



The Role of Urban Landscape elements Promoting Non-Motorized Transportation for Improving Microclimate Conditions in Humid Subtropical Cities

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Abstract. Rapid urbanization and motorized transportation have significantly impacted urban microclimate conditions like degrading air quality, increasing surface temperature, and increasing heat stresses in urban cities. Microclimate conditions impact the adoption of non-motorized transportation [NMT], specifically in humid subtropical urban areas. This study explores the potential of urban landscape elements to improve microclimate conditions to enhance the NMT usage. The study identifies and explores the urban landscape elements that contribute towards thermal comfort and user experience for NMT users. The methodology combines systematic literature review, case studies, and thematic analysis. The study has a comparative analysis of three international cities: Chengdu [China], Taipei [Taiwan], and Brisbane [Australia]. By this integrated approach, landscape elements are classified into two broad domains: natural landscape elements & built landscape elements. The finding shows that natural elements, particularly street trees and continuous green corridors, have the greatest cooling potential [lowering ambient temperature by approximately 2-3 degrees Celsius through shading & evapotranspiration]. Whereas, built landscape elements, with permeable pavements and green drainage systems also play a significant role in improving surface thermal conditions by 1-2°C. Results also show that strategically combining these natural landscapes & built landscape elements generates cumulative cooling benefits of up to 7°C. This suggests that a thermally comfortable NMT route creates ecologically beneficial environments. The study underscores the importance of integrating microclimate-sensitive landscape design into NMT planning and broader urban mobility policies. Such intervention can support climate resilient urban development and promote sustainable, human-centered urban mobility systems suitable for humid subtropical climates.

Keywords: Non-Motorized Transportation, Microclimate, Urban landscape, and Sustainable mobility.

1 Introduction

Rapid urbanization has emerged as one of the most transformative global trends of the twenty-first century. Urbanization led to an increase in motorized transportation, presenting complex challenges like traffic congestion, noise pollution, air pollution & degrading microclimatic conditions. In many developing countries, particularly in fast-developing nations like India, financial growth and urban sprawl have increased reliance on motorized personal transportation, including car & motorbikes. The increase in the use of motorized vehicles has resulted in increased consumption of fossil fuel and greenhouse gas emissions, exacerbating the urban heat island effect and degrading the air quality. The maximum use of motorized transportation alters the urban energy balance by increasing surface heat, lowering albedo on asphalt surfaces, etc. All of these exacerbate the local microclimate within an urban area [1]. Cities with high motorization rates resulted in higher land surface temperatures, higher ambient air temperatures, and slower wind speeds causing thermal discomfort and negative health consequences. Furthermore, prioritizing road space for cars often leaves less room for vegetation, shade, and public open spaces, all of which are critical for microclimate conditions.

In order to do this, SDG's goal 11 advocates NMT usage where NMT reduces total fuel consumption, which in turn reduces emissions of CO₂ and other local pollutants. Empirical research and intervention evaluations show that safe infrastructure for NMT trends promotes active travel and also decreases emissions [2]. Infrastructure upgrading makes NMT more attractive and secure. Trees and shaded areas mitigate radiant heat and surface heat at sidewalk level, enhancing NMT comfort during warmer periods. The public are more likely to choose NMT with microclimate enhancement. Many studies measuring the cooling effects of trees and green spaces show that well-planned street greenery lowers microclimate temperatures and improves thermal comfort.

The research aims to identify the urban landscape elements that help in improving microclimatic conditions to encourage the non-motorized transportation in humid subtropical climatic zones. Case studies were chosen with a criterion having a similar climate zone to identify strategies for urban landscape elements & NMT planning. Case studies show that different strategies are implemented in each case. Comparative analyses of all case studies identified elements that improve microclimatic condition. The findings provide the insight for the policymakers and designers to make a climate-oriented non-motorized transportation network.

2 Background study

Non-motorized transportation systems are severely hampered by heat waves, especially in areas with humid subtropical climates. Walking and cycling can be discouraged by high temperatures and high humidity levels, which can cause discomfort, dehydration, and heat-related illnesses. This decline in NMT usage not only impacts individual

health but also derails efforts to promote sustainable urban mobility. According to [3], heat waves and high temperatures make NMT users vulnerable.

Urban areas have experienced extreme heat waves in past decade that have impacted non-motorized transportation usage. In order to support NMT in the face of rising temperatures, it is significant to put climate-resilient infrastructure into practice.

Use of non-motorized transportation reduces the carbon emission and helped improve air quality and temperature. Another way to achieve this is by having adequate urban landscape elements and strategies with specific implementation. To understand the urban landscape elements and their impact on NMT users, comparative analysis of case studies has been done. The finding helps in the improvement of microclimatic conditions, which ultimately encourages the NMT's users.

3 Methodology

This study employs a comparative analysis approach to understand the impact of urban landscape elements on microclimatic conditions to promote non-motorized transportation. A comprehensive review of literature and reports [2015–2025] was used to identify landscape element interventions that influencing NMT adoption. To understand what landscape elements, improve thermal comfort and active travel behavior. The case studies focus on cities with humid subtropical climatic conditions that have implemented successful climate-responsive NMT systems. The comparative analysis of case studies is conducted to identify the most effective design strategies that strongly influence NMT use & improve microclimate. The result outlines the design strategies for thermally comfortable, pedestrian friendly and sustainable urban corridors. The recommendations made for decision makers & planners emphasize on the integration of ecological design with active mobility planning to enhance sustainability. An optimistic design develops, integrating landscape design to improve microclimatic condition and NMT promotion. The methodology progresses from theoretical understanding to practical application and provides a replicable design framework for sustainable, microclimate-sensitive NMT planning in humid subtropical climate context shown in Figure 1.

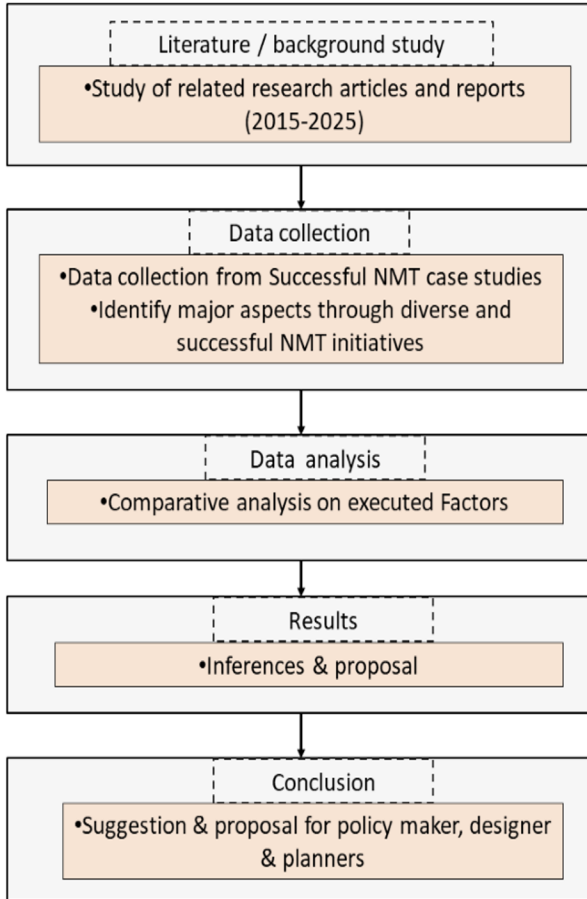


Fig.1. Research methodology followed for this work.

4 Data collection

The selection criteria for the case study are based on the integration of non-motorized transportation and urban landscape design in the humid subtropical climate zone. The data is collected from the selected three international case studies. The selected three international case studies are Chengdu [China], Taipei [Taiwan], and Brisbane [Australia]. The climate relevancy is explained in the next paragraph.

Chengdu has a humid subtropical climate characterized by high humidity, abundant rainfall, and four distinct seasons. Chengdu is located in the Sichuan Basin, surrounded by mountains [4]. Taipei has a humid subtropical climate, classified as Cfa by the Köppen-Geiger system. The Significant rainfall throughout the year, with long hot

summers, is sweltering and very humid, with temperatures often exceeding 30°C. Brisbane has a humid subtropical climate, having hot, wet, and humid weather, with average temperatures ranging from 21–29.8 °C. Its proximity to the Coral Sea influences its weather, keeping the region free from temperature extremes compared to inland areas. The recorded temperature and annual rainfall for all three international cities are shown in Figure 2 & Figure 3 below.

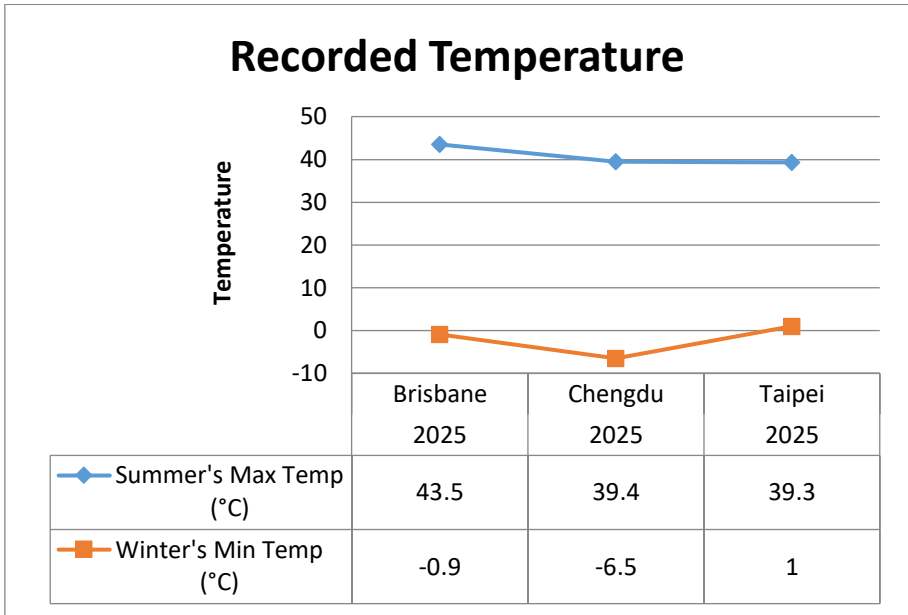


Fig.2. Highest & lowest recorded temperature for case examples:-Chengdu, Taipei, and Brisbane.

Source: - Authors

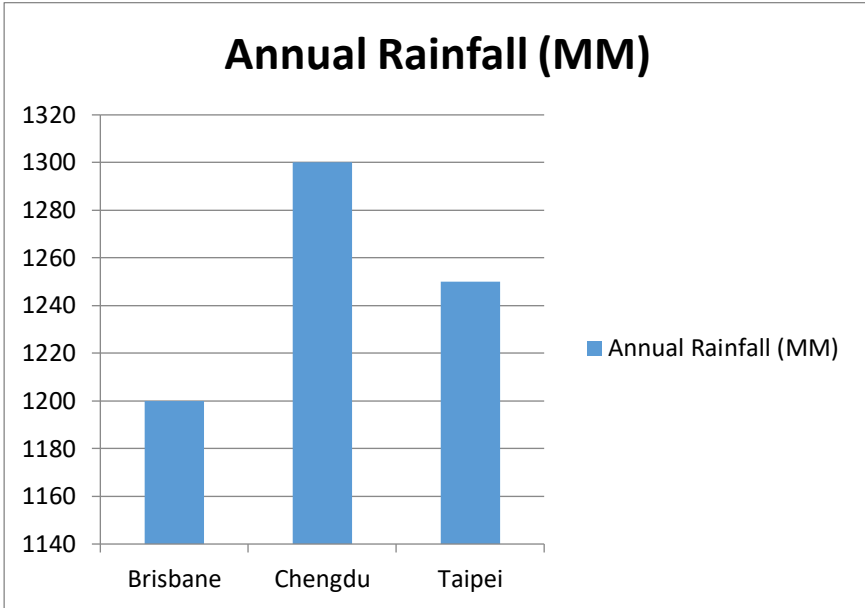


Fig.3. Annual rainfall recorded for case examples: -Chengdu, Taipei, and Brisbane.

Source: - Authors

Case study: - Chengdu [China]

Chengdu [China]: - Chengdu features a compact urban structure situated in Sichuan basin, which has a humid subtropical climate. The climatic conditions increase the urban heat island effect, especially in central district [4]. Chengdu’s urban development approach integrates non-motorized corridors with greenway systems, connecting parks, riverbanks and residential areas. According to research [4], the “Tianfu greenway network”, combining cycling and pedestrian-friendly environments with continuous green belts spread over 16,930km, has significantly improved the city’s microclimate. Particularly in warmer months the shaded tree canopies, water sensitive urban design and native vegetation buffers have reduced surface heat retention and improved thermal comfort, resulting in increased NMT activity [5]. Chengdu Municipality initiated the “Tianfu Greenway Scheme”, a 16,930-km greenway network shown in figure 4 and a typical plan & section shown in figure 5.

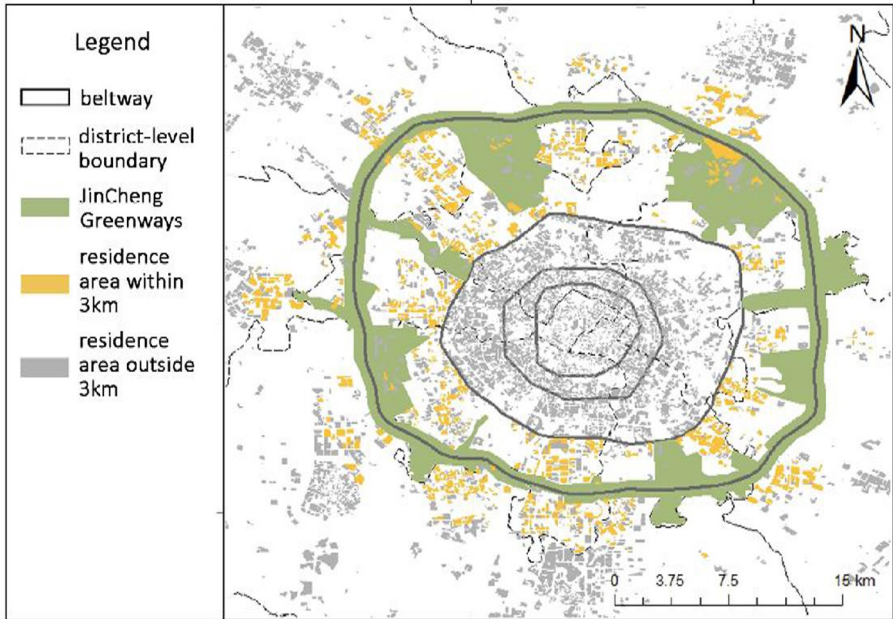


Fig.4. The “Tianfu greenway network”. Source: - [6]

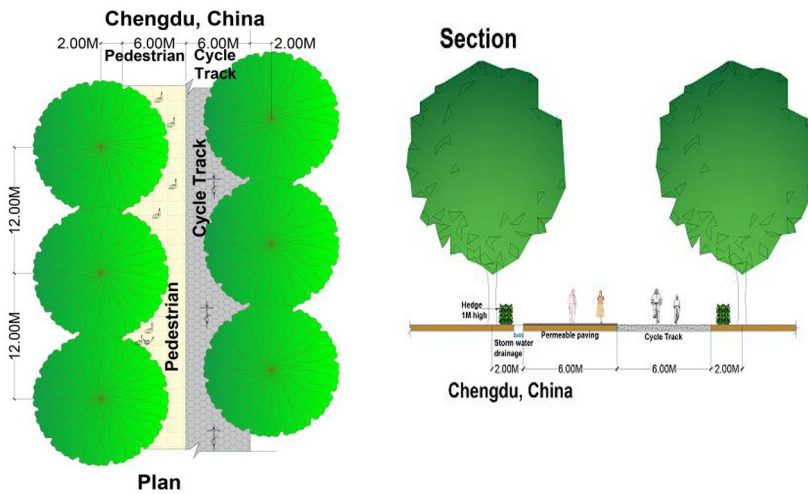


Fig.5. Typical plan & section of a road in Chengdu. Source: - Author’s

Taipei [Taiwan]: - Taipei has a dense urban form considered a mixed land use and lies in a humid subtropical climate zone, with hot humid summers and mild winters. Urban heat accumulation due to limited air circulation and compact built-up creates challenges to thermal comfort. Taipei has developed a widespread bicycle-sharing system and well-integrated pedestrian comfort and air quality. The “Green city” and “Walkable city” initiatives highlight tree lined boulevards, green roofs, and the green corridors. These interventions have shown the reduction of surface temperature, lower mean radiant temperature, and improved walk ability [7]. Shaded pedestrian pathways and green facades help in reducing heat stress and encouraging year-round walking and cycling [8]. The “Green city” and “Walkable city” programs by Taipei government are shown below in Figure 6, and typical plan & section are shown in Figure 7.

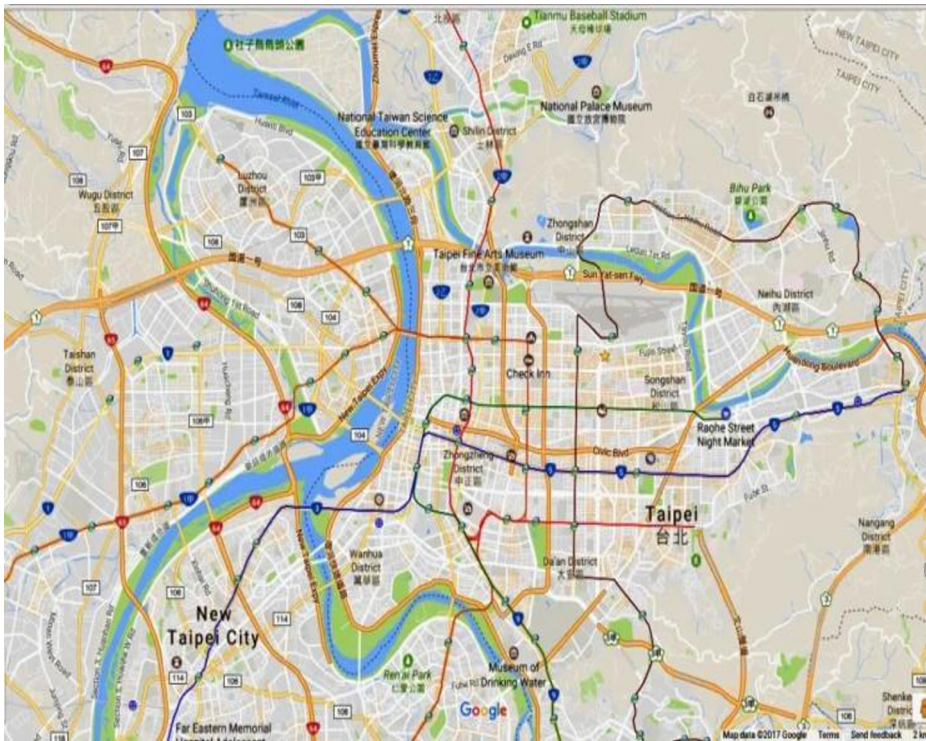


Fig. 6. The “Green city” and “Walkable city”. Source: - Map source

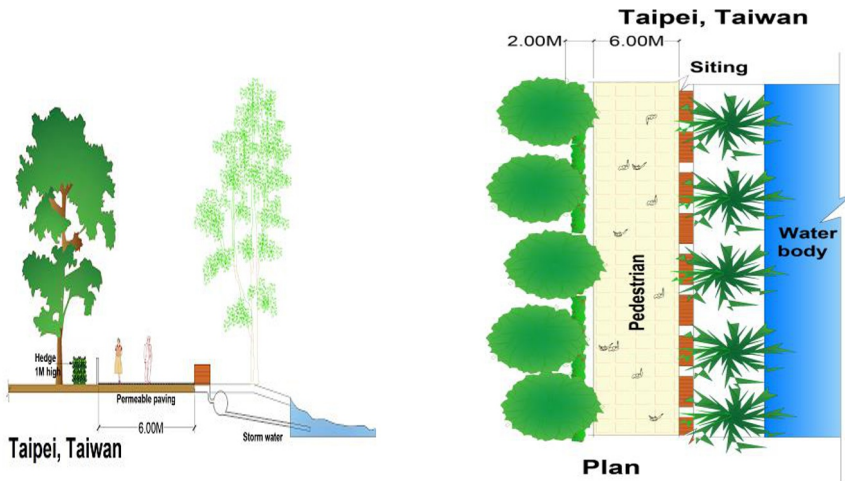


Fig.7. Taipei pedestrian walkways Typical plan & section. Source: - Author's

Brisbane [Australia]: - Brisbane has a low to medium-density urban structure that integrates green spaces, river corridors, and suburban developments. The city has a humid subtropical climate where heat mitigation becomes a priority in urban areas. Brisbane's widespread bikeway network along the Brisbane River, green bridges, and shaded pedestrian zones promotes NMT [9]. The city plan 2014 integrates landscape-based cooling strategies with NMT infrastructure. Projects such as "The Brisbane Green Infrastructure Strategy" and "City Cycle Program" combine vegetation corridors, porous paver pavements and riverside tree plantations to enhance cooling [10]. According to the study, it was shown that temperature reduction in shaded area increased NMT adoption [10]. The "City Cycle Program" scheme plan is shown in Figure 8 and a typical plan & section shown in Figure 9.

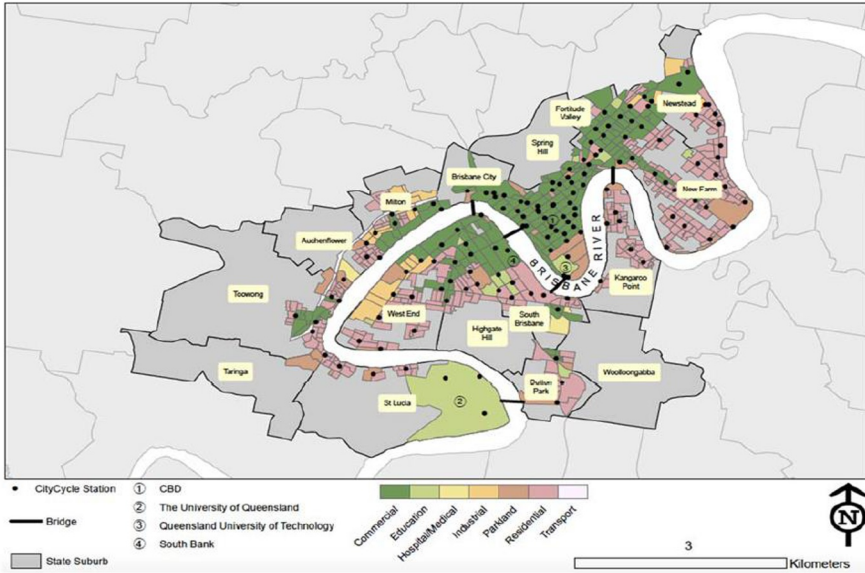


Fig.8. The city cycle scheme of Brisbane [Australia].

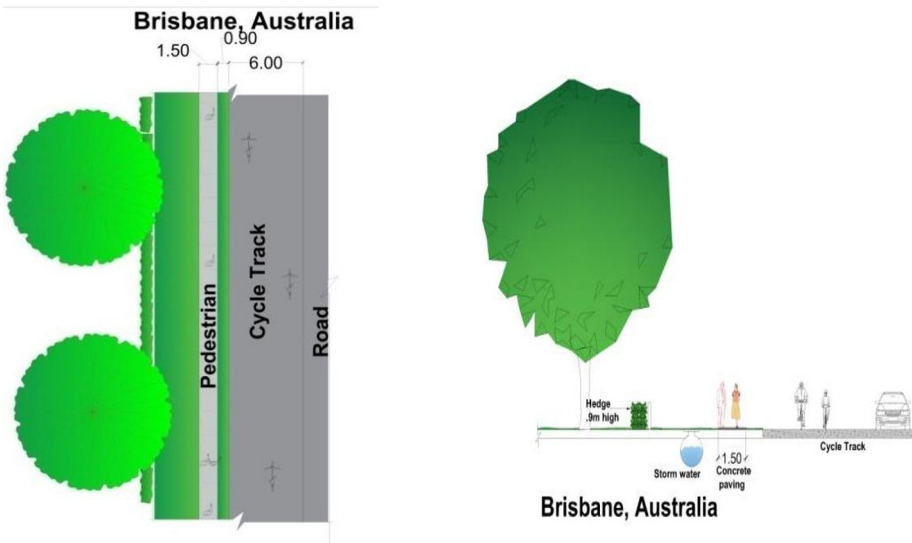


Fig.9. Brisbane pedestrian walkways typical plan & section. Source: - Author's

5 Comparative analysis

After carefully understanding each aspect of all three international case studies, urban landscape elements affecting microclimate conditions and advancement of non-motorized transportation were identified. These factors were systematically classified into two themes for comparison among cities. This thematic formulation resulted from the combination of literature and case study fusion.

The formulated themes are “natural landscape elements” & “built landscape elements”. The “natural landscape elements” theme is formed from the factors associated with ecological system that directly impact on thermal conditions [11]. On the other hand, the “built landscape elements” theme evolved from design-based interventions. These elements are introduced to support the human activity, microclimate condition and thermal comfort in urban areas. Unlike natural elements, built landscape element’s cooling effects are restricted but strategically significant, encouraging pedestrian movement and providing thermal comfort within the NMT corridors [12]. The comparative analysis was carried out on the two themes discussed below.

Theme 1: Natural Landscape Elements

The first theme, “natural landscape elements” has considered tree& green corridors, hedges & shrubs, vegetated medians & buffer zones as factors. These factors play a vital role in influencing microclimate, comfort, safety and usability of non motorised transportation routes. These natural landscape elements influence thermal comfort and personal choice for NMT [13]. The comparative analysis highlights the present “natural landscape elements” in three cities, Chengdu [China], Taipei [Taiwan], and Brisbane [Australia], that have integrated landscape-based strategies to promote NMT discussed in Table 1.

Table 1. Comparative analysis of “natural landscape element” applications in Chengdu, Taipei and Brisbane and their impact on microclimate and NMT users.

Elements	Chengdu [China]			Taipei [Taiwan]			Brisbane [Australia]			
	Function	Microclimate Impact	Reduced Temperature in degree	Function	Microclimate Impact	Reduced Temperature in degree	Function	Microclimate Impact	Reduced Temperature in degree	NMT Influence
Trees & Green Corridors	Shaded Greenery & biodiversity	Reduce urban heat, improve air quality, moderate humidity	2-3°C	Urban greenery, recreation	Reduce heat, improve air quality, buffer wind	2-3°C	Street trees, riverside greenways	Cool surfaces, shade, improved air quality	1-2°C	Encourage walking, recreational cycling
Hedges & Shrubs	Visual buffers & biodiversity	Minor cooling, air purification	0.5-1°C	Street hedges for aesthetics	Reduce glare, minor cooling	0.5-1°C	Hedges along sidewalks	Reduce heat along pavements	1-2°C	Safer walking environment

Vegetated Medians & Buffer Zones	Noise buffer, air filter	Reduce noise, improve air quality	1-2°C	Tree belts along highways	Cool streets, reduce wind	0.5-1°C	Vegetated medians & parkways	Moderate heat, reduce pollution	1-2°C	Safer pedestrian/cycling environment
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a) *Trees and Green Corridors along NMT networks*

The comparative analysis shows that the trees & green corridors form as a backbone of the city’s ecological infrastructure in Chengdu, These trees and green corridors moderate the heat island effect in urban areas by reducing surface and air temperature by 2–3°C through shading [5]. Similarly, Taipei shows similar benefits, where tree along streets and riverside parks improve the air quality and provide thermal comfort. According to [7], a study shows that greenways systems report a comparable 2–3°C cooling, particularly improving pedestrian comfort and NMT usage. On the other hand, Brisbane uses mature tree canopies to reduce Surface temperature by 1–2°C [10].

b) *Hedges and Shrubs along NMT networks*

The “hedges and shrubs” contribute secondary important cooling and comfort benefits for environment & NMT users. In Chengdu, hedges are used as visual & noise buffers, filter particulate matter, and slightly reduce local temperatures by 0.5–1°C [14]. Similarly, Taipei hedges are reducing local temperatures by 0.5–1°C. Hedges are plants for glare reduction, and contributing to pedestrian comfort and sense of safety [7]. Brisbane employs shrubs and low vegetation along sidewalks and bikeways to create thermal relief zones, which studies indicate provide up to 1–2°C reduction near pavements [9]. Although the cooling effect of hedges and shrubs is smaller than that of trees, shrubs increase perceived comfort and safety factors that influence NMT choice.

c) *Vegetated Medians and Buffer Zones*

Vegetated medians and buffers act as green spaces that separate NMT users from motorized traffic and improve safety and comfort. In Chengdu, buffers are used to reduce noise and pollution while providing microclimate cooling of 1–2°C [4]. Tree belts along roads act as wind breakers, lowering near-road temperature by .05-1°C and encouraging NMT in Taipei [11]. In Brisbane, vegetated pathways and medians contribute to heat resilience and pollution. Safety and attractiveness of NMT corridors are decisive factors of transport mode choice, which enhanced by green buffers [15]. In total, all three cities have natural landscape elements that show measurable enhancement in NMT adoption and microclimate improvements.

Theme 2: Built Landscape Elements

The second theme, “Built landscape element” considered paving material and drainage system as integral to human scale urban design. Built landscape elements enhance comfort and improve usability of NMT Infrastructure [16]. All three cities have integrated these components differently based on climate, cultural patterns, and planning priorities discussed in table 2.

Table 2. Comparative analysis of “built landscape element” applications in Chengdu, Taipei and Brisbane and their impact on microclimate and NMT users.

Elements	Function	Chengdu [China]		Function	Taipei [Taiwan]		Function	Brisbane [Australia]		
		Microclimate Impact	NMT Influence		Microclimate Impact	NMT Influence		Microclimate Impact	NMT Influence	
Paving Materials	Permeable & heat-reflective	Reduce surface heat, improve drainage	1 - Safer & cooler 2 - walking/cycling	Permeable paths	Lower heat absorption & improve drainage	1 - Cool pavements encourage walking/cycling 2 - Encourage walking/cycling	Asphalt & concrete	Manage heat island effect	1 - Decrease walking/cycling routes 2 - Better fit	1 - Safer & scenic walking routes
Drainage Infrastructure	Stormwater management, aesthetics	Reduce runoff, minor cooling	1 - Enhance pedestrian experience 2 - C	Green stormwater systems	Mitigate flooding, slight cooling	1 - Encourage walking along park ways 2 - C	Rain gardens along streets	Reduce surface temperature	1 - 2 - C	1 - Safer & scenic walking routes

a) Paving Materials

Paving materials significantly influence pedestrian thermal comfort and urban heat buildup. Permeable pavements on Pedestrian Streets and bicycle tracks were introduced in Chengdu and Taipei cities to reduce surface heat and improve storm water infiltration [14]. Permeable pavers provided water infiltration through tracks and demonstrated a surface cooling effect of 1-2°C, providing thermal comfort for NMT users [17]. Brisbane used asphalt and concrete as materials on the pavements in NMT routes. Asphalts and concrete are durable, exhibit high heat absorption, block water, and create a negative impact on thermal comfort, often resulting in higher local surface temperatures during summer. According to [17], studies show that conventional asphalt is up to 4–9°C hotter than cool or permeable pavers. This negative impact discourages pedestrian activity during peak heat hours.

b) Drainage Infrastructure

Drainage management contributes to both microclimate conditions and NMT user's thermal comfort. In Chengdu, semi open drainage not only reduces runoff but also reduces surface temperature by 1–2°C due to evaporative cooling [18]. Taipei integrates green storm water infrastructure, like bio swales and basins, within its “Blue green Network plan”. These elements mitigate flooding and provide slight microclimate cooling by 1–2°C while improving user's comfort at NMT routes [7]. Brisbane introduced rain garden and water-sensitive urban design [WSUD] principles that reduce surface runoff and heat buildup. The rain gardens near pathways reduce surface temperatures by 1–2°C, creating safer, visually appealing NMT environments [19].

6 Results & Discussion

The comparative study of three international cities, Chengdu, Taipei, and Brisbane, shows that the incorporation of “natural landscape element” and “built landscape element” enhances the microclimatic condition and the non-motorized transportation usage. In all three cities, design approaches that combine human-centered infrastructure with ecological planning result in better thermal comfort and encourage NMT.

Chengdu's Tianfu greenway network act as an example, that the long, shaded walkways reduce local air temperatures and promote NMT during the warmer months by providing cooling through evapotranspiration. Water filtration through permeable pavers provides thermal comfort and mitigates floods as shown in Chengdu and Taipei case. Incorporating small-scale elements like bio swales, permeable pavements, and street tree canopies can improve thermal comfort even in dense urban fabrics, as demonstrated by Taipei's Blue-Green Network Plan. Whereas, Brisbane uses Water Sensitive Urban Design [WSUD] principles, integrating vegetation, drainage, and shading along NMT routes to reduce surface heat and increase accessibility during extreme heat.

These findings suggest that layered landscape design, where “natural landscape elements”, “built landscape elements”, and “human comfort” interact harmoniously, can help humid subtropical cities achieve sustainable NMT enhancement.

Together, they provide a comprehensive landscape-based approach for improving microclimate conditions and promoting NMT usages in urban areas.

7 Conclusion

The study concludes that landscape-based interventions play an important & influential role in providing thermally comfortable NMT environments.

Among all interventions:

- Trees and green corridors deliver the strongest microclimate benefit [2–3°C reduction].
- Vegetated medians and buffer zones enhance safety and comfort while achieving a 1–2°C reduction.
- Hedges and shrubs provide cooling of 0.5–2°C and aesthetic coherence. Permeable pavements contribute to 1–2°C surface cooling.
- Drainage systems regulate surface water and provide an additional 1–2°C cooling effect.

Individually, each element improves environmental conditions, and collectively, they produce thermal reductions of 4–7°C, creating NMT-friendly environments that mitigate heat stress and sustainable urban mobility. The comparative analysis shows that the highest performing systems share a common integrative logic: they treat “natural landscape elements” and “built landscape element” systems not as separate entities but as interdependent layers of one adaptive landscape. Thus, urban landscape planning for NMT must prioritize integration, continuity, and multi-functionality that transform NMT corridors into climate-resilient ecological networks.

8 Recommendations

To develop a climate-responsive and landscape-integrated framework that enhances microclimatic conditions and increases non-motorized transportation adoption in humid subtropical cities through the strategic application of “natural landscape elements” and “built landscape elements”. The Optimistic design option provides thermally comfortable, secure, and visually appealing corridors for non-motorized transportation by integrating ecological, infrastructure, and human comfort layers. It builds on findings from Brisbane, Taipei, and Chengdu, all of which show how “natural” & “built landscape elements” can successfully control microclimate while enhancing NMT user’s experience quality.

8.1 Optimistic design option

Design practice must prioritize multifunctional corridors that combine ecological and infrastructural functions. Rain gardens and bioswales should be considered essential parts of storm water management and thermal regulation systems rather than separate beautification elements. To maximize cooling effectiveness and long-term sustainability, the selection of materials and vegetation should also take into account regional climatic and spatial conditions. To connect design intent with environmental performance, coordination between the fields of urban design, landscape architecture, climatology, and transport engineering is crucial.

The Optimistic design option shown in Figure10 can be used in Pilot projects, a useful tool for evaluating and improving these strategies. Cities with similar humid subtropical climates, like Chandigarh, and Lucknow, provide appropriate settings for the installation of demonstration corridors. The cooling potential and comfort enhancements connected to integrated landscape-based NMT design can all be verified by these pilot projects.

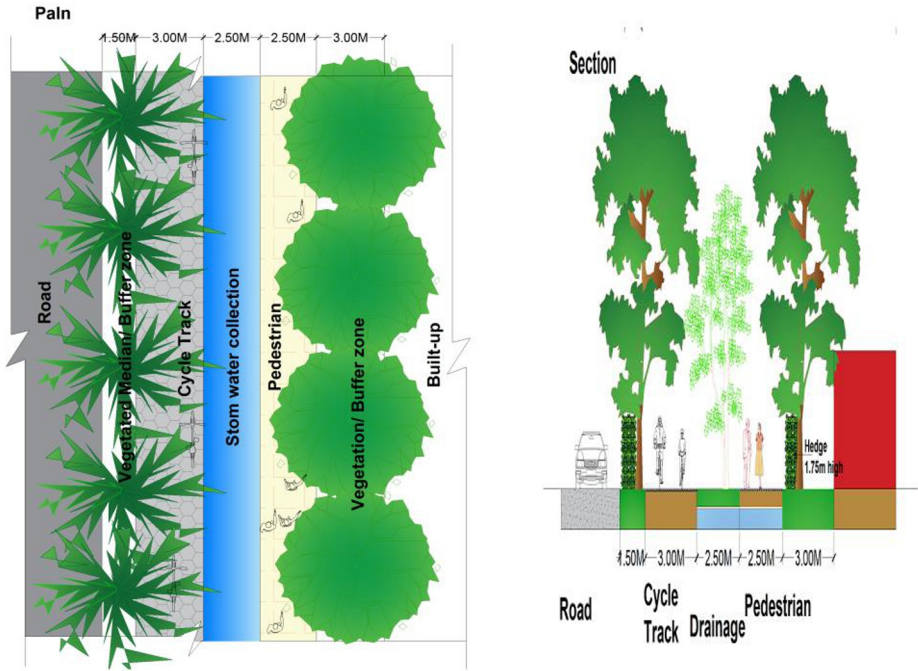


Fig.10.Optimistic design option: - Plan & section of NMT corridor for humid subtropical climate cities.

In the end, cities can design flexible, healthy, and human-centered transportation systems that promote environmental sustainability and improve general urban livability by incorporating green infrastructure principles into urban mobility policies and development codes.

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