how GIS can spotlight locales threatened by multiple pressures, blending geospatial analysis with human need. Conceptual representation: One quadrant of the downtown grid is shaded to signify hypothetical vulnerability. Actual assessments would nuance this shading by stacking data sets-household poverty indices, recent infrastructure surveys, coordinates of active conflict perimeters, and service accessibility scores-thereby crystallizing who is at elevated risk and why. Mapping exposure is not merely academic: it is the prelude to humanitarian action planning and to mapping resilient futures. By clarifying the locations where requirements and hazards intersect, this analysis enables decision-makers to guide attention and flows of assistance toward the groups and districts whose survival and rehabilitation are most precarious.

5.3 Limitations and Future Research

Field surveys, in conjunction with shadow and ground-truthing satellite collections, can incrementally enrich secondary layers of data, allowing the MCDA to adapt to symptomatic trajectories and to emerging community perceptions of risk, trade-offs, and priorities. This continual participatory calibration serves not only to improve credibility for decision-makers but also to embed the MCDA exercise within formal and informal accountability mechanisms, thus reinforcing its role as both an analytical and a governance tool. These restrictions suggest a number of significant avenues for further study. There is a clear requirement for more on-the-ground data collection in Yemen's cities, including household surveys and traffic counts, to validate and refine the findings of this study. Further research is also required to develop the concept of post-conflict TOD in greater detail, including the development of specific design guidelines and financing mechanisms. In closing, the systematic long-term observation and evaluation process for the reconstruction schemes will be critical in measuring the breadth and depth of their repercussions, while simultaneously

yielding insights applicable to subsequent endeavors. Even allowing for these constraints, the present inquiry offers an instructive and contemporaneous input to our grasp of the urban facets of Yemen's ongoing crisis. By delivering a methodical examination aligned alongside a coherent strategic architecture, the expectation is that the findings will guide the adoption of a more efficient and enduring course for the rehabilitation of Yemen's urban fabric.

Table 2: Five indicators summarized (Taiz City maps).

Maps	The indicator	Goal	Significant representation
Accessibility based on gravity	Building and road network	Provides a reference for diagnosing damage and displays the urban structure.	Buildings as filled shapes, roads as lines.
Centrality of Closeness	Density of buildings	Draws attention to the degree of clustering for planning services.	High to low density is shown by the red gradient.
Centrality of Betweenness	Centrality and connectivity	Finds the accessible core and important transport nodes.	The theoretical central district is highlighted by the circle.
KDE, or building density	The vulnerability overlay	Combines layers of housing, damage, and elevation.	High-risk intersections are revealed by transparent overlap.
Priority / composite vulnerability (MCDA)	Mapping exposure	Identifies high-risk and critical locations.	Vulnerable populations are indicated by shaded quadrants.

**sources: all data obtained from references in text.*

The table concludes the factors of urban network analysis for Taiz City's exposure, vulnerability, density, and structure, allowing for evidence-based recovery planning and the prioritization of critical interventions.

6. Conclusion

The Yemen crisis is a sobering reminder of the devastating impact of modern conflict on cities. This study has tried to move beyond a simplistic narrative of ruin and to provide a more considered and analytical account of the specific mechanisms by which the conflict has ruptured the crucial nexus between housing and transport. The conclusions of this study are at once a sobering report of the current state and a vision for a more sustainable future. The GIS-based spatial analysis has yielded clear and measurable evidence to underpin the main hypothesis of this study. The decline of transport infrastructure has actually developed "islands of inaccessibility," leaving millions of Yemenis, particularly the poor and displaced, out of reach of the essential services and opportunities required for a life of dignity. The study has mapped these places of severe exposure more precisely, establishing a valuable evidence base for humanitarian and development interventions. But what has also emerged from this study is that the process of reconstruction itself provides a unique opportunity to solve such long-standing issues of Yemeni urban planning and development. The automobile-dominated, conventional pattern of urban growth is neither sustainable nor just. The integrated housing and transportation reconstruction approach outlined in this paper, based on the philosophy of Transit-Oriented Development, is one such viable alternative. By giving highest priority to the rehabilitation of critical network links, investment in public transportation, and promoting pedestrian mixed-use development, Yemeni cities can become not only more resilient to future shocks but also more economically vibrant, socially just, and ecologically sustainable (Jabareen, 2019). The road ahead to the rebuilding of Yemen will be hard and long and will require a concerted and coordinated initiative by a wide range of stakeholders similar to the Yemeni government, civil society, and the international community. This study provides a scientific and methodological foundation for such an initiative.

Thus, the core hypothesis of the study is validated, as the transport system deterioration is shown to have a significant impact on the housing functionality, which warrants the required for integrated reconstruction approaches. By an evidence-led, networked, and forward-looking strategy, it is possible to guarantee the massive investments to be spent on reconstruction do facilitate restoring the status quo and instead establish the basis for a more secure and enhanced city future for all Yemenis.

7. Recommendations

Based on this study's findings, the following is suggested for policymakers, urban planners, and Yemen reconstruction-working humanitarian and development agencies:

For immediate action (0-2 years):

1. Rehabilitate "choke point" interventions: The first priority should be the high-priority transportation infrastructure projects that have been outlined by the MCDA. Rehabilitation of priority bridges and intersections will yield the vital and immediate benefit of overall accessibility.

2. Establish emergency transit services: Conduct primitive public transport services connecting IDP camps and peripheral neighborhoods to urban centers. This could be established through buses or other big-body vehicles and would provide a lifeline for the worst-hit groups.

Hold on-the-ground assessments: Augment remote sensing data with on-the-ground inspections of housing and infrastructure status (REACH Initiative, 2022).

3. The determination of priorities and aspirations should involve indigenous residents in a participatory manner.

For planning that is medium-term (2–5 years):

1. Develop integrated urban reconstruction plans: Move from a project-by-project approach and develop integrated reconstruction plans for all rapid cities (Bertram & Tawab, 2020). The plans should be TOD-principled and should be developed through a participatory mechanism for all the interested stakeholders.

2. Solve land tenure issues: Implement an open and transparent dispute resolution system for land tenure disputes. This is both a housing and infrastructure program prerequisite and a requirement to be accomplished in order to realize long-term stability (Leckie, 2009).

3. Think investment in local capacity building: Provide local government authorities and community organizations with training and technical assistance in project management, urban planning, and GIS. This will aid in the realization of long-term reconstruction sustainability (Leckie, 2009).

Regarding long-term vision (5+ years):

1. Put into practice a national urban policy: Establish and approve a national urban policy for Yemen that encourages resilient, equitable, and sustainable urban growth. The TOD principles should be explicitly promoted in the policy, along with a framework for their application in Yemen (UN-Habitat, 2022).

2. Make an investment in a national spatial data infrastructure (NSDI): Conduct a nationwide framework for collecting, organizing, and disseminating spatial data. This will give every sector a crucial foundation for evidence-based planning and decision-making (Alnsour, 2021).

3. Promote research and innovation: Finance continued research and innovation in the field of post-conflict urban reconstruction. This should include monitoring and evaluation of reconstruction projects to harvest lessons and to progressively improve practice. By means of these recommendations, all parties engaged in Yemen's reconstruction shall guarantee that the devastation is neither simply replaced nor restored, but that an enduring and dynamic urban future is actively constructed for the country's cities and their residents.

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Conflicts of Interest

The authors declare no conflict of interest.

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