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TEXNIKA FANLARI DOKTORI, PROFESSOR MIRAXMEDOV MAXAMADJON MIRAXMEDOVICH TAVALLUDINING 80 YILLIGIGA BAG‘ISHLANGAN “SAMARALI QURILISH MATERIALLARI, KONSTRUKSIYALARI VA TEXNOLOGIYALARI” MAVZUSIDAGI XALQARO ILMIY-AMALIY KONFERENSIYASI ILMIY ISHLARI TO‘PLAMI

Toshkent davlat transport universiteti RAASN akademigi, O'zbekistonda xizmat ko'rsatgan yoshlar murabbiyi, texnika fanlari doktori, professor Miraxmedov Maxamadjon Miraxmedovich tavalludining 80 yilligiga bag'ishlangan, ilmiy ishlar to'plami nashr etilishi ko'zda tutilgan «Samarali qurilish materiallari, konstruksiyalari va texnologiyalari» mavzusidagi Xalqaro ilmiy-amaliy konferensiyani o'tkazishni rejalashtirmoqda.

M.M. Miraxmedov kompozitsion qurilish materiallarining polistruktura nazariyasini rivojlantirishga salmoqli hissa qo'shgan. Uning qurilish materialshunosligi sohasidagi ilmiy hissasi e’tirofi sifatida 1995-yilda Rossiya arxitektura va qurilish fanlari akademiyasining (RAASN) xorijiy a’zosi etib saylangan. M.M. Miraxmedov 6 ta monografiya, 200 dan ortiq ilmiy maqolalar va 25 ta ixtiroga mualliflik guvohnomalari muallifidir.

Ushbu konferensiyaning asosiy maqsadi - qurilish materialshunosligi, bino va inshootlarni loyihalash va qurilish sohasidagi ilmiy tadqiqotlar natijalarini, shuningdek, muhandislik ta’limini takomillashtirish yo'llarini muhokama qilishdan iborat.

Konferensiya ishida ishtirok etish uchun oliy o'quv yurtlari va ilmiy tadqiqot institutlari olimlari, O'zbekiston Respublikasi va xorijiy davlatlarning ishlab chiqarish vakillari, ilmiy tadqiqotlarda salmoqli natijalarga ega bo'lgan mutaxassislar taklif etiladi.

“Samarali qurilish materiallari, konstruksiyalari va texnologiyalari” mavzusidagi xalqaro ilmiy-amaliy konferensiyaning asosiy yo‘nalishlari quyidagilardan iborat:

1. Resurs va energiya tejovchi qurilish materiallari va texnologiyalari.
2. Atrof-muhitning transport infratuzilmasiga ta’siri va uni himoya qilish usullari.
3. Bino va inshootlarning qurilish konstruksiyalari: hisoblash va loyihalashning zamonaviy usullari.
4. Arxitektura, shaharsozlik va shahar muhitini rivojlantirish.
5. Qurilishni tashkil etishning innovatsion usullari va qurilish jarayonlari texnologiyalari.
6. Transport obyektlarini loyihalash va qurishda raqamli texnologiyalar hamda sun’iy intellekt.
7. Temir yo‘l transporti infratuzilmasi obyektlarini loyihalash, qurish va ekspluatatsiya qilish.
8. Zamonaviy muhandislik ta’limi tizimini takomillashtirish.

Mazkur konferensiya ilmiy hamjamiyatning turli vakillarini bir joyga jamlab, qurilish materialshunosligi sohasidagi zamonaviy muammolar va istiqbollarni muhokama qilish uchun qulay platforma vazifasini bajardi.

Integrating Roadside Greening and Urban Microclimate into Pedestrian Accessibility Assessment: A Case Study of Tashkent City

J.I. Sodikov[1][a], K.N. Musulmanov[1][b] and A.D. Adizov[1][c]
[1]Tashkent State Transport University, Uzbekistan

Abstract: Rapid urbanization has intensified the urban heat island (UHI) effect, particularly in hot-climate cities, affecting pedestrian mobility and comfort. While roadside greening provides important environmental benefits, its role in transport accessibility remains underexplored. This study develops a climate-sensitive accessibility model by integrating roadside vegetation and microclimate factors in Tashkent city.
Remote sensing data (LST and NDVI) and GIS-based network analysis were used to assess thermal conditions and walking accessibility (5, 10, and 15 minutes). A Thermal Comfort Index (TCI) was developed to incorporate temperature, vegetation, and shading into accessibility evaluation.
Results show that conventional models overestimate accessibility by ignoring environmental conditions. High-temperature, low-vegetation areas have reduced real accessibility, while green and shaded corridors improve pedestrian conditions.
The study proposes a new framework linking greening, microclimate, and transport accessibility, supporting more sustainable and climate-responsive urban planning.
Keywords: Urban Heat Island (UHI), Roadside Greening, Pedestrian Accessibility, Urban Microclimate, GIS-Based Analysis, Thermal Comfort, Climate-Sensitive Accessibility, Land Surface Temperature (LST), NDVI, Sustainable Urban Planning

1. INTRODUCTION

Rapid urbanization and the expansion of transport infrastructure have significantly transformed urban environments worldwide. Modern cities are increasingly characterized by dense road networks, high traffic volumes, and extensive impervious surfaces, which collectively contribute to environmental challenges such as air pollution, increased surface temperatures, and the urban heat island (UHI) effect. These issues are particularly pronounced in rapidly developing cities, where transport planning has traditionally prioritized vehicular mobility and efficiency, often at the expense of environmental and human-centered considerations.

Urban roads are not only mobility corridors but also important public spaces where people are directly exposed to environmental conditions. In this context, roadside environments play a crucial role in shaping urban microclimates and influencing human comfort. Numerous studies have demonstrated that vegetation, particularly trees and structured green elements along streets, can significantly reduce air temperature through shading and evapotranspiration, thereby mitigating the negative impacts of UHI. For example, roadside vegetation has been shown to lower land surface temperatures and improve thermal conditions at the pedestrian level, especially in dense urban areas where heat accumulation is most severe [1].

Beyond thermal regulation, roadside greenery is increasingly recognized as an integral component of urban green infrastructure. It provides multiple ecosystem services, including carbon sequestration, air pollutant removal, stormwater management, and biodiversity support. Recent studies highlight that roadside forests and vegetation belts can store substantial amounts of carbon, reduce atmospheric pollutants, and contribute to climate-resilient urban development [2]. In addition, vegetation barriers along roads can reduce pedestrian exposure to traffic-related pollutants by influencing airflow and enhancing particulate deposition, thereby improving public health outcomes [3].

At the same time, the relationship between roadside greening and pedestrian comfort has gained increasing attention. Thermal comfort is a key determinant of outdoor activity, particularly walking behavior in urban environments. Street-level conditions such as shading, tree canopy coverage, and spatial configuration of vegetation significantly influence perceived and actual comfort. Studies have shown that tree shading can reduce pedestrian heat exposure and improve the usability of urban spaces, especially during extreme heat conditions [4]. However, most of these studies focus on environmental or design aspects, without explicitly linking these factors to transport accessibility.

Transport accessibility is traditionally defined in terms of travel time, distance, and network

[a] https://orcid.org/0000-0002-4005-9766
[b] https://orcid.org/0000-0001-8906-9909
[c] https://orcid.org/0009-0008-2988-4061

connectivity. Conventional models, including isochrone-based analyses, assume that all routes within a given distance or time threshold are equally accessible. However, this assumption does not reflect real-world conditions, particularly in hot climates where thermal stress can significantly influence pedestrian movement. In cities such as Tashkent, where summer temperatures frequently exceed 35–40°C, walking behavior is strongly affected by environmental conditions such as shade availability and surface temperature.

Despite the growing body of research on urban greening, microclimate, and ecosystem services, there remains a critical gap in integrating these aspects with transport accessibility analysis. Existing studies tend to examine vegetation effects, thermal comfort, or transport systems in isolation, with limited efforts to develop a unified framework that captures their interdependencies. In particular, the influence of roadside greening on "real" pedestrian accessibility—defined not only by distance but also by environmental comfort—has not been sufficiently addressed.

Therefore, this study aims to bridge this gap by integrating roadside greening into urban transport and microclimate systems. Using the case of Tashkent city, the research evaluates how vegetation structure, thermal conditions, and street-level environmental factors influence pedestrian accessibility. The study proposes a climate-sensitive approach to accessibility assessment, in which roadside greening is treated as a key variable affecting both environmental quality and transport usability. By doing so, it contributes to the development of more sustainable, resilient, and human-centered urban transport planning frameworks.

2. LITERATURE REVIEW

Urban road corridors are increasingly recognized not only as transport infrastructure but also as multifunctional ecological systems. Previous studies indicate that roadside vegetation provides a wide range of ecosystem services, including microclimate regulation, air pollution mitigation, carbon sequestration, and improvement of pedestrian comfort [1–3].

Roadside vegetation plays a critical role in regulating urban thermal environments. Li et al. [1] demonstrated that the structure and composition of vegetation significantly influence land surface temperature (LST), with tree-dominated areas producing the strongest cooling effects in dense urban environments. Similarly, urban greenery enhances thermal comfort through shading and evapotranspiration, thereby reducing pedestrian exposure to heat stress [4].

From a green infrastructure perspective, roadside vegetation is an essential component of sustainable urban systems. Niu et al. [2] highlighted that roadside forests contribute to biodiversity, climate regulation, and urban resilience, while also providing measurable ecosystem services such as carbon storage, air pollutant removal, and stormwater interception. Moreover, the effectiveness of roadside greening varies depending on road type, suggesting that context-specific planting strategies are required rather than uniform approaches.

In addition, vegetation acts as a natural barrier that reduces exposure to traffic-related air pollution. Barwise and Kumar [3] emphasized that the effectiveness of vegetation barriers depends on plant characteristics such as leaf structure, density, and spatial configuration. These findings underline the multifunctional role of roadside greenery in improving both environmental quality and human well-being.

Despite these advances, a significant research gap remains. Most studies focus on the environmental and ecological aspects of roadside vegetation, while transport accessibility is typically assessed using distance, travel time, and network connectivity. Such approaches neglect thermal conditions, shading, and pedestrian-level comfort, which are particularly important in hot-climate cities such as Tashkent.

Therefore, this study aims to integrate roadside greening into transport accessibility and microclimate analysis by incorporating environmental comfort factors into accessibility assessment, thereby developing a climate-sensitive approach to urban mobility evaluation.

3. DATA COLLECTION METHOD

This study integrates multi-source spatial, environmental, and transport datasets to analyze the e relationship between roadside greening, microclimate conditions, and urban transport accessibility in Tashkent city. The overall data collection and integration framework is presented in Figure 1.

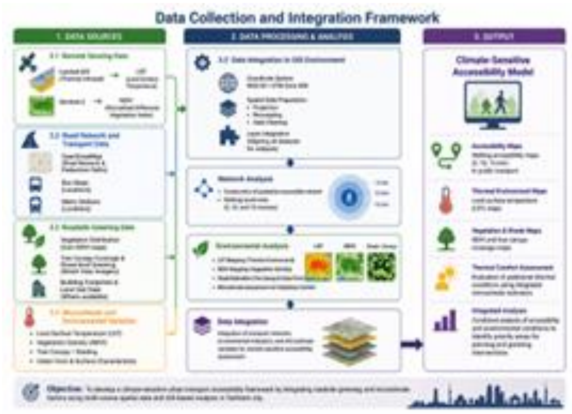

Fig. 1. Integrated Framework for Data Collection, Processing, and Climate-Sensitive Accessibility Analysis

The figure illustrates the workflow of the study, including data sources (remote sensing, transport, and greening data), GIS-based processing, network analysis, environmental assessment, and the development of a climate-sensitive accessibility model.

3.1. Remote Sensing Data

To assess the urban thermal environment, satellite imagery was used to derive Land Surface Temperature (LST) and vegetation indices. Landsat 8/9 thermal infrared bands were utilized to calculate LST, while Sentinel-2 imagery was employed to compute the Normalized Difference Vegetation Index (NDVI), which represents vegetation density and distribution. These datasets provide medium-resolution (10–30 m) spatial coverage suitable for city-scale analysis.

3.2. Road Network and Transport Data

The urban road network and pedestrian-accessible paths were extracted from OpenStreetMap (OSM). Public transport data, including bus stops and metro stations, were collected from available geospatial datasets and local sources. These data were used to construct a network-based accessibility model, including walking isochrones (5, 10, and 15 minutes).

3.3. Roadside Greening Data

Roadside vegetation characteristics were assessed using a combination of spatial and visual data sources. Vegetation distribution was derived from NDVI maps, while additional information on tree canopy coverage and street-level greening was obtained through street-view imagery and GIS-based interpretation. Where available, building footprints and land-use data were also incorporated to better represent urban morphology affecting shading and microclimate conditions.

3.4. Microclimate and Environmental Variables

In addition to LST and NDVI, environmental variables influencing pedestrian comfort were considered. These include surface temperature, vegetation density, and proxy indicators of shading, such as tree canopy coverage and urban form. These variables were used to evaluate the thermal conditions experienced by pedestrians at the street level.

3.5. Data Integration

All datasets were processed and integrated within a Geographic Information System (GIS) environment. Spatial layers were harmonized to a common coordinate reference system (WGS 84 / UTM Zone 42N) and analyzed using network analysis tools. The integration of remote sensing data, transport networks, and environmental indicators enabled the development of a climate-sensitive accessibility framework.

4. METHODOLOGY

This study proposes an integrated framework that combines urban transport accessibility analysis with microclimate and roadside greening factors. The methodology consists of four main stages: (1) data preprocessing, (2) conventional accessibility modelling, (3) environmental factor assessment, and (4) development of a climate-sensitive accessibility model.

4.1. Data Preprocessing and Spatial Framework

All spatial datasets were processed in a GIS environment. The road network, public transport stops, and environmental layers (LST, NDVI, vegetation coverage) were projected into a unified coordinate system (WGS 84 / UTM Zone 42N). Raster datasets were resampled to a consistent spatial resolution (30 m) to ensure compatibility.

The study area (Tashkent city) was divided into analysis units based on a regular grid system. Each grid cell was assigned environmental attributes, including land surface temperature, vegetation index, and proximity to green infrastructure.

4.2. Network-Based Accessibility Analysis

Accessibility was calculated using a network-based approach. The pedestrian-accessible road network was used to generate walking isochrones (5, 10, and 15 minutes) around public transport stops.

The conventional accessibility index was defined as:

$$A_{network} = \sum_{i=1}^{n} W_i$$

where:

W_i - accessibility weight based on walking time threshold.

This model assumes equal accessibility within a given time threshold, without considering environmental conditions.

4.3. Environmental and Microclimate Assessment

To incorporate environmental conditions, two key indicators were used:

- **Land Surface Temperature (LST)** – representing thermal exposure
- **Normalized Difference Vegetation Index (NDVI)** – representing vegetation density

Additionally, proxy indicators such as tree canopy coverage and urban form (building density) were used to estimate shading conditions.

A **Thermal Comfort Index (TCI)** was developed to represent the environmental suitability for pedestrian movement:

$$TCI = \omega_1 * (1 - LST_{norm}) + \omega_2 * NDVI_{norm} + \omega_3 * Shade$$

Where:

LST_{norm}- normalized land surface temperature

$NDVI_{norm}$- normalized vegetation index

***Shade*-** shading indicator (tree canopy / urban morphology)

ω_1; ω_2; ω_3- weighting coefficients

4.4. Climate-Sensitive Accessibility Model

To reflect real pedestrian behavior, environmental factors were integrated into the accessibility model.

The proposed **real accessibility index** is defined as:

$$A_{real} = A_{network} * (1 + \lambda TCI)$$

λ- environmental sensitivity coefficient.

This formulation adjusts conventional accessibility by incorporating thermal comfort and environmental quality.

In this model:

- areas with high temperature and low vegetation → reduced accessibility
- areas with shading and high greenery → increased accessibility

4.5. Spatial Analysis and Mapping

The final stage involved spatial overlay analysis to combine accessibility and environmental layers. The results were visualized using GIS-based maps, including:

- conventional accessibility maps
- thermal comfort distribution
- climate-sensitive accessibility maps

Comparative analysis was conducted to identify differences between traditional and environmentally adjusted accessibility patterns.

4.6. Validation and Interpretation

The model results were interpreted in relation to urban structure, road types, and distribution of green infrastructure. Particular attention was given to identifying:

- areas with high accessibility but low thermal comfort
- areas where greening significantly improves accessibility

5. RESULTS AND DISCUSSION

5.1. Spatial Distribution of Urban Thermal Environment

The analysis of Land Surface Temperature (LST) and vegetation density (NDVI) in Tashkent city reveals a strong relationship between urban thermal conditions and the spatial distribution of greenery. High-temperature zones are mainly concentrated along major road corridors, densely built-up districts, and areas with limited vegetation coverage. In contrast, urban areas characterized by higher vegetation density demonstrate noticeably lower surface temperatures.

The results indicate that roadside greenery and urban vegetation contribute significantly to mitigating thermal accumulation within the urban environment. Areas with continuous vegetation cover and tree canopy exhibit improved thermal conditions compared to impervious and highly urbanized surfaces. These findings confirm the important role of green infrastructure in reducing urban heat exposure and improving environmental comfort in transport-oriented urban spaces.

5.2. Conventional Accessibility Patterns

Network-based accessibility analysis shows that a large portion of the study area falls within 5–10 minute walking distance to public transport stops. According to the traditional model, these areas are considered highly accessible due to their proximity and connectivity within the road network.

However, this model assumes uniform conditions across all routes and does not account for environmental factors such as heat stress or shading.

5.3. Thermal Comfort Distribution

The Thermal Comfort Index (TCI) results indicate significant spatial differences in environmental suitability for pedestrian movement. Areas with high vegetation density and shading demonstrate higher TCI values, indicating more comfortable conditions. Conversely, zones characterized by high LST and low vegetation show low TCI values, reflecting unfavorable thermal conditions.

The results highlight that thermal comfort is not evenly distributed and is strongly influenced by the presence and structure of roadside greenery.

5.4. Climate-Sensitive Accessibility

When environmental factors are integrated into the accessibility model, significant changes are observed. The climate-sensitive accessibility (A_real) shows a reduction in accessible areas in zones with high temperatures and low vegetation.

In contrast, green corridors and streets with continuous tree canopy coverage maintain higher accessibility levels even under high-temperature conditions. This demonstrates that roadside greening can effectively enhance real pedestrian accessibility by improving thermal comfort.

5.5. Comparative Analysis

A comparison between conventional accessibility (A_network) and climate-sensitive accessibility (A_real) reveals that traditional models overestimate accessibility in heat-exposed areas. In several locations, areas classified as accessible under the network-based model become partially or fully inaccessible when thermal conditions are considered.

This discrepancy is particularly evident in central urban zones and major road corridors lacking sufficient greenery.

5.6. Key Findings

The results of this study demonstrate that:

- Urban heat significantly reduces real pedestrian accessibility
- Roadside vegetation improves thermal comfort and enhances accessibility
- Accessibility is strongly dependent on environmental conditions, not only distance and time

— Traditional accessibility models fail to capture spatial inequalities caused by microclimate factors.

DISCUSSION

The results of this study demonstrate that urban transport accessibility cannot be fully understood without considering environmental conditions, particularly microclimate and roadside greening. While conventional network-based models classify large areas as accessible based on distance and travel time, the integration of thermal and vegetation factors reveals significant spatial differences in real accessibility.

The findings confirm that roadside vegetation plays a critical role in shaping the urban thermal environment and pedestrian experience. Consistent with previous studies, areas with higher vegetation density and tree canopy coverage exhibit lower temperatures and improved thermal comfort. This is mainly due to shading effects and evapotranspiration processes, which reduce solar radiation exposure and ambient temperature at the street level. As a result, these areas support more favorable conditions for walking and outdoor activities.

In contrast, zones characterized by high land surface temperatures and limited vegetation demonstrate reduced environmental suitability for pedestrian movement. These areas, often located along major road corridors and dense urban structures, are subject to intensified urban heat island effects. The results suggest that such conditions can discourage walking behavior, even when transport infrastructure is physically accessible. This highlights a critical limitation of traditional accessibility models, which assume uniform conditions across all routes.

The integration of the Thermal Comfort Index (TCI) into accessibility analysis provides a more realistic representation of urban mobility. The comparison between conventional accessibility and climate-sensitive accessibility clearly shows that environmental factors can significantly modify accessibility patterns. In particular, the presence of continuous roadside greenery and shaded routes enhances accessibility, while heat-exposed areas experience a reduction in effective accessibility.

These findings have important implications for urban planning and transport policy. First, they emphasize the need to move beyond purely network-based approaches and incorporate environmental quality into accessibility assessment. Second, they highlight the strategic importance of roadside greening as a tool for improving both environmental conditions and transport usability. Rather than being treated as an aesthetic or secondary element, vegetation should be considered an integral component of transport infrastructure.

Furthermore, the results support the concept of climate-sensitive urban planning, where green infrastructure is used to mitigate the negative impacts of urban heat and improve human well-being. In the context of Tashkent, where summer temperatures frequently exceed 35–40°C, integrating greening into transport systems is particularly important for ensuring sustainable and inclusive mobility.

Despite these contributions, the study has several limitations. The use of remotely sensed data may not fully capture micro-scale variations in shading and thermal conditions at the pedestrian level. In addition, the Thermal Comfort Index is based on selected indicators and weighting assumptions, which may require further calibration using field measurements or behavioral data. Future research should focus on incorporating real-time climate data, pedestrian surveys, and high-resolution 3D urban models to improve the accuracy of climate-sensitive accessibility analysis.

6. CONCLUSION

This study demonstrates that urban transport accessibility cannot be accurately assessed without considering environmental conditions, particularly microclimate and roadside greening. While conventional accessibility models rely on distance and travel time, they fail to capture the influence of thermal stress and environmental quality on pedestrian movement.

By integrating remote sensing data, GIS-based network analysis, and environmental indicators, this research developed a climate-sensitive accessibility model for Tashkent city. The results show that high temperatures and low vegetation coverage significantly reduce real pedestrian accessibility, whereas shaded and green corridors enhance walking conditions and improve accessibility. This highlights the critical role of roadside vegetation in mitigating urban heat and supporting more comfortable pedestrian environments.

The study contributes to the existing literature by linking three traditionally separate domains—transport accessibility, urban microclimate, and green infrastructure—into a unified analytical framework. It introduces a Thermal Comfort Index (TCI) to adjust accessibility based on environmental conditions, providing a more realistic representation of urban mobility.

From a practical perspective, the findings emphasize that roadside greening should be treated as an essential component of transport infrastructure rather than a purely aesthetic element. In hot-climate cities such as Tashkent, integrating vegetation into road design and planning can significantly improve thermal comfort, promote walking, and enhance overall urban sustainability.

In conclusion, the proposed climate-sensitive approach offers a valuable tool for urban planners and decision-makers to design more resilient, livable, and environmentally responsive transport systems. Future research should focus on incorporating high-resolution data, field-based measurements, and behavioral analysis to further refine accessibility models and better understand the interaction between environment and human mobility.

Climate adaptation and planning implications

The findings of this study highlight the importance of integrating environmental factors, particularly roadside greening and microclimate conditions, into urban transport planning. Based on the results, several policy recommendations can be proposed to improve pedestrian accessibility and support sustainable urban development in Tashkent.

Integration of Greening into Transport Infrastructure

Urban planning policies should recognize roadside vegetation as an essential component of transport infrastructure rather than a purely aesthetic element. Municipal authorities should incorporate tree planting and green corridors into road design standards, especially along major pedestrian routes and public transport access paths.

Climate-Sensitive Accessibility Planning

Transport accessibility assessments should move beyond traditional distance- and time-based approaches by incorporating environmental indicators such as temperature, shading, and vegetation coverage. Planning guidelines should adopt climate-sensitive accessibility models to ensure that pedestrian routes remain usable under extreme heat conditions.

Development of Shaded Pedestrian Networks

Priority should be given to the creation of shaded walking corridors connecting residential areas to public transport stops. Continuous tree canopy coverage, combined with appropriate urban design elements, can significantly improve thermal comfort and encourage walking behavior, particularly during summer periods.

Strategic Placement of Public Transport Stops

The location of bus stops and metro access points should consider not only network efficiency but also environmental conditions. Stops should be placed in areas with adequate shading and vegetation or be equipped with artificial shading structures where natural greenery is insufficient.

Targeted Greening in High-Temperature Zones

High-temperature areas identified through LST analysis should be prioritized for greening interventions. These zones, often located along major road corridors and densely built environments, require targeted planting strategies to reduce thermal stress and improve environmental quality.

Adoption of GIS-Based Decision Support Systems

Urban planning institutions should implement GIS-based tools that integrate transport, environmental, and climatic data. Such systems can support evidence-based decision-making and enable the identification of priority areas for greening and infrastructure improvements.

Climate Adaptation and Urban Resilience Strategies

Given the increasing frequency of extreme heat events, roadside greening should be included as a key component of climate adaptation policies. Integrating green infrastructure into transport systems can enhance urban resilience, reduce heat-related risks, and improve overall quality of life.

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INFORMATION ABOUT THE AUTHOR

Jamshid Sodikov	Tashkent State Transport University, Urban infrastructure engineering and artificial intelligence, Tashkent, Uzbekistan E-mail: sodiqov_j@tstu.uz https://orcid.org/0000-0002-4005-9766
Kuvonchbek Musulmanov	Tashkent State Transport University, Urban infrastructure engineering and artificial intelligence, Tashkent, Uzbekistan

	E-mail: musulmanov_kuvonchbek@tstu.uz https://orcid.org/0000-0001-8906-9909
Dilshodbek Adizov	Tashkent State Transport University, Urban infrastructure engineering and artificial intelligence, Tashkent, Uzbekistan E-mail: adizov_d@tstu.uz https://orcid.org/0009-0008-2988-4061

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