ISSN: 1648-6897 / eISSN: 1822-4199

VILNIUS TECH
Vilnius Gediminas Technical University

JOURNAL of ENVIRONMENTAL ENGINEERING & LANDSCAPE MANAGEMENT

2026
Volume 34
Issue 2
Pages 139–152
https://doi.org/10.3846/jeelm.2026.26841

ANALYSING THE ROUTE CHOICES TO ACCESS PUBLIC OPEN SPACES IN HILL CITIES USING SPACE SYNTAX APPROACH

Vicky LALRAMSANGI✉, Yogesh Kumar GARG, Shashikant Nishant SHARMA

Department of Architecture and Planning, Maulana Azad National Institute of Technology, Bhopal, Madhya Pradesh, India

Highlights:

- the research uses space syntax approach exploring vertical movement via steps to understand pedestrian route options to reach public open spaces in outdoor environments;
- streets are better integrated with the presence of steps as connectors from different levels;
- accessibility will be enhanced with the addition of more steps offering more choices (most commuted shorter paths) to pedestrians;
- increase in steps as route options may encourage people to walk more, providing advantages including sustainable mobility options, improved health, and enhanced pedestrian safety.

Article History:

- received 02 April 2025
- accepted 03 November 2025

Abstract. Public open spaces serve as vital components of urban well-being, offering spaces for recreation, social interaction, and environmental balance. In hill cities, however, the steep terrain and irregular street networks create distinctive challenges for pedestrian accessibility and route selection. This study investigates how users navigate and choose routes to access public open spaces (POS) in the hill city of Aizawl, Mizoram, employing the space syntax approach to analyze spatial configuration and pedestrian movement patterns. By examining route connectivity, visual integration, and topographic influence, the study identifies how spatial hierarchy and elevation differences affect pedestrian safety, comfort, and decision-making. The analysis integrates spatial metrics with field observations to reveal critical barriers and preferred pathways that influence accessibility and user experience. The findings highlight the need for designing safe, inclusive, and topographically sensitive pedestrian networks that enhance access to public open spaces. Ultimately, this research advances the discourse on three-dimensional urban morphology in hill cities and provides actionable insights for planners to improve pedestrian mobility and spatial equity in complex urban terrains.

Keywords: space syntax, public open space, hill city, pedestrian routes, steps.

✉Corresponding author. E-mails: *vickylalramsangi@manit.ac.in*; *vickylalramsangi@gmail.com*

1. Introduction

Public open spaces (POS) are essential urban assets that foster social cohesion, ecological resilience, and public well-being. However, ensuring equitable accessibility to these spaces remains a challenge, particularly in hill cities where steep gradients, irregular street geometries, and fragmented spatial structures complicate pedestrian movement. Understanding route choice behavior in such complex terrains is fundamental for advancing inclusive and safe mobility planning. Recent literature emphasizes that the interaction between urban form and mobility significantly affects travel behavior, accessibility, and the quality of public life (Lodhi et al., 2025; Sharma & Dehalwar, 2025b).

Pedestrian route choice, as defined by (Prato, 2009) and later refined by Tong and Bode (2022), extends beyond distance minimization and encompasses safety perceptions, visibility, connectivity, and environmental comfort. In hill cities, these factors are further shaped by elevation, slope, and the interconnectivity of multi-level networks. Basu et al. (2022) in their systematic review identified that route choice decisions are deeply influenced by perceived safety, walkability, and spatial continuity. Similarly, Sharma et al. (2024) noted that leveraging advanced analytical tools can help identify surrogate safety risks in urban transport systems. Integrating these perspectives, this research applies the space syntax approach to explore how spatial configurations influence pedestrian route choices to access POS in Aizawl, Mizoram, India.

The space syntax framework provides an evidence-based method to analyze the spatial logic of urban systems, focusing on configurational attributes such as connectivity, integration, and choice. Earlier studies have demonstrated its value in understanding movement patterns and accessibility dynamics in both flat and complex terrains (Karimi, 2018; Van Nes & Yamu, 2021). Open space serves multiple purposes, and accessibility using steps is common in hilly towns (Lalramsangi et al., 2025). However, as Kumar et al. (2025) highlight, the evolution of spatial modeling in urban research must accommodate multi-dimensional realities, especially in topographically constrained environments. Despite its wide applications, most space syntax research still assumes a planar city structure, neglecting the third dimension that defines hill cities.

In this context, three-dimensional space syntax offers a novel lens to study the vertical interconnections that characterize hill settlements such as stairs, ramps, terraces, and layered roads which serve as critical pedestrian corridors. Sharma and Dehalwar (2025a) emphasized that sustainable urban development hinges on integrating transport and land use, while Sharma and Dehalwar (2025c) advocate for inclusive mobility systems that account for vulnerable groups such as senior citizens. Building upon these ideas, this study examines how spatial hierarchy, route safety, and pedestrian comfort interact in the unique setting of hill cities.

This paper seeks to bridge the gap between two domains: spatial configuration analysis and behavioral understanding of pedestrian route choice. Drawing insights from bounded rationality models (Di & Liu, 2016) and empirical studies on walking behavior (Koohsari et al., 2016), it aims to identify the spatial and perceptual factors that guide pedestrian movement to POS. By focusing on Aizawl, a city characterized by steep slopes and dense morphological patterns, the research contributes to a deeper understanding of how accessibility and safe mobility can be enhanced through spatial design.

Space syntax provides a powerful and increasingly sophisticated framework for analyzing pedestrian accessibility in complex urban environments, making it particularly valuable for hilly cities where topography poses unique challenges. Recent advances demonstrate its capacity to go beyond traditional two-dimensional representations, incorporating three-dimensional spatial morphology and multilayered networks to capture vertical variations in movement (Zhang et al., 2023). As Mohamed and van der Laag Yamu (2024) highlighted in their comprehensive bibliometric review, space syntax has matured into a robust analytical tradition widely recognized for its applicability across diverse urban contexts, with growing attention to inclusivity and sustainable design. Moreover, when combined with emerging tools such as GIS-based processing and deep learning techniques for pedestrian route detection, as demonstrated by Martínez-Chao et al. (2024), the method provides enhanced precision in understanding accessibility at fine-grained scales. In this light, applying space syntax to hill cities represents a novel and timely approach, enabling researchers to assess how integrated stairways, slopes, and pathways shape equitable accessibility in terrain-constrained urban fabrics.

Ultimately, this study extends the application of space syntax to a three-dimensional urban context, advancing theoretical and practical knowledge for planners and designers. It underscores the importance of incorporating spatial equity, route safety, and topographical sensitivity in the planning of public open spaces in hill cities, fostering more connected and pedestrian-friendly environments.

1.1. Objectives of the research

The objective of this research are as follows:

1. To analyze the route choices for accessing public open spaces (POS).
2. To assess the integration of steps in influencing accessibility.
3. To discuss and interpret its applicability in hilly areas.

2. Definitions and concepts

2.1. Understanding public open space (POS)

Public open spaces (POS) represent vital components of urban ecosystems that contribute to both environmental quality and social vitality. Defined across multiple disciplines, POS are publicly accessible, managed environments that serve recreational, aesthetic, and social purposes. POS is a "managed open space, typically green and available and open to all, even if temporally controlled" (Carmona, 2010); freely accessible by the public without an entry fee (Edwards et al., 2013), and includes parks and playgrounds, maidans (Appadurai, 2000), having public value, and offering sports and recreational opportunities and contributing to visual amenities (Alexander et al., 1977; Lalramsangi et al., 2026). From urban squares and pedestrian promenades to playgrounds and neighbourhood parks, such spaces collectively shape the physical and social fabric of cities (Han et al., 2022).

POS enhance daily human experience by promoting physical activity, leisure, and psychological restoration. Empirical studies link the presence of local or neighbourhood green spaces to increased walking (Sugiyama et al., 2010), higher levels of physical exercise, and improved social interaction (Lackey & Kaczynski, 2009). Furthermore, broader research has underscored their contributions to environmental health, air quality, and mental well-being (Crouse et al., 2021; Groenewegen et al., 2012). In compact and topographically constrained urban forms such as hill cities, POS provide critical breathing spaces and function as nodes of accessibility, sociability, and urban balance, underscoring the need to analyse the routes leading to POS.

2.2. Fundamentals of Space Syntax theory

Space Syntax theory offers an analytical lens through which the spatial configuration of urban environments can be quantitatively examined in relation to human activity patterns (Space Syntax, n.d.). Originally developed by Hillier and Hanson, this methodology establishes a bridge between spatial geometry and behavioural dynamics, explaining how the structure of space influences movement, visibility, and social interaction (Van Nes et al., 2021).

Core spatial components

Axial lines and maps

The axial map is a foundational representation within space syntax, composed of the minimum number of longest straight lines called axial lines that capture all possible routes of direct movement (Koohsari et al., 2014). According to Puckett (2009), street configurations directly shape how individuals orient and navigate within urban systems. These lines represent both visibility and accessibility pathways, playing a critical role in human navigation, especially under dynamic or stressful conditions (Van Nes et al., 2021). However, as Asami et al. (2003) observed, conventional two-dimensional axial representations fail to capture elevation variations in complex topographies, limiting their ability to model vertical pedestrian links such as stairs or ramps, a gap that becomes significant in hill-city analyses.

Depth and connectivity

Topological depth, a key syntactic property, measures the number of turns or syntactic steps between a given street and others within the network. A greater depth implies lower accessibility and connectivity, as it reflects more directional changes from a primary street to peripheral ones. Depth thus acts as an indicator of urban connectivity, shaping both wayfinding efficiency and pedestrian movement potential.

Integration

Integration, often interpreted as the "closeness" of one space to all others, serves as a measure of spatial centrality. High integration values indicate streets that are spatially and functionally significant within the network, spaces that naturally attract pedestrian flow and social interaction (Peponis & Wineman, 2002). Integration can be studied at both global (city-wide) and local (neighborhood) scales. Locally integrated streets tend to host commercial or recreational activities with higher movement, while less integrated ones often remain quiet and residential (Van Nes et al., 2021).

Choice

Choice, sometimes referred to as "betweenness," quantifies the likelihood that a given street or segment lies on the shortest paths between all other pairs of spaces (Hillier & Iida, 2005). High-choice values identify key corridors that serve as preferred routes, reflecting both navigational importance and potential pedestrian density.

2.3. Three-dimensional limitations and relevance to hill cities

While space syntax has been extensively validated in planar cityscapes, its conventional two-dimensional focus poses limitations in hilly terrains where spatial hierarchy is vertical as much as horizontal. Asami et al. (2003) acknowledged this shortcoming in their exploration of road curvature and elevation but excluded pedestrian stairs as navigable connectors between street levels. Contemporary research calls for integrating 3D spatial syntax with topographic data to more accurately model the experiential and functional realities of cities like Aizawl. This shift not only enriches spatial analysis but also enhances the understanding of how accessibility, visibility, and safety influence pedestrian route choices in complex urban morphologies.

3. Methods and materials

3.1. Research methodology

The study follows a space syntax approach to analyze the pedestrian route choices to access POS. The analysis focuses on the locality of Bawngkawn, specifically examining Brigade Street, which leads to the POS, along with the other streets for the syntactic analysis. The road network is created in QGIS (version 3.36.1) using Google Earth imagery, the same is imported into AutoCAD (version 2022) for refinement of the routes. The location of the steps is manually mapped through field mapping and drawn in the AutoCAD file since Google Earth imagery could not capture the location of the steps. The file is subsequently input into DepthMapX to conduct integration and choice analysis.

Spatial analysis

The first step to be performed after importing the file into DepthMapX is the creation of an axial map. The fundamental idea of constructing an axial map is to reduce the quantity of lines and the angular variation between any pairs of lines. DepthMapX offers a feature for converting the original map into an axial map. The axial map also provides an option for modification by linking or unlinking lines when necessary, such as bridges and tunnels. Upon finalization, the axial map is converted into a segment map, whereby further editing is prohibited and is utilized solely for syntactic analysis.

In the study, axial maps with and without steps are generated, followed by the creation of segment maps, and the analysis is performed. A 500-meter radius was selected to examine integration and choice patterns, since the study concentrates on route options to access POS at the neighborhood level. Research indicates that a distance of 300–500 meters (5–7 minutes) is a comfortable walking range for pedestrians to reach POS (Pinto et al., 2022; Schindler et al., 2022; World Health Organization, 2016), and this distance is conventionally used in pedestrian accessibility studies (Benati et al., 2024; D'Orso et al., 2025; Zhao et al., 2022; Zhou et al., 2022). While many urban planning studies adopt catchment radii of 400–800 meters (Sun & Cui, 2025; Yenisetty & Bahadure, 2021), the lower bound was chosen here to account for the steeper gradients and higher physical exertion typical of hilly terrains such as Aizawl. Also, in hilly terrains, variations in walkable distance may arise depending on the slope (Pais et al., 2025). Therefore, a metric radius of 500 meters is employed for the spatial analysis. This selected distance balances methodological comparability with practical considerations of the local context.

Data and statistical analysis

For the statistical analysis, the data is extracted from DepthmapX derived from the integration and choice values (with and without steps). The correlation coefficients are then analysed using STATA and Python, followed by interpretations and discussions, recommendations and conclusions. The proposed methodology is shown in Figure 1. We computed Pearson correlations to test whether the *relative* ordering of axes was preserved between scenarios; a high r therefore indicates that the global network hierarchy remains similar, while absolute increases identify which axes gained accessibility. For the correlation analysis presented in Figure 6, we use the straight-line (Euclidean) distance from the midpoint of each pedestrian link to the centroid of the public open space (POS), measured in meters.

It is important to note that in the current analysis, stairway segments were modeled in DepthMapX based on their planimetric geometry. No additional weighting was applied to represent gradient or vertical rise, meaning that a steep stairway of 50 meters in length is treated equivalently to a flat alley of the same plan length. While this approach ensures comparability with conventional space syntax analyses, it does not capture the differential physical effort associated with vertical movement in hilly terrain. Since no weighting was applied for vertical distance, the study also included a primary survey conducted through interviews with 80 respondents to ascertain pedestrian preferences on the usage of steps and to validate that the model accurately represents pedestrian behaviour. This combination allowed both spatial visualization and quantitative assessment of accessibility outcomes.

3.2. Study location

The study location is Aizawl, Mizoram, a city in the northeastern region of India with precise geographical coordinates of 23.7307° N and longitude 92.7173° E (Figure 2). Aizawl, the capital city of Mizoram, serves as the central location for political, commercial, educational, and cultural activities in the State. The Aizawl Planning area has a population of 310,891, out of which 97.4% of the population reside in urban areas (Urban Development and Poverty Alleviation Department, 2023). Aizawl's geological structure features a highly undulating and uneven topography, situated at a ridge of 1132 meters above mean sea level (State Investment Project Management and Implementation Unit, 2010). This leads to a reduced flat land availability in the city. The recreational areas in Aizawl constitute 0.18% of

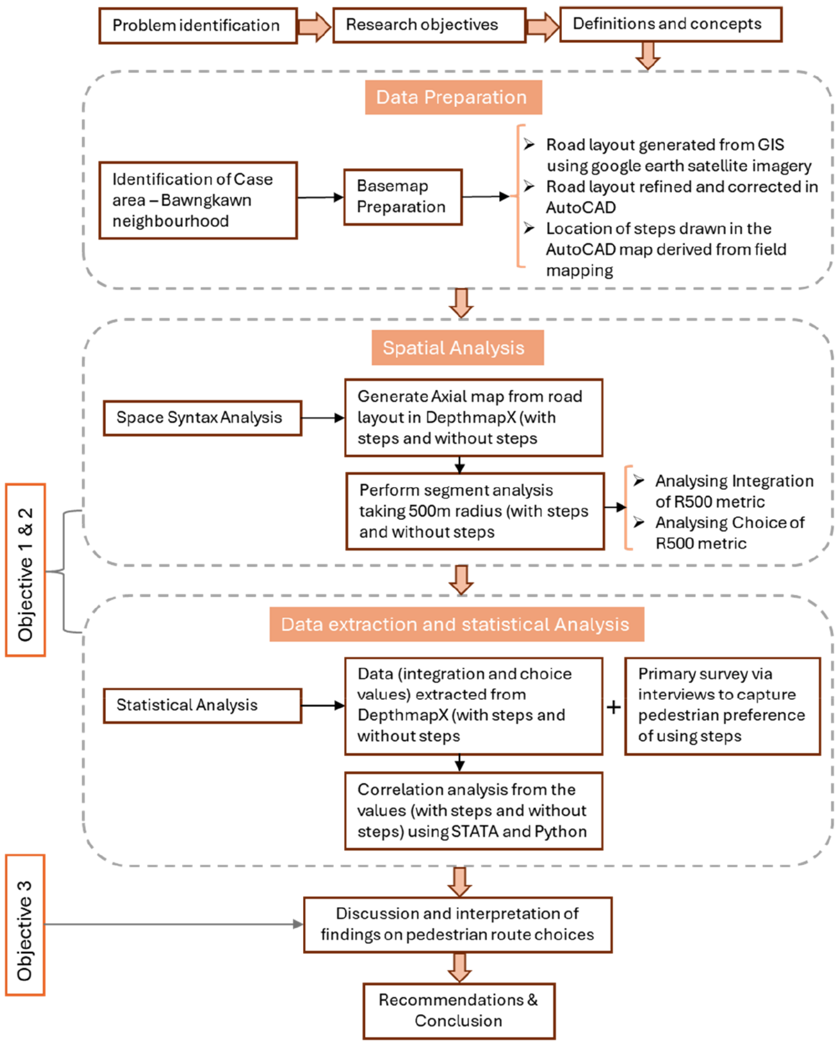

Figure 1. Proposed methodology (source: author)

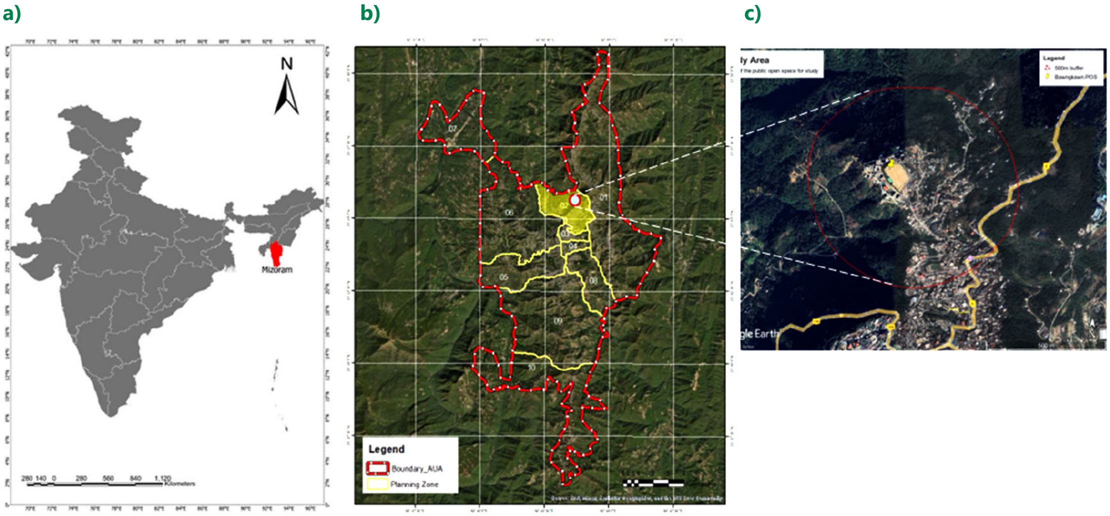

Figure 2. Location map: a) India map highlighting Mizoram state; b) Aizawl city; c) Study area Bawngkawn locality

the total area which includes gardens, parks, playgrounds, stadiums, resorts and auditoriums etc. (Urban Development and Poverty Alleviation Department, 2023). POS comes under the category of recreational areas and almost every locality/ neighbourhood has a designated open space resembling playgrounds. These neighbourhoods are centred around or near the POS, following the vernacular settlement pattern and featuring significant structures in proximity (Lalramsangi et al., 2022).

4. Results and findings

4.1. Role of steps in enhancing pedestrian accessibility

Field observations reveal that stairways play a pivotal role in supporting everyday pedestrian mobility across different age groups in hill cities. Unlike in plain urban contexts, where ramps or lifts might substitute vertical movement, in Aizawl the stairway system locally known as "*Vantlang Steps*" functions as a key connective infrastructure (Figure 3). These steps provide direct, vehicle-free shortcuts that substantially reduce travel distance and effort when compared with conventional road loops. In many cases, the stair routes act as social and mobility corridors, integrating multiple street levels and providing safer alternatives to steep vehicular roads.

In the Bawngkawn Brigade area as shown in Figure 4, the urban network consists of the primary arterial NH-6, a secondary street (Brigade Street), and several tertiary links. Spatial mapping identified three major stair connections between NH-6 and Brigade Street, exhibiting level variations ranging between 26 and 83 meters, and an additional connection descending from Brigade Street to the

Figure 3. Steps serving as shorter routes in the study area (source: author)

tertiary road network with approximately 27 meters of level change. These vertical connections redefine the pedestrian catchment area of adjacent neighborhoods, making uphill and downhill travel significantly more manageable.

4.2. Spatial integration analysis

To understand spatial accessibility, an axial map was generated and later converted into a segment map to capture fine-grained spatial behavior. Two scenarios were analyzed: (a) the network composed solely of roads and (b) the network enhanced with stair segments. The integration analysis was conducted at a 500-meter radius to correspond to the pedestrian movement scale, represented in Figures 5a and 5b.

Without the inclusion of stairs, the results showed fragmented spatial relationships within the network. Brigade Street (X–Y) functioned as a semi-integrated connector with limited pedestrian flow potential. However, once the stair connections were incorporated, integration values for the same corridor increased substantially, revealing stronger

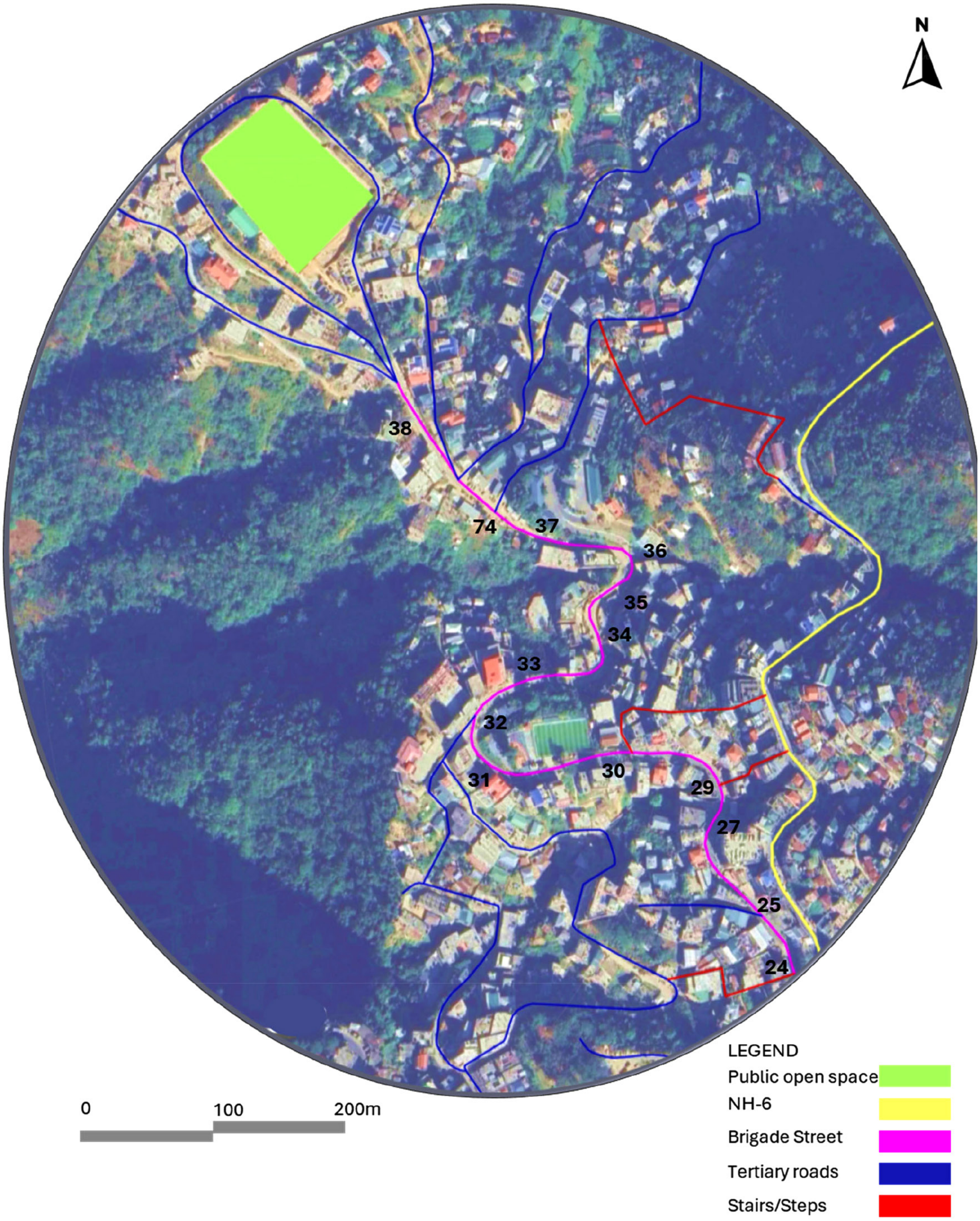

Figure 4. Route network map showing routes for accessing POS in the study area (source: author)

spatial continuity and improved walkability. The street gained prominence as a key pedestrian spine, supported by multiple entry and exit points facilitated by steps.

The analysis also revealed a clear enhancement in pedestrian safety and comfort levels. Routes incorporating stairs allowed for more direct, relatively shaded, and vehicle-free travel, particularly important for children, the elderly, and women, who tend to avoid isolated or longer vehicular roads. The improved integration reinforced natural surveillance and passive safety through increased pedestrian presence, aligning with principles discussed by Sharma et al. (2024) in their work on surrogate safety in urban transport systems.

4.3. Spatial choice (betweenness) analysis

While integration measures the overall connectivity of each segment, choice quantifies the extent to which a particular path lies along the shortest routes between multiple origins and destinations. In both scenarios represented in Figures 5c and 5d, the Street X–Y corridor remained the dominant pathway due to its geometric alignment and centrality. However, the addition of steps slightly shifted local peaks of choice values, indicating that new pedestrian options emerged in the network.

Notably, localized increases in choice were observed near the upper intersections along NH-6 and in the lower tertiary roads. These increments suggest that the stair connections not only improve accessibility but also diversify the available route options. Pedestrians are thus more likely to select paths based on comfort, visibility, and directness rather than mere distance, echoing findings from Basu et al. (2022) and Tong and Bode (2022) regarding human route selection behavior.

The expanded network effectively redistributed pedestrian flow, balancing movement density across multiple corridors rather than concentrating it on a single arterial route. This outcome supports a more resilient and safer walking environment, reducing congestion and encouraging greater access to public open spaces.

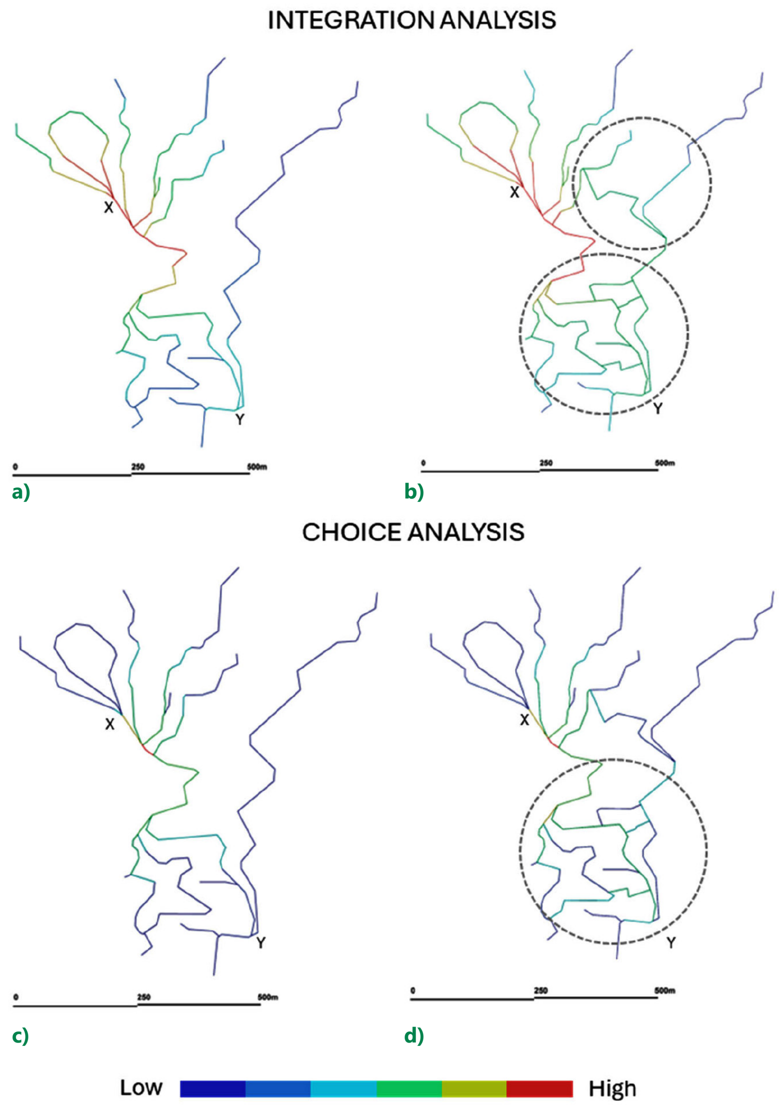

Figure 5. Segment maps of local integration and choice at radius 500 m: a) Integration map of roads; b) Integration map of roads and steps; c) Choice map of roads; d) Choice map of roads and steps (source: author)

4.4. Integration and choice analysis using DepthMapX

DepthMapX, a specialized software for spatial network analysis, was employed to quantify the integration and choice values for the study area's axial network. These values offer insight into how spatial configuration influences movement potential within the Bawngkawn Brigade area. Integration measures the accessibility of a space relative to all others in the system, indicating how centrally connected it is, whereas choice identifies spaces most likely to be traversed along the shortest paths between multiple origin–destination pairs. Together, these two measures describe how efficiently pedestrians can navigate urban environments and where movement intensity is likely to concentrate.

The axial reference map of Brigade Street (Figure 4) was processed in DepthMapX to generate these spatial metrics. Each axial line, representing the longest uninterrupted line of sight and movement, was assigned a unique numerical identifier to facilitate calculation. Among the numerous values produced, data corresponding specifically to Brigade Street and its connecting streets were extracted for subsequent analysis. These figures were used to evaluate two scenarios: (i) existing road network without steps, and (ii) enhanced network with the inclusion of pedestrian stairways. There's a strong positive relationship among Distance (m), Integration, Choice, and Choice (With steps). Axial line also trends positively with these, but to a lesser degree. Street reference shows weak correlations relative to the others.

Quantitative outcomes

Figure 6 depicts the integration and choice values derived from DepthMapX. The results indicate a marked increase in both parameters when steps are introduced into the model. For example, axial line references 24, 29, and 30 (Figure 4), which represent critical links connecting NH-6 with Brigade Street, exhibited significant gains in integration and choice. In contrast, axial lines closer to the POS (e.g., 38 and 74) demonstrated relatively modest improvements, suggesting that step connectivity primarily benefits mid-network access points.

Higher integration values indicate greater spatial cohesion and accessibility, while elevated choice values signify enhanced potential for pedestrian flow through frequently used corridors. The analysis confirms that step-based linkages not only shorten travel distances but also improve the legibility and usability of the pedestrian network, allowing residents to reach public open spaces more efficiently and safely.

Correlation and spatial interpretation

A comparative correlation analysis between "without steps" and "with steps" conditions revealed a strong positive relationship. Integration values exhibited a correlation coefficient of 0.966, while choice values showed 0.938,

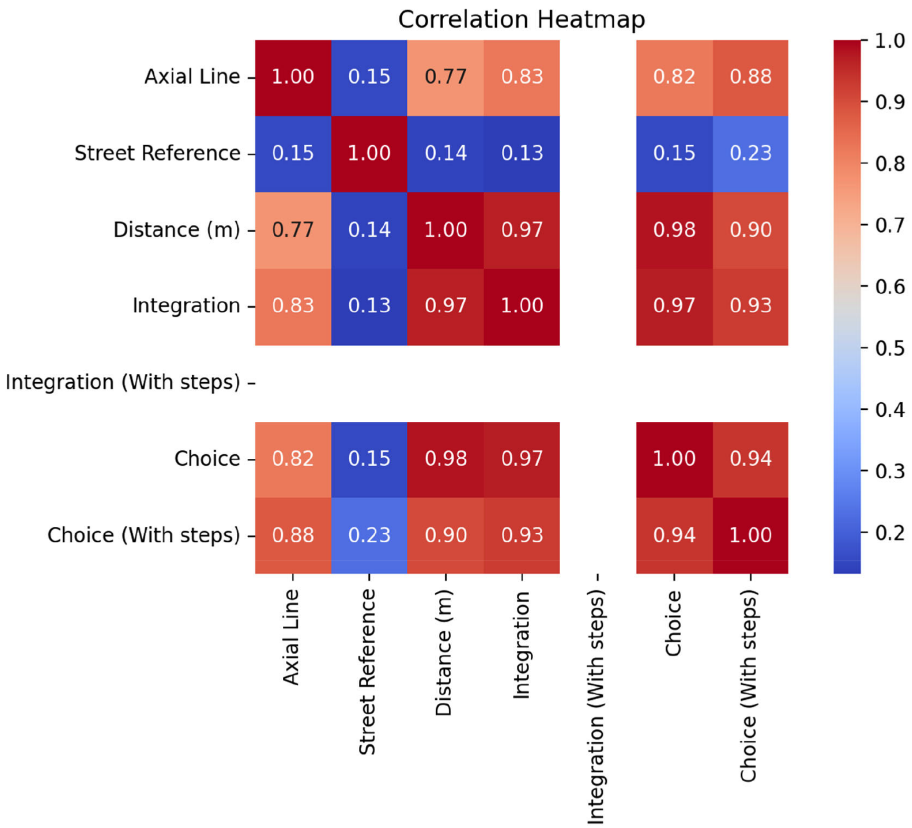

Figure 6. Correlation matrix for the choice and integration analysis

implying consistency between both spatial metrics across conditions. However, the inclusion of steps led to substantial enhancements: integration improved by 23.3%, and choice increased by 87.5%. These findings illustrate that steps serve as critical connectors, transforming fragmented terrain into a coherent pedestrian system.

Heatmap visualizations further highlight the spatial relationships between distance, integration, and choice. Weak positive correlations were identified (r = 0.13–0.14 for integration; r = 0.15–0.23 for choice), indicating that distance exerts limited influence on overall connectivity. Yet, slightly stronger associations in longer paths suggest that step connectivity becomes increasingly valuable for extended pedestrian journeys. In other words, steps have a disproportionate effect in improving accessibility where terrain or distance would otherwise discourage walking.

4.5. Preference for using steps as route options

As a part of a survey for a larger purpose for 80 respondents from the study area, one of the questions posed was "I prefer to use steps for walking to POS" requiring respondents to answer either "Yes" or "No". Figure 7 illustrates that 95% of residents prefer to walk via steps when they have to reach multiple levels and to POS. Further examination of the age demographic shows that the elderly age group accounts for the non-preference of step usage. This is likely due to the difficulty older residents face in ascending or descending the steps. These results show that the pedestrians prefer to use steps as a mode of movement, which aligns with the model findings.

4.6. Implications for urban design and mobility

The study demonstrates that incorporating stairs within the road network transforms the accessibility dynamics of hill settlements. The integration and choice analyses jointly indicate that such interventions can elevate both functional and perceptual connectivity. Enhanced integration values reflect greater ease of movement, while increased choice values correspond to diversified pedestrian routing, together forming the foundation for inclusive and sustainable mobility design.

These findings corroborate the arguments of Basu et al. (2022) and Sharma et al. (2025b), who emphasized the significance of spatial structure and transport, and land use coordination in achieving equitable urban mobility. In the case of Aizawl, stair connectivity strengthens neighborhood-level integration, minimizes detours, and fosters pedestrian safety through active usage.

The inclusion of community stairways, when planned systematically, can significantly improve access to public open spaces, reduce walking effort, and enhance the spatial cohesion of hill cities. The synthesis of quantitative space syntax analysis with empirical field observation offers valuable guidance for urban designers and planners to create more connected, human-centered environments that promote accessibility and active mobility.

4.7. Interpretive discussion

The spatial results underscore that pedestrian steps are not merely supplementary links but essential components of the urban movement framework in hill cities like Aizawl. Their inclusion redefines accessibility by bridging elevation gaps and redistributing pedestrian activity more evenly across the network. The outcomes align with urban transport theories emphasizing integrated, walkable systems that accommodate local topography and user behavior.

The improvement in integration and choice values demonstrates that step-based interventions contribute to creating a more connected, inclusive, and safer pedestrian environment. They enable diverse user groups such as children, elderly residents, and women to travel along more direct, visible, and vehicle-free routes. Ultimately, incorporating strategically positioned stairways into urban design can significantly enhance spatial accessibility

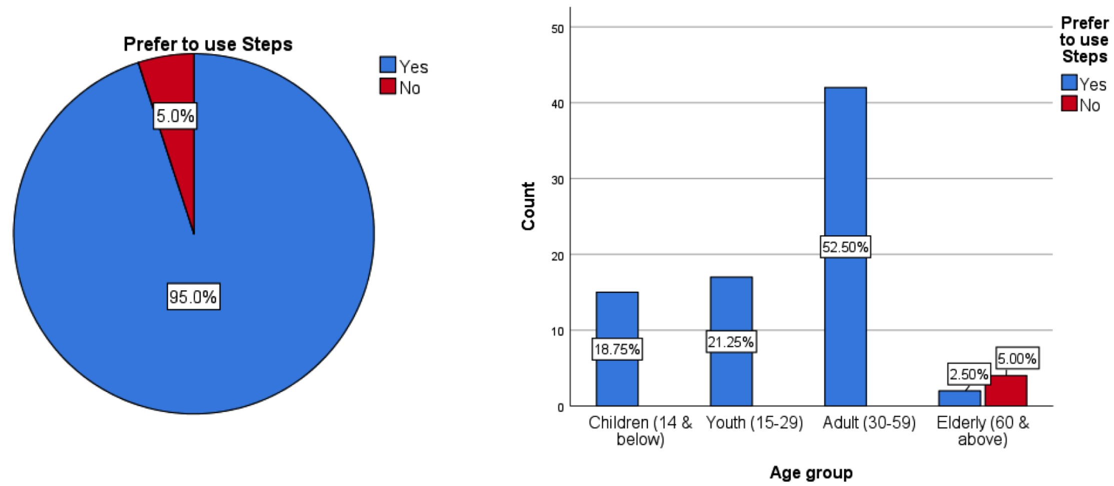

Figure 7. Preference for using steps

and strengthen the socio-functional relationship between neighborhoods and public open spaces.

Although the Pearson correlations between the two scenarios are very high (r = 0.966 for integration; r = 0.938 for choice), this should not imply that steps have a negligible effect. Rather, the high correlations indicate that the hierarchy of the network, and the relative ordering of the most integrated and most used corridors is largely preserved (for example, the main NH-6 corridor remains the dominant axis). At the same time, the steps selectively amplify connectivity values of certain intermediate connectors. In our case, axial lines 24, 29 and 30 (the connector axes that link the hill-side neighbourhoods to the POS via stair routes) show the largest absolute increases in both integration and choice scores, while axes immediately adjacent to the POS show smaller changes. This pattern implies that steps function as augmentative connectors; they do not reorder the primary network backbone, but they raise the accessibility of previously peripheral connectors, improving their relative importance for pedestrian routing.

We computed Pearson correlations between link distance and space-syntax metrics (global integration and choice) to test whether longer links were associated with different connectivity values. The correlations are weak but positive (r = 0.13–0.23), indicating only a small tendency for longer links to have higher integration/choice values. This weak relationship implies that physical length alone explains very little of the spatial connectivity structure. Nevertheless, the slightly higher correlation for choice at longer distances suggests a plausible functional interpretation: for longer trips (longer links or links farther from the POS), pedestrians rely relatively more on through-movement corridors (choice), and the addition of steps increases the through-movement potential of certain connectors, marginally strengthening the link between distance and choice. In short, distance (as measured above) is not a dominant determinant of integration, but it has a modest association with choice — consistent with steps facilitating longer, through-oriented pedestrian movements.

5. Discussion

5.1. Linking to space-syntax theory (interpretive frame)

Our findings indicate that the addition of stair shortcuts selectively amplifies the integration and choice values of intermediate connectors while leaving the global backbone largely unchanged, which aligns with the configurational logic central to space-syntax theory. Hillier (1996) argued that spatial configuration determines the distribution of movement potentials and that local modifications to configuration can alter movement relationships without necessarily overturning the global hierarchy of a system. Thus, steps operate as local configurational interventions that raise the accessibility of previously peripheral axes while the major thoroughfares retain their primacy.

5.2. Comparison with hill-city / stair studies (empirical parallels)

Empirically, our results echo recent case studies in hilly historic districts that report similar patterns: stair and stepped linkages improve access to uphill neighbourhoods and increase the importance of connector axes, but do not replace the dominant role of main corridors in structuring movement flows. For instance, Lyu et al. (2023) use space-syntax measures in a Chinese historic hill context and report analogous selective uplifts in connectivity associated with stepped interventions. Our study also resonates with recent methodological advances advocating for multilayer or 3-D treatments of urban networks, where vertical connectors are represented as distinct but interacting layers (Zhang et al., 2023). This cross-case similarity strengthens the interpretation that stair networks function as augmentative rather than transformative infrastructural elements in steep urban terrains.

5.3. Accessibility and inclusion literature (limits and trade-offs)

Our interpretation of steps as accessibility enhancers should be contextualised within recent accessibility and inclusion scholarship. Studies that assess pedestrian accessibility and route quality emphasise that physical interventions such as stairs may simultaneously improve connectivity for able-bodied pedestrians while excluding others (older adults, wheelchair users) or creating seasonal/safety vulnerabilities; therefore, syntactic improvements must be complemented by inclusive design measures to deliver equitable access. This integrative position is consistent with recent pedestrian-accessibility assessments that combine syntactic indicators with on-the-ground accessibility audits.

5.4. Contextualisation

While the findings from Aizawl highlight the role of integrated stairways in enhancing accessibility, the degree of generalizability requires careful consideration. Certain lessons, such as the importance of safe design features (e.g., handrails, lighting, non-slip surfaces), and the potential of stairway networks to reduce walking time, are broadly applicable to other hill and dense urban settings where elevation changes restrict conventional mobility solutions. Aizawl's distinctive characteristics such as its long-standing cultural acceptance of stair use and community-managed step routes align with those of other hill cities in India, such as Nagaland, Meghalaya, and Arunachal Pradesh, as well as with cities in China. Cities without such embedded practices may require additional behavioral or institutional interventions to encourage adoption.

5.5. Design implications and mitigation strategies

To avoid exclusionary outcomes, interventions that rely on steps should be integrated with complementary measures that promote inclusive mobility. Practical measures include: providing parallel step-free routes where feasible (ramps, switchbacks, accessible zig-zags), installing handrails and frequent resting platforms, improving surface treatments and drainage to reduce slipping risk, ensuring adequate night-time lighting and clear wayfinding, and locating nearby accessible public transport or mobility hubs that reduce the need for long uphill walking. In constrained locations where step-free alternatives are not feasible, other technologies (e.g., stair lifts, platform lifts) and community transport options can partially mitigate exclusion. Importantly, planning decisions about stair networks should be guided by local accessibility standards and by consultation with older adults and people with disabilities so that connectivity gains are not achieved at the expense of social inclusion.

5.6. Limitations and trade-offs of steps for accessibility

While our analysis shows that steps selectively amplify connectivity of peripheral connectors and reduce pedestrian travel distance, it is important to emphasise that steps alone do not resolve the broader accessibility challenges of hill cities. Steps inherently create a vertical barrier: they disadvantage people with reduced mobility (elderly users, people using wheelchairs or mobility scooters), caregivers with prams, and cyclists, and they can impede emergency and delivery access. Steps can also exacerbate seasonal or safety concerns (e.g., slippery surfaces in wet seasons, low-lighting conditions at night) and may differentially benefit able-bodied pedestrians compared with other groups. Thus, although steps are effective augmentative connectors in the pedestrian network, their positive contribution to connectivity must be interpreted within the constraints of universal access and equity.

5.7. Methodological limitations

A methodological limitation arises from the use of two-dimensional segment analysis, which does not fully reflect the vertical dimension of movement. Prior studies have noted that traditional space syntax tends to underrepresent the effect of slope or elevation on pedestrian behavior, as paths are assessed by topological or geometric distance in plan view rather than perceived effort (Kim & Penn, 2004; de Smith, 2004). In our case, the lack of slope weighting may overestimate the attractiveness of very steep shortcuts, potentially diverging from actual user preferences. Future research could integrate slope-adjusted impedance measures, three-dimensional network modeling, or combined GIS–syntax approaches to more accurately represent pedestrian accessibility in hill cities.

6. Recommendations

Based on the analytical results and spatial observations, several recommendations are proposed to enhance pedestrian accessibility, connectivity, and safety in hill cities through context-sensitive design and planning interventions.

6.1. Design guidance and prioritisation for stairway interventions

While our results show that steps can produce measurable connectivity gains in hill cities, planners should treat stair networks as one element in a wider, inclusive mobility strategy. We recommend the following layered approach: design for safety and usability; prioritize new links where syntactic and demand evidence indicate the highest impact; and couple stair provision with complementary measures for inclusion and maintenance.

Safety and usability (design fundamentals)

Provide continuous handrails on both sides, intermediate landings for long flights, and tactile cues at the top and bottom of stairways to assist visually impaired users. Use non-slip surface treatments, ensure adequate drainage to prevent water pooling, and design steps with clear, uniform geometry to reduce trip risk. Illuminate stairs and adjacent paths to ensure safe night-time use, and include conspicuous wayfinding and signage showing step-free alternatives when available. Where feasible, provide parallel step-free alternatives (ramps, zig-zag switchbacks, or low-gradient bypass routes) or last-mile assistive measures (e.g., stair/platform lifts, community transport) to avoid exclusion of wheelchair users, caregivers with prams, and others with limited mobility. Ensure steps are designed and sited in accordance with local building codes and universal design guidance; when proposing new designs, consult accessibility standards and local authorities early in the process.

Where to prioritize new steps — a reproducible prioritization framework

Planners can combine network analysis with simple on-the-ground feasibility checks to identify "missing links" where a stairway would dramatically shorten journeys or raise an axis' connectivity. We suggest a transparent scoring rubric to rank candidate links. The rubric can be computed in GIS/space syntax workflows and used to prioritise investment. A suggested prioritisation criteria (eg; weights are illustrative and should be adapted locally) is shown in Table 1. The proposed weights could include Syntactic uplift (ΔIntegration / ΔChoice from "with vs without step" simulation), *weight*: *25%*; Reduction in travel distance/time (estimated % saving for common O–D pairs), *weight*: *20%*; Pedestrian demand potential (population, housing units, proximity to origins/destinations such as markets, schools, POS), *weight*: *20%*; Equity priority (served vulnerable groups, low-income neighborhoods), *weight*: *10%*; Constructability & land availability (physical feasibility, land tenure constraints), *weight*: *10%*; Safety & environmental risk (slope stability, exposure, seasonal hazards), *weight*: *10%*; Rough cost estimate/maintenance burden, *weight*: *5%*.

Table 1. Simple scoring table template (to compute final priority score)

Parameter	Score
ΔIntegration (norm)	0.72
ΔChoice (norm)	0.65
Travel time reduction (%)	24
Demand score	8
Equity score	7
Feasibility score	9
Safety risk score	6
Cost score	4
Weighted total	0–100

Note: "norm" indicates normalised values (0–1) across all candidates. Define demand, equity and feasibility scoring scales locally (e.g., 0–10). The weighted total ranks links for intervention.

6.2. Suggested implementation workflow (step-by-step)

- Map the existing pedestrian network in GIS (planar streets + pedestrian-only links & stairs) and generate a "with" and "without-steps" map.
- Run space syntax and network metrics (global/local integration, choice/betweenness, closeness) for both scenarios to compute Δ metrics.
- Overlay trip attractors (POS, transit nodes, markets, educational institutions) and residential density to estimate demand and compute travel-time reductions for representative O–D pairs.
- Apply the prioritisation rubric to produce a ranked short-list. For the top-ranked connections, perform site visits and feasibility checks (land tenure, slope stability, drainage, lighting, sightlines, crime risk).
- Collaborate for detailed design with local stakeholders, including older adults and disability groups, and secure permissions. Where step-free access is not feasible, include mitigations (resting platforms, handrails, lighting) and complementary service provision.
- Pilot the highest-priority stair(s), monitor pre/post changes in connectivity (space-syntax re-run), pedestrian counts, and user surveys, then scale up based on results.

6.3 Aizawl typology and generalization to other hill cities

In Aizawl, the studied steps connect an elevated ridge road (NH-6 corridor) down to a lower valley street (Brigade Street) that leads toward the POS, a common hill-city pattern where long ridge corridors dominate vehicular movement while stepped links provide local valley access. Planners in similar contexts should therefore search for ridge-to-valley connection points where a short stair can produce large ΔIntegration/ΔChoice and meaningful time-savings for uphill neighbourhoods.

7. Conclusions

This research reaffirms the critical role of spatial configuration in shaping pedestrian behavior and accessibility within hill cities. The study demonstrates that public open spaces (POS) are not only recreational destinations but also integral components of daily urban life, dependent on how effectively people can reach them. Despite the leisure-oriented purpose of POS, pedestrians exhibit a consistent preference for routes that are shorter, more direct, and perceived as safer, qualities most effectively achieved through stair-based connectivity.

The analysis using Space Syntax and DepthMapX provides strong evidence that the integration of steps within urban street networks significantly enhances spatial performance. With integration values rising by over 23% and choice values by nearly 88%, the results underscore how simple physical interventions can transform accessibility in complex topographies like Aizawl. Steps improve both the physical and perceptual dimensions of walkability, offering shaded, vehicle-free, and visible routes that increase comfort and security for all users.

More importantly, the findings highlight that these improvements are not isolated enhancements but part of a systemic recalibration of urban accessibility. Stair connections effectively bridge elevation disparities, reduce travel effort, and extend the pedestrian catchment of public spaces. In doing so, they contribute to spatial equity by ensuring that access to POS is not constrained by terrain or mobility limitations.

Therefore, incorporating step-based linkages into urban design frameworks should be viewed as a strategic intervention rather than a secondary convenience. Such context-sensitive planning can reshape mobility in hill settlements thereby promoting sustainability, inclusivity, and active travel. By harmonizing spatial form with topographic realities, cities can create public environments that are not only accessible but also vibrant, safe, and socially cohesive.

While rooted in the specificities of Aizawl, the study offers insights that can inform accessibility planning in other hilly and topographically constrained cities. Generalizable lessons include the value of designing stairways with inclusivity and safety in mind, and the potential of such networks to complement formal transit systems. At the same time, the cultural embeddedness of stair use in Aizawl highlights the importance of contextual adaptation when applying these strategies elsewhere.

Future work

Our space-syntax analysis describes how steps change network connectivity but does not capture detailed differential impacts across population groups. Future studies should combine syntactic measures with demographic and mobility data (age, disability status, mode share) and with physical attributes of pedestrian links (slope, cumulative elevation gain, step count, tread/riser geometry, surface condition). Field observations, user surveys, and accessibility audits will permit quantifying who benefits and who is excluded by step-based shortcuts (for example, estimating the share of residential units that gain step-free access). Such mixed methods would allow trade-off analysis and prioritisation of interventions that maximise accessibility while minimising exclusion.

Declaration of interest

The authors declare that there is no potential conflict of interest related to this research.

Funding

No funds or grants are received for this research.

References

Alexander, C., Ishikawa, S., Silverstein, M., Jacobson, M., Fiksdahl-King, I., & Angel, S. (1977). *A pattern language*. Oxford University Press.

Appadurai, A. (2000). Urban cleansing: Notes on Millenial Mumbai. *Public Culture*, *12*(3), 627–651. https://doi.org/10.1215/08992363-12-3-627

Asami, Y., Kubat, A. S., Kitagawa, K., & Iida, S.-I. (2003, January). Introducing the third dimension on Space Syntax: Application on the historical Istanbul. In *4th International Space Syntax Symposium* (pp. 48.1–48.19). https://www.spacesyntax.net/symposia-archive/SSS4/abstracts/48_AsamiKubatIda_abstract.pdf

Basu, N., Oviedo-trespalacios, O., King, M., & Haque, M. (2022). The influence of the built environment on pedestrians' perceptions of attractiveness, safety and security. *Transportation Research Part F*: *Psychology and Behaviour*, *87*, 203–218. https://doi.org/10.1016/j.trf.2022.03.006

Benati, G., Calcagni, F., Matellozzo, F., Ghermandi, A., & Langemeyer, J. (2024). Unequal access to cultural ecosystem services of green spaces within the city of Rome – A spatial social media-based analysis. *Ecosystem Services*, *66*, Article 101594. https://doi.org/10.1016/j.ecoser.2023.101594

Carmona, M. (2010). Contemporary public space, part two: Classification. *Journal of Urban Design*, *15*(2), 157–173. https://doi.org/10.1080/13574801003638111

Crouse, D. L., Pinault, L., Christidis, T., Lavigne, E., Thomson, E. M., & Villeneuve, P. J. (2021). Residential greenness and indicators of stress and mental well-being in a Canadian national-level survey. *Environmental Research*, *192*, Article 110267. https://doi.org/10.1016/j.envres.2020.110267

D'Orso, G., Yasir, M., & Migliore, M. (2025). Combining walkability assessments at different scales in measuring spatial inequalities in access to railway stations. *Journal of Transport and Health*, *44*, Article 102081. https://doi.org/10.1016/j.jth.2025.102081

de Smith, M. J. (2004). Distance transforms as a new tool in spatial analysis, urban planning, and GIS. *Environment and Planning B*: *Planning and Design*, *31*(1), 85–104. https://doi.org/10.1068/b29123

Di, X., & Liu, H. X. (2016). Boundedly rational route choice behavior: A review of models and methodologies. *Transportation Research Part B*, *85*, 142–179. https://doi.org/10.1016/j.trb.2016.01.002

Edwards, N., Hooper, P., Trapp, G. S. A. A., Bull, F., Boruff, B., & Giles-Corti, B. (2013). Development of a Public Open Space Desktop Auditing Tool (POSDAT): A remote sensing approach. *Applied Geography*, *38*(1), 22–30. https://doi.org/10.1016/j.apgeog.2012.11.010

Groenewegen, P. P., van den Berg, A. E., Maas, J., Verheij, R. A., & de Vries, S. (2012). Is a green residential environment better for health? If so, why? *Annals of the Association of American Geographers*, *102*(5), 996–1003. https://doi.org/10.1080/00045608.2012.674899

Han, S., Song, D., Xu, L., Ye, Y., Yan, S., Shi, F., Zhang, Y., Liu, X., & Du, H. (2022). Behaviour in public open spaces: A systematic review of studies with quantitative research methods. *Building and Environment*, *223*, Article 109444. https://doi.org/10.1016/j.buildenv.2022.109444

Hillier, B. (1996). *Space is the machine*. Cambridge University Press. https://doi.org/10.4324/9781003172147-2

Hillier, B., & Iida, S. (2005). Network and psychological effects: A theory of urban movement. *International Conference on Spatial Information Theory*, *1987*, 475–490. https://doi.org/10.1007/11556114_30

Karimi, K. (2018). Space syntax: Consolidation and transformation of an urban research field. *Journal of Urban Design*, *23*(1), 1–4. https://doi.org/10.1080/13574809.2018.1403177

Kim, Y. O., & Penn, A. (2004). Linking the spatial syntax of cognitive maps to the spatial syntax of the environment. *Environment and Behavior*, *36*(4), 483–504. https://doi.org/10.1177/0013916503261384

Koohsari, M. J., Kaczynski, A. T., Mcormack, G. R., & Sugiyama, T. (2014). Using space syntax to assess the built environment for physical activity: Applications to research on parks and public open spaces. *Leisure Sciences*, *36*(2), 206–216. https://doi.org/10.1080/01490400.2013.856722

Koohsari, M. J., Sugiyama, T., Mavoa, S., Villanueva, K., Badland, H., Giles-Corti, B., & Owen, N. (2016). Street network measures and adults' walking for transport: Application of space syntax. *Health and Place*, *38*, 89–95. https://doi.org/10.1016/j.healthplace.2015.12.009

Kumar, G., Vyas, S., Sharma, S. N., & Dehalwar, K. (2025). Urban growth prediction using CA-ANN model and spatial analysis for planning policy in Indore city, India. *GeoJournal*, *90*(3), 1–28. https://doi.org/10.1007/s10708-025-11393-7

Lackey, J. L., & Kaczynski, A. T. (2009). Correspondence of perceived vs. objective proximity to parks and their relationship to park-based physical activity. *International Journal of Behavioral Nutrition and Physical Activity*, *6*, 1–9. https://doi.org/10.1186/1479-5868-6-53

Lalramsangi, V., Garg, Y. K., & Shukla, B. (2026). Studying utility of public open spaces: A synthesis of variables influencing public open spaces usage through systematic literature review. *Journal of Planning Literature*, 1–19. https://doi.org/10.1177/08854122261439104

Lalramsangi, V., Garg, Y. K., & Sharma, S. N. (2025). Route choices to access public open spaces in hill cities. *Environment and Urbanisation ASIA*, *16*(2), 1–17. https://doi.org/10.1177/09754253251388721

Lalramsangi, V., Khiangte, L., & Lallianthanga, A. (2022). Manifestation of cultural and settlement patterns of vernacular mizo villages in modern neighborhoods of Mizoram, India. *ISVS E-Journal*, *9*(3), 86–102.

Lodhi, A. S., Jaiswal, A., & Sharma, S. N. (2025). Assessing bus users satisfaction using discrete choice models: A case of Bhopal. *Innovative Infrastructure Solutions*, *9*, Article 437. https://doi.org/10.1007/s41062-024-01652-w

Lyu, Y., Abd Malek, M. I., Ja'afar, N. H., Sima, Y., Han, Z., & Liu, Z. (2023). Unveiling the potential of space syntax approach for

revitalizing historic urban areas: A case study of Yushan Historic District, China. *Frontiers of Architectural Research*, *12*(6), 1144–1156.
https://doi.org/10.1016/j.foar.2023.08.004

Martínez-Chao, T. E., Menéndez-Díaz, A., García-Cortés, S., & Agostino, P. D. (2024). Urban pedestrian routes' accessibility assessment using geographic information system processing and deep learning-based object detection. *Sensors*, *24*(11), Article 3667. https://doi.org/10.3390/s24113667

Mohamed, A. A., & van der Laag Yamu, C. (2024). Space syntax has come of age: A bibliometric review from 1976 to 2023. *Journal of Planning Literature*, *39*(2), 203–217.
https://doi.org/10.1177/08854122231208018

Pais, F., Sousa, N., Monteiro, J., Coutinho-Rodrigues, J., & Natividade-Jesus, E. (2025). Walking to public transport: Rethinking catchment areas considering topography and surrogate buffers. *ISPRS International Journal of Geo-Information*, *14*(5), 1–18.
https://doi.org/10.3390/ijgi14050205

Peponis, J., & Wineman, J. (2002). Spatial structure of environment and behavior. In R. Bechtel & A. Churchman (Ed.), *Handbook of environmental psychology* (pp. 271–291). Wiley.

Pinto, L. V., Ferreira, C. S. S., Inácio, M., & Pereira, P. (2022). Urban green spaces accessibility in two European cities: Vilnius (Lithuania) and Coimbra (Portugal). *Geography and Sustainability*, *3*(1), 74–84. https://doi.org/10.1016/j.geosus.2022.03.001

Prato, C. G. (2009). Route choice modeling: Past, present and future research directions. *Journal of Choice Modeling*, *2*(1), 65–100. https://doi.org/10.1016/S1755-5345(13)70005-8

Puckett, R. R. (2009). *Multi-agent crowd behaviour simulation for tsunami evacuation* [Masters thesis]. Department of Information and Computer Sciences, University of Hawaii.

Schindler, M., Le Texier, M., & Caruso, G. (2022). How far do people travel to use urban green space? A comparison of three European cities. *Applied Geography*, *141*, Article 102673.
https://doi.org/10.1016/j.apgeog.2022.102673

Sharma, S. N., & Dehalwar, K. (2025a). A systematic literature review of pedestrian safety in urban transport systems. *Journal of Road Safety*, *36*(4), 55–78.
https://doi.org/10.33492/JRS-D-25-4-2707507

Sharma, S. N., & Dehalwar, K. (2025b). A systematic literature review of transit-oriented development to assess its role in economic development of city. *Transportation in Developing Economies*, *11*(2), 1–21.
https://doi.org/10.1007/s40890-025-00245-1

Sharma, S. N., & Dehalwar, K. (2025c). Examining the inclusivity of India's national urban transport policy for senior citizens. In *Transforming healthcare infrastructure* (1st ed., pp. 115–134). Taylor & Francis. https://doi.org/10.1201/9781003513834-5

Sharma, S. N., Singh, D., & Dehalwar, K. (2024). Surrogate safety analysis- leveraging advanced technologies for safer roads. *Suranaree Journal of Science and Technology*, *31*(4), Article 010320. https://doi.org/10.55766/sujst-2024-04-e03837

Space Syntax. (n.d.). *Spatial form analysis*. Retrieved April 20, 2024, from https://www.spacesyntax.online/applying-space-syntax/urban-methods-2/spatial-form-analysis/

State Investment Project Management and Implementation Unit. (2010). *Draft EIA Report "Development of Landfill Site for Aizawl City"* [F. No.10-73/2010-IA-III].

Sugiyama, T., Francis, J., Middleton, N. J., Owen, N., & Giles-Corti, B. (2010). Associations between recreational walking and attractiveness, size, and proximity of neighborhood open spaces. *American Journal of Public Health*, *100*(9), 1752–1757.
https://doi.org/10.2105/AJPH.2009.182006

Sun, X., & Cui, X. (2025). Mapping mobility gaps: Geospatial analysis of accessibility and equity from socioeconomic perspectives. *Transportation Research Part D*: *Transport and Environment*, *146*, Article 104909. https://doi.org/10.1016/j.trd.2025.104909

Tong, Y., & Bode, N. W. F. (2022). The principles of pedestrian route choice. *Journal of the Royal Society Interface*, *19*(189), Article 20220061. https://doi.org/10.1098/rsif.2022.0061

Urban Development and Poverty Alleviation Department. (2023). *Draft master plan report*: *GIS-based master plan formulation for aizawl city under Amrut* (Vol. 1). https://udpa.mizoram.gov.in/uploads/attachments/2024/02/a62e584d25a0ea39b649bdad88b579a5/posts-196-final-draft-master-plan-r6-v1-04-01-24.pdf

Van Nes, A., & Yamu, C. (2021). *Introduction to space syntax in urban studies*. Springer.
https://doi.org/10.1007/978-3-030-59140-3

World Health Organization. (2016). *Urban green spaces and health*. https://www.who.int/europe/publications/i/item/WHO-EURO-2016-3352-43111-60341

Yenisetty, P. T., & Bahadure, P. (2021). Assessing accessibility to ASFs from bus stops using distance measures: Case of two Indian cities. *Land Use Policy*, *108*, Article 105567.
https://doi.org/10.1016/j.landusepol.2021.105567

Zhang, J., Senousi, A. M., Zhao, P., Law, S., & Liu, X. (2023). Exploring 3D spatial morphology using multilayered space syntax, network science and wi-fi log data. *Urban Informatics*, *2*(1), 1–14. https://doi.org/10.1007/s44212-023-00023-7

Zhao, Z., Li, X., Xu, Y., Yang, S., Jiang, Y., & Wang, S. (2022). Evaluating spatial accessibility of cultural urban land use by using improved 2SFCA method in Xi'an, China. *Heliyon*, *8*(12), Article e11993. https://doi.org/10.1016/j.heliyon.2022.e11993

Zhou, S., Chen, F., & Xu, Z. (2022). Evaluating the accessibility of urban parks and waterfronts through online map services: A case study of Shaoxing, China. *Urban Forestry and Urban Greening*, *77*, Article 127731.
https://doi.org/10.1016/j.ufug.2022.127731