RESEARCH ARTICLE

Optimizing Street Tree Selection Model for Sustainable Urban Landscapes in Malaysia

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Abstract

Managing urban street trees poses significant challenges, especially in fast-growing urban areas where environmental stressors and conflicts with infrastructure are common. This study addresses the critical need for a robust tree species selection model tailored to urban environments, focusing on the integration of tree morphology to enhance the sustainability and functionality of urban forestry. The research explores the limitations of existing frameworks, such as those by Amir and Misgav (1990), Miller (1997), Roy (2015), and Ramly (2018). This model incorporates advanced methodologies like Partial Least Squares Structural Equation Modelling (PLS-SEM) to validate species selection criteria that account for environmental resilience, social acceptance, and economic viability. The findings highlight the importance of considering tree morphology characteristics such as root structure, canopy size, and growth patterns in species selection to prevent infrastructure damage, reduce maintenance costs, and ensure long-term ecological benefits. The study concludes that integrating morphological characteristics into selection models is essential for developing urban forests that are not only resilient to climate change and urban stressors but also capable of providing significant ecological and social benefits. This research contributes to the advancement of urban forestry practices by offering a scientifically validated, context-sensitive framework that can be adapted to various urban environments globally.

Keywords: *Urban forestry, tree morphology, species selection, Partial Least Squares Structural Equation Modelling (PLS-SEM)*

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Introduction

Street trees are integral to urban green spaces, contributing not only to environmental functions but also to the visual quality and aesthetics of city streets. In Malaysia's major cities, however, tree failures remain a persistent concern, raising issues of user safety, management, and maintenance. Standards of street tree conditions also appear to vary considerably across urban areas, reflecting uneven approaches to planting and care. Urban tree planting in Malaysia has evolved significantly over time. Historical records indicate that the earliest plantings date back more than a century, with *Pterocarpus indicus* (Angsana) planted in Malacca in 1778 (Koening, 1894) and in Penang in 1802 (Burkill, 1966). During the colonial era, indigenous species were poorly understood, leading to the introduction of non-native species such as *Cassia fistula* and *Swietenia spp.* for rapid revegetation. A more structured greening effort began in 1973 with Kuala Lumpur's Beautification Unit, launched under the Federal Territory's Beautification Programmes. Over the past decade, local authorities and property developers have intensified efforts in urban greening and beautification. While these initiatives have achieved visible success, they are often undermined by inadequate tree management, particularly in the selection of species for street planting. This shortcoming underscores the urgent need for standardized guidelines and enhanced professional competencies among landscape architects. The objective of this study is to develop a robust tree species selection model tailored to urban environments, with a particular focus on integrating tree morphology to enhance the sustainability, functionality, and resilience of urban forestry. Strengthening expertise in species selection and placement is critical to minimizing tree failures, aligning planting strategies with environmental and safety requirements, and ensuring long-term urban forest sustainability.

Research Method

This study addresses the critical need for a robust tree species selection model tailored to urban environments, focusing on the integration of tree morphology to enhance the sustainability and functionality of urban forestry. This study adopts a positivist, deductive, and quantitative research approach using a mono-method design centered on structured survey questionnaires, enabling objective measurement and hypothesis testing through Partial Least Squares Structural Equation Modelling (PLS-SEM). As shown in Figure 1, this methodology is designed to ensure that the framework is not only scientifically robust but also practically applicable in real-world urban settings. Given the complexity of urban ecosystems and the multifaceted role that trees play within them, it is essential to adopt a research approach that systematically integrates both theoretical and empirical insights.

First, a comprehensive literature review was conducted to identify gaps in existing urban tree selection practices, setting the aims, objectives and related issues. The research explores the limitations of existing frameworks, such as those by Amir and Misgav (1990), Miller (1997), Roy (2015), and Ramly, (2018). A comparative analysis of urban tree selection models provides a comprehensive understanding of the various approaches and factors influencing urban tree selection. This review of seminal works established a foundational understanding of key factors influencing tree selection.

Secondly, qualitative data were collected through conducting a pilot study (30 respondents) and expert validation (6 experts); and administering a full-scale survey (n=155) for final model validation. Expert interviews and focus group discussions with landscape architects, urban planners, and arborists, focusing on current practices and the challenges of tree species selection. Insights from these interactions highlighted critical factors that shaped the conceptual model's development.

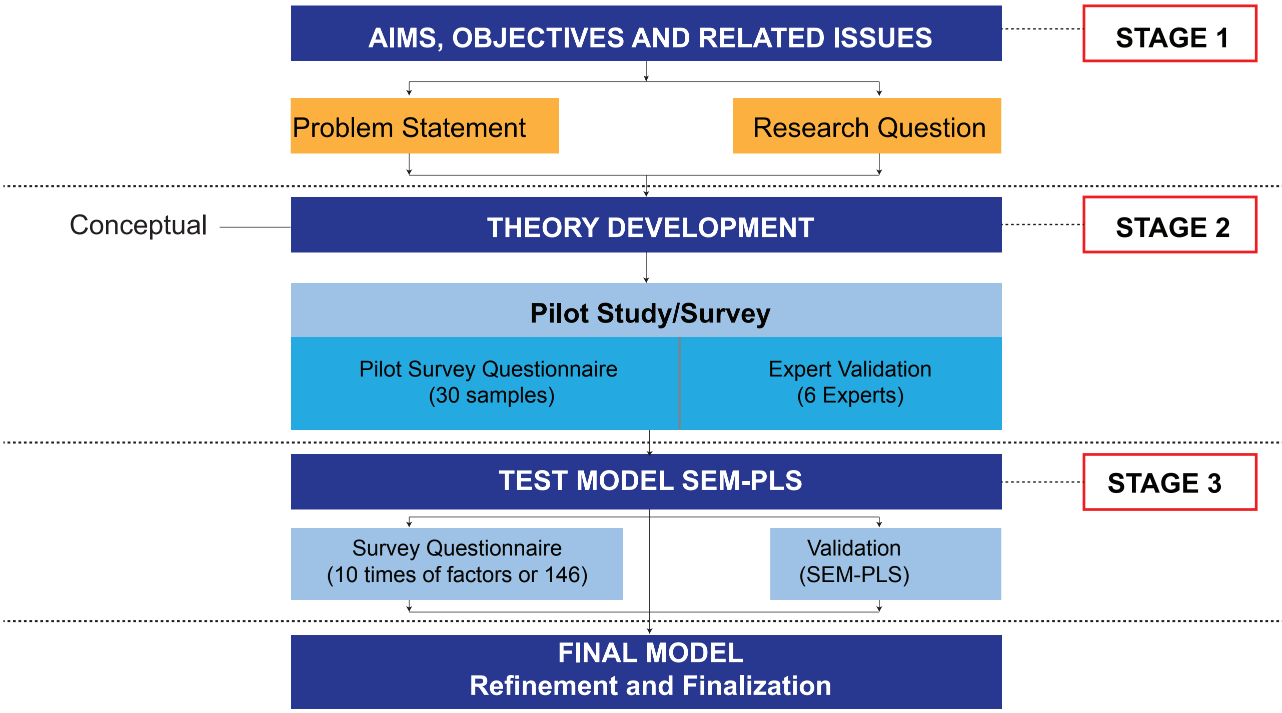

Figure 1: Research Design to Develop Species Selection Model

Then, the conceptual model will undergo quantitative validation using Partial Least Squares Structural Equation Modelling (PLS-SEM), a statistical approach that examines the relationships among factors influencing urban street tree selection. Data for validation will be collected through surveys distributed to industry professionals, ensuring the model comprehensively represents the complexities of urban environments. Subsequently, an expert panel will evaluate the model for practicality, relevance, and scientific rigor, facilitating iterative refinements.

A pilot test will further assess the model's practical application in species selection. Feedback from real-world conditions will inform final adjustments, enhancing the framework's focus on resilience to urban stressors, infrastructure compatibility, and ecological benefits, thereby offering a robust strategy for sustainable urban forestry. The resulting model integrates ecological, environmental, social, and economic factors, alongside tree morphological characteristics like root structure and canopy size, creating a holistic framework that addresses the benefits and potential conflicts of urban street trees.

Research Design

Research design serves as the foundational framework guiding the entire research process, encompassing data collection and analysis (Bryman, 2012). Commonly employed in social research, five primary research designs include experimental, cross-sectional (or survey), longitudinal, case study, and comparative designs (Bryman, 2012; Veal, 2011). Each design offers distinct advantages, such as experimental designs enabling causal inference, cross-sectional studies capturing data at a specific time point, and longitudinal designs examining changes over time. Case studies provide in-depth insights into specific contexts, while comparative designs facilitate the analysis of differences across groups or settings, making them versatile tools in diverse research domains.

This study employs a cross-sectional survey design, as outlined in Table 1, to ensure a comprehensive and methodologically rigorous research approach. This design facilitates the systematic collection of data at a single point in time, enabling an in-depth analysis of key variables and their relationships (Bryman, 2012). This design is particularly effective for generating snapshots of trends, behaviors, or opinions, making it ideal for large-scale studies in social sciences. Surveys, as a primary tool, gather quantitative data efficiently from diverse populations, enabling comparisons across subgroups. While it is cost-effective and time-efficient, this design does not establish causality, as it captures data from a single temporal context (Veal, 2011).

The research employs a quantitative approach to systematically investigate street tree selection and benefits using a mono-method design. This approach focuses on measurable data to identify relationships between tree morphology, planting benefits, and selection criteria (Bryman, 2012). A survey strategy is utilized, involving self-administered questionnaires distributed online. This method is effective for gathering data from diverse respondents, including urban planners, arborists, and landscape architects, ensuring efficiency and scalability (Veal, 2011).

The study adopts a cross-sectional time horizon, collecting data at a single point in time. This design provides a snapshot of current practices and perceptions related to street tree planting, allowing the identification of trends and relationships without requiring long-term observations (Bryman, 2012). Data collection is carried out through self-administered questionnaires, which are cost-effective and convenient for participants, ensuring accessibility and high response rates. The survey captures variables such as tree morphology, ecological benefits, and selection factors, facilitating a comprehensive understanding of their interconnections.

Table 1: Summary of Research Design

Summary of Research Design	Choices for Research Design
Methodological approach: quantitative, qualitative, or mixed methods	Quantitative (mono method)
Strategies: experiment, survey, archival research, case study, ethnography, action research, grounded theory, or narrative inquiry.	Survey using a self-administered questionnaire
Time horizon: Cross-sectional or longitudinal	Cross-sectional study
Data collection: Surveys, interviews, experiments, in-person questionnaires, observational studies, and archival research	Data collection using self-administered questionnaires via online survey.
Data analysis: statistical, thematic, or computational methods.	Statistical validation and hypotheses testing using PLS-SEM.

The data analysis employs Partial Least Squares Structural Equation Modeling (PLS-SEM), a robust statistical method for testing hypotheses and validating complex relationships among variables (Hair et al., 2011). PLS-SEM is particularly suited for exploratory research and models with multiple constructs, making it ideal for analyzing the multifaceted factors influencing street tree selection. This structured research design ensures a rigorous and systematic exploration of the topic, providing actionable insights to inform sustainable urban forestry practices.

Literature Review

A thematic review using ATLAS.ti 24, as introduced by Zairul (2020), is implemented in this study to apply a thematic analysis procedure in the literature review. Clarke and Braun (2013) define thematic analysis as identifying patterns and constructing themes through thorough reading. The research objective is to analyze the current issues and trends in species selection for street tree planting. This study focuses on investigating the prevailing practices and challenges in urban street tree planting, both within Malaysia and in other global contexts. It involves a thorough examination of the trends in tree species selection, identifying best practices, and understanding the specific issues that affect urban areas. By analyzing these factors, the research aims to establish a foundation for developing an improved tree selection framework that addresses both local and global challenges. As a result, the purpose of this article is to conduct a thematic assessment of discussions on trends in tree species selection for urban street planting that have been published between 2019 and 2024, using the research question below:

RQ: What are the current trends in tree species selection for urban street planting being discussed from 2019 to 2024?

The subsequent step involves identifying patterns and categories to understand trends in street tree selection. The research aims to analyze and interpret findings to recommend future research in street tree selection models. Literature selection criteria include 1) publications from 2019-2024, 2) keywords "street," "tree species," and "selection," and 3) a focus on street tree selection, specifically limiting the scope to urban planting.

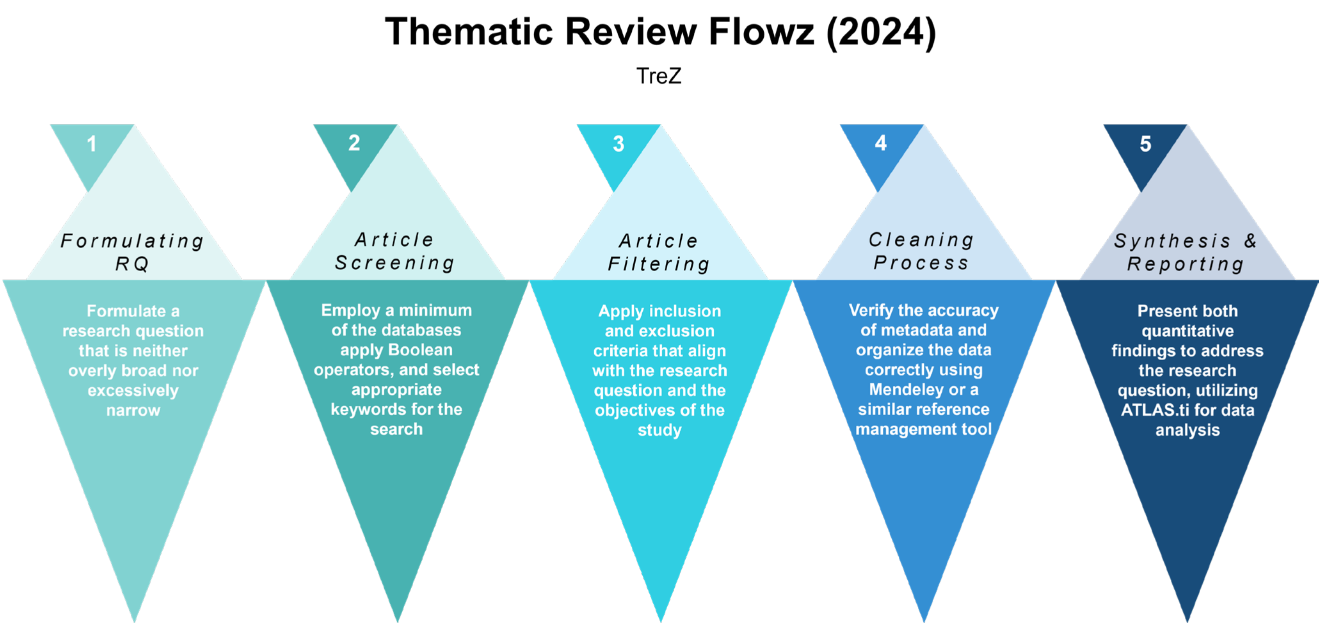

Figure 2: Processes Involved in the Thematic Review Flowz (2024)

The process as shown in Figure 2 begins with developing the research question (Define RQ) and setting the focus and scope of the review. Next, the article screening step (Screen) involves identifying and preliminarily selecting relevant studies. This is followed by the filtering stage (Filter), applying inclusion and exclusion criteria to refine the selection. The fourth step, called 'cleaning' (Finalize) thoroughly checks the metadata for accuracy and completeness. Finally, data extraction (Synthesis) is conducted, using thematic analysis tools like ATLAS.ti to develop themes from the selected articles. This structured approach ensures a reliable and comprehensive literature analysis.

Table 2: Search Strings from Scopus and Wos

Database	Search Strings	Result
SCOPUS	TITLE-ABS-KEY (street AND “tree species” AND selection) AND PUBYEAR > 2018 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA, “ENVI”) OR LIMIT-TO (SUBJAREA, “AGRI”) OR LIMIT-TO (SUBJAREA, “SOCI”) OR LIMIT-TO (SUBJAREA, “ENGI”)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SRCTYPE, “j”))	34
Web of Science (WoS)	Results for “street” AND “tree species” AND “selection” (All Fields) and Open Access and 2024 or 2023 or 2022 or 2021 or 2020 or 2019 (Publication Years) and Article (Document Types) and English (Languages)	148

Subsequently, to examine trends in tree species selection for urban street planting, literature published between 2019 and 2024 was analyzed. Key criteria included recent publication dates and relevant keywords to ensure a comprehensive review of current insights and developments, forming the foundation for future research recommendations. The review was conducted using two major academic databases—SCOPUS and Web of Science (WoS)—selected for their extensive coverage of peer-reviewed journals relevant to urban tree species selection.

In SCOPUS, the search employed the keywords “street,” “tree species,” and “selection” within titles, abstracts, and keywords (TITLE-ABS-KEY), focusing on publications from 2019 to 2024. The results were restricted to academic journal articles in English and open access, further limited to subject areas of Environmental Science, Agriculture, Social Sciences, and Engineering (LIMIT-TO (DOCTYPE, “ar”), LIMIT-TO (LANGUAGE, “English”), LIMIT-TO (SRCTYPE, “j”), LIMIT-TO (SUBJAREA, “ENVI” OR “AGRI” OR “SOCI” OR “ENGI”)).

This study employed a meticulous selection process, applying consistent search strings across both databases. The initial search identified 34 articles in SCOPUS and 148 in WoS, reflecting differences in indexing depth, journal coverage, and search algorithms. After merging the results and removing 26 duplicates, the consolidated dataset underwent rigorous screening based on predefined inclusion and exclusion criteria following TreZ (Zairul, 2023) as shown in Figure 3. This process excluded 111 articles, leaving 45 studies that fully met eligibility requirements for inclusion in the thematic review. The systematic approach ensures a comprehensive and balanced analysis, minimizing bias and strengthening the validity and reliability of the review’s conclusions. The detailed selection process, presented in Table 2 and Figure 3, highlights the rigor undertaken and provides a transparent foundation for future replication and confidence in the findings.

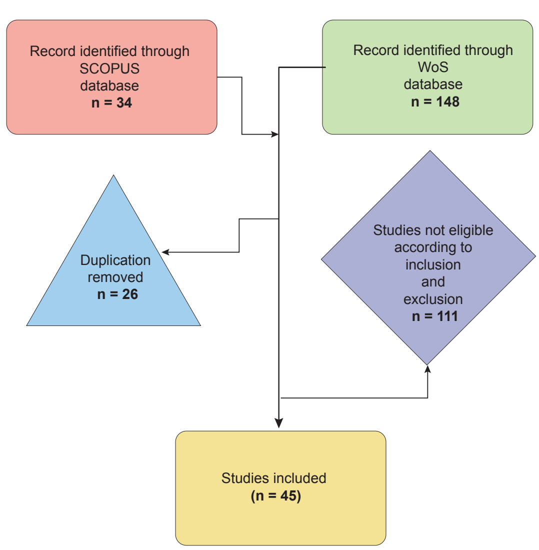

Figure 3: Inclusion and Exclusion Criteria in Trez (Zairul, 2023)

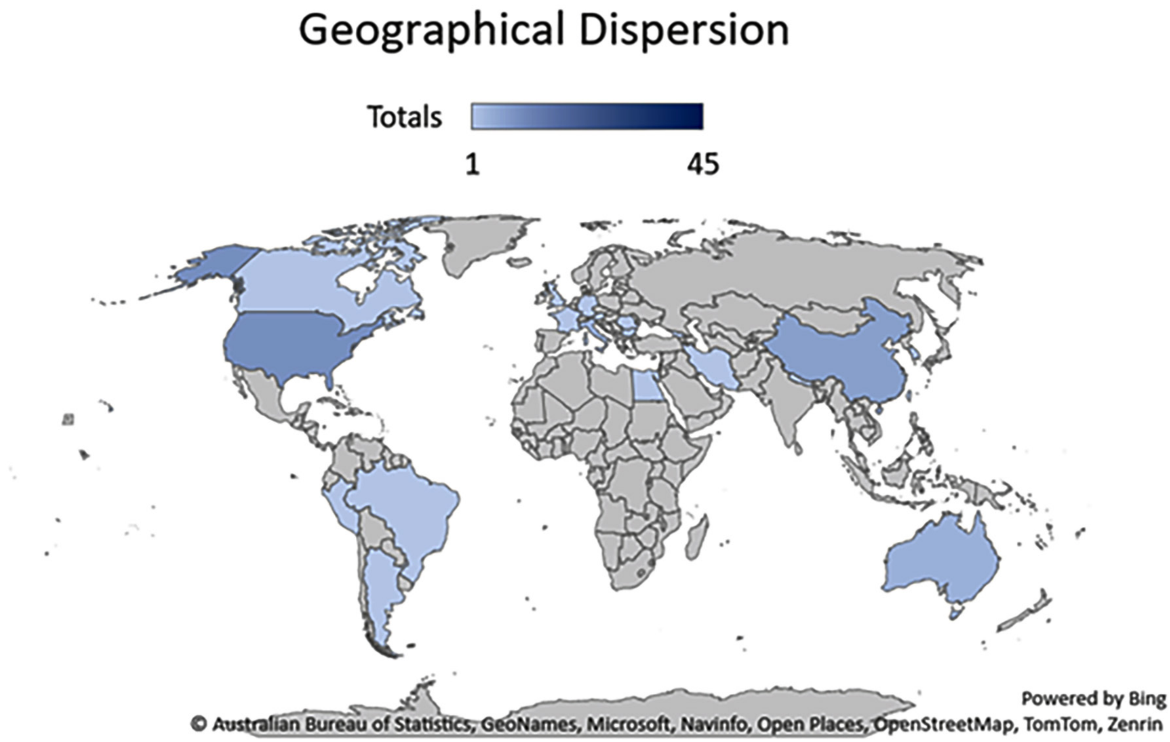

Figure 4: Map Showing the Geographical Distribution of Paper Based on Contributions from Various Countries

Global Research Trends in Urban Tree Species Selection

The thematic review of 45 articles on urban tree species selection, visualized through a geographic distribution map as shown in Figure 4, highlights significant contributions from multiple countries, reflecting diverse approaches and criteria. The United States and China lead in research output, underscoring their strong commitment to urban forestry. European countries, particularly Italy and the United Kingdom, provide influential studies, with Italy emphasizing multifactorial evaluation of selection criteria. In Australia, research centers on species-specific performance and adaptability, critical for managing urban forests across varied climates. South American contributions from Brazil and Argentina focus on the ecological functions of urban trees, while Asian studies from South Korea and Hong Kong examine public perceptions and environmental services. In arid regions, research from Egypt and Iran stresses water scarcity and climate adaptability as key considerations. Collectively, these studies cover themes of species diversity, ecosystem services, climate resilience, public perception, and management strategies, underscoring the need for diverse species selection and strategic planning to strengthen urban forest sustainability.

This review synthesizes current trends in tree species selection for urban street planting from 2019 to 2024, with themes visualized through a word cloud as shown in Figure 5. Prominent terms such as “urban,” “tree,” “species,” “street,” and “environmental” reflect the central focus of the literature. The findings consistently highlight the importance of selecting diverse and resilient tree species to enhance urban forest health and deliver ecosystem services such as carbon sequestration, air pollution reduction, and improved thermal comfort. Studies also emphasize adaptive management to address climate change impacts, particularly drought tolerance and phenotypic plasticity. Public perception emerges as a critical factor, with community engagement shaping species preferences and improving alignment between urban forestry practices and societal values.

Finally, strategic planning and efficient management are identified as essential to mitigate challenges such as water scarcity and urban heat islands. Overall, this review advocates for an integrated approach that combines scientific evidence, community involvement, and effective management to build sustainable and climate-resilient urban forests, thereby enhancing urban livability and environmental health.

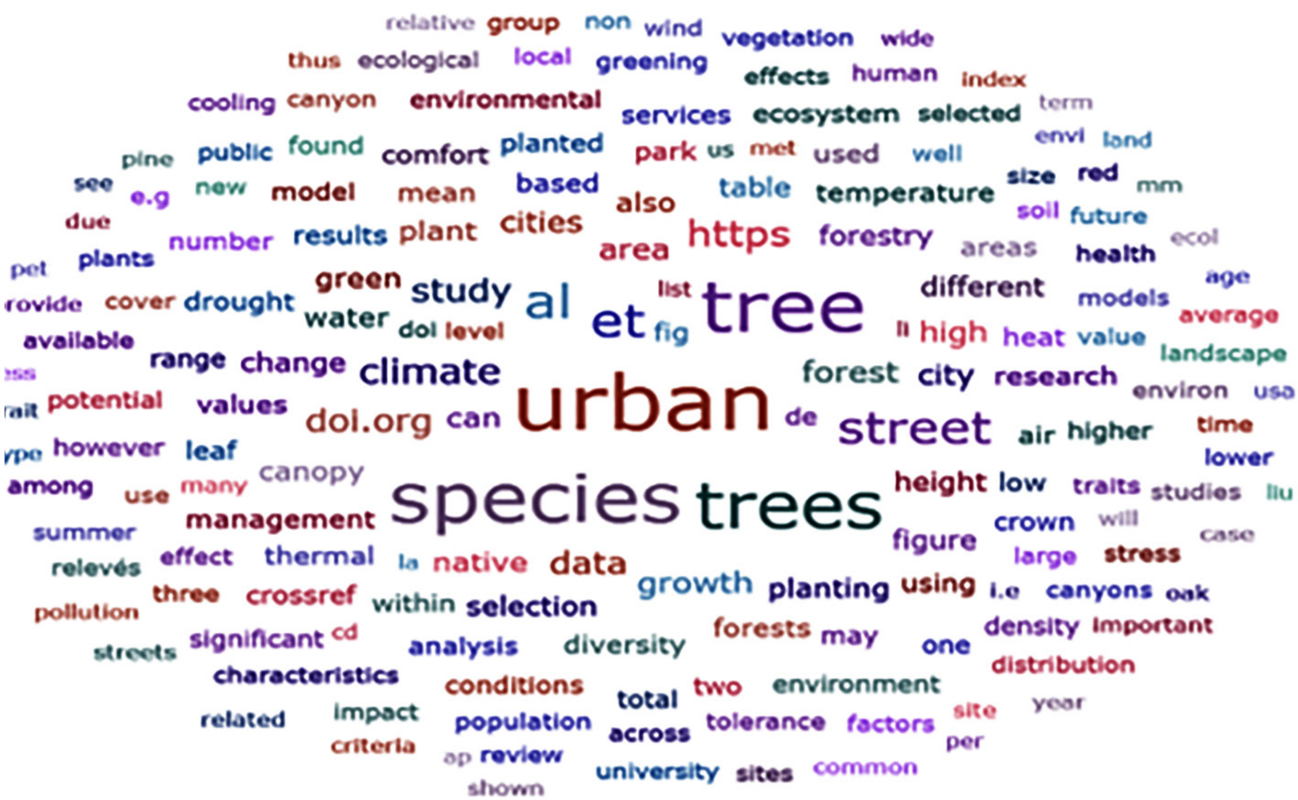

Figure 5: Word Frequencies Identifying Key Themes and Patterns in Street Tree Selection

Thematic Review Reporting

This thematic review identifies five key themes, as shown in Figure 6, which include urban tree species diversity and selection, environmental and ecosystem services, climate change adaptability, public perception, and urban tree management strategies. Emphasizing environmental services underscores their role in promoting urban sustainability, while the focus on species diversity highlights the importance of biodiversity and forest resilience. Additionally, research on climate adaptability and public perception emphasizes the need for climate-resilient species and community involvement. Collectively, these themes enhance the understanding and implementation of effective urban tree species selection, addressing both ecological and social aspects.

Theme 1: Research in this theme underscores how species diversity and morphological traits contribute to urban forest performance. Xiao (2024) and Morakinyo (2020) show that strategic species selection enhances thermal comfort and mitigates urban heat, while Ma (2020) and Hilbert (2022) link species diversity to long-term forest health. Watkins (2021) and Falfan (2021) highlight phenotypic and genotypic traits that support resilience, and comparative studies in 2022 and 2024 model crown expansion to predict canopy benefits. Recent work in 2023 also stresses drought tolerance as critical for arid cities. Despite these advances, long-term studies on adaptability, genetic stress tolerance, and the integration of ecosystem services remain limited, with insufficient public engagement and adaptive management strategies to meet evolving urban and climatic demands.

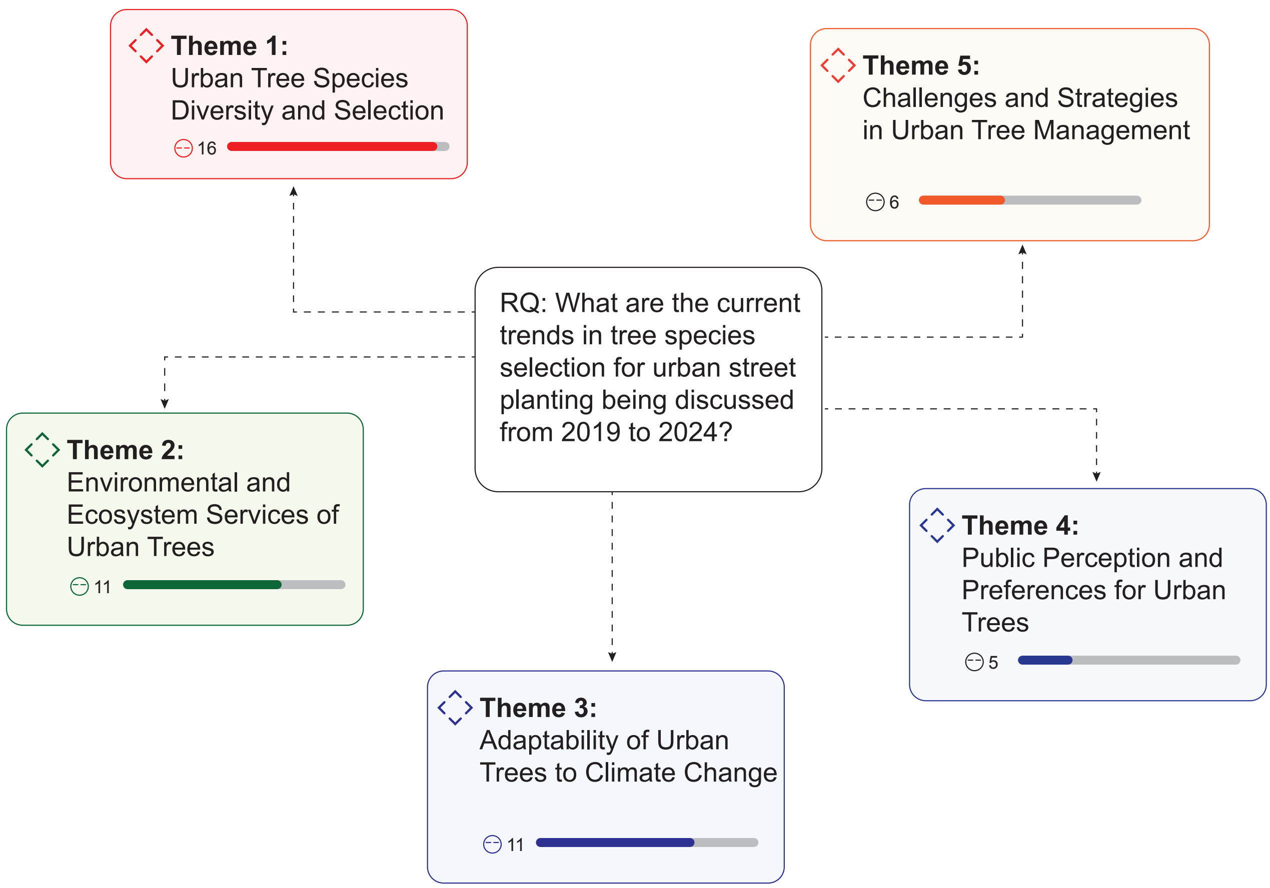

Figure 6: The Themes to Answer the Research Question (RQ)

Theme 2: Environmental and ecosystem services research highlights urban trees' roles in carbon sequestration and air pollution mitigation (Parsa 2020; Moreno 2024). Speak (2022) and D'Amato (2023) emphasize context-specific management, while Cregg (2023) explores genotypic variability in response to heat and drought. Studies by Alpaidze (2021) model ecosystem services, with Zheng (2024) and Shah (2022) introducing new methods for evaluating thermal comfort and energy benefits. Wujeska-Klause (2020) underscores the dual cooling effects and nighttime warming, stressing balanced management. Despite progress, gaps remain in long-term studies, comprehensive modelling, species-specific adaptation, and public engagement, with further research on climate resilience essential for maximizing urban forestry benefits.

Theme 3: This theme synthesizes 11 studies on tree resilience under climate stress. Fririon (2023) emphasizes genetic diversity for drought resistance, while Li (2021) demonstrates phenotypic flexibility under multiple stressors. Case studies by Muller (2019) in Minnesota and Liu (2021) in Shanghai highlight the importance of localized adaptation strategies, and Hurley (2024) with Esperon-Rodriguez

(2022) examine microclimate effects and vulnerability metrics for species selection. Karrer (2022) and Petrov (2019) stress drought tolerance, while Hirons (2021) and Ren (2023) explore the roles of botanical gardens and the minimal effects of urban density on native trees. Nonetheless, gaps persist in long-term monitoring, comprehensive adaptation models, and participatory approaches to enhance resilience planning and public relevance.

Theme 4: Public perception and preferences of urban trees highlight five studies that underscore the importance of community engagement in urban forestry. Jeong (2023) explores residents' perspectives in Seoul, developing maintenance guidelines aligned with public expectations, while Kim (2021) identifies the influence of aesthetics, shade, and air quality on tree preferences in Busan. Acharya (2023) examines species selection in Pokhara, advocating alignment with local preferences for community support. Davis (2021) demonstrates the value of interactive tools in engaging the public, and Wang (2023) emphasizes integrating expert and public criteria for balanced management. A participatory approach enhanced public education, and policy integration are essential for the sustainability and success of urban forestry initiatives.

Theme 5: Challenges and strategies in urban tree Management highlight essential strategies for effective urban forestry. Hilbert (2023) examines human factors affecting tree diversity, while Abdelmejeed (2024) optimizes microclimate and water management strategies in Cairo. Hui (2020) addresses species-specific growth in Hong Kong, Dorowski (2020) advocates for diverse planting in the Northeastern U.S., and Huber-Smith (2023) stresses the need for fire-resistant species in Australia. These studies underscore adaptive management strategies that integrate ecological, social, and economic factors. However, gaps remain in long-term sustainability studies, localized strategies, public engagement, and climate adaptation. Addressing these through comprehensive research will strengthen urban tree management, enhance urban forest resilience and improve urban environmental health.

Issues Faced by Landscape Practitioners in Managing Landscape Trees

Landscape practitioners encounter several challenges in managing landscape trees, impacting urban green spaces' sustainability and functionality. One of the primary issues is the lack of specific guidelines for tree species selection and placement. Moreover, In Malaysia, the lack of specific guidelines for tree species selection poses a significant challenge for landscape practitioners tasked with urban forest management. This deficiency often results in the planting of tree species that are not well-adapted to the local climatic and soil conditions, leading to increased maintenance costs and higher mortality rates among urban trees (Ahmad et al., 2021). For example, the frequent selection of exotic species over native ones, driven by aesthetic considerations rather than ecological suitability, has contributed to issues such as poor tree health and increased vulnerability to pests and diseases (Latif et al., 2019). This problem is exacerbated by Malaysia's diverse climatic zones, where a one-size-fits-all approach to tree selection fails to account for the unique environmental conditions of each region (Ismail et al., 2022). The core research problem lies in developing a comprehensive and practical framework for selecting street tree species that are both resilient to urban environmental stressors and compatible with urban infrastructure. Improper tree selection can lead to hazardous conditions, especially in street areas where the interaction between tree growth and infrastructure can pose significant safety risks (Ramly Hasan et al., 2017). Local authorities are responsible for landscape planning, including tree species selection, to ensure public safety and maintain infrastructure integrity. However, the current practices often involve reactive measures, such as pre-emptive tree removal, which undermine the long-term benefits of urban forestry and contribute to an unsustainable cycle of planting and removal.

Managing urban landscape trees presents significant challenges, particularly in regions like Malaysia, where diverse climatic zones and urban pressures complicate tree species selection. A critical issue is the absence of specific guidelines for selecting and placing tree species, which often leads to the planting of unsuitable species. These species may fail to adapt to local soil and climate conditions, resulting in high mortality rates and increased maintenance costs (Ahmad et al., 2021). The frequent preference for exotic species driven by aesthetic preferences rather than ecological compatibility exacerbates the problem, often leading to poor tree health and heightened vulnerability to pests and diseases (Latif et al., 2019). Malaysia's varied climatic zones further complicate the situation, as a uniform approach fails to address region-specific environmental conditions effectively (Ismail et al., 2022).

Formulating and Addressing Research Problem

The core research problem lies in developing a comprehensive and practical framework for selecting street tree species that are both resilient to urban environmental stressors and compatible with urban infrastructure. Improper tree selection can lead to hazardous conditions, especially in street areas where the interaction between tree growth and infrastructure can pose significant safety risks (Ramly Hasan et al., 2017). Local authorities are responsible for landscape planning, including tree species selection, to ensure public safety and maintain infrastructure integrity. However, the current practices often involve reactive measures, such as pre-emptive tree removal, which undermine the long-term benefits of urban forestry and contribute to an unsustainable cycle of planting and removal.

This research problem is crucial to solve because the failure to address these issues can have far-reaching consequences for urban environments. The removal of trees before they mature denies communities the full spectrum of ecological, social, and economic benefits that mature trees provide. Furthermore, the cycle of planting and removal is not only unsustainable but also economically inefficient, as it incurs repeated costs without yielding long-term benefits. Addressing this research problem is essential for ensuring that urban forestry practices in major Malaysian cities, and beyond, are both sustainable and cost-effective. The importance of solving this research problem extends beyond infrastructure management; it is also vital for enhancing urban resilience to climate change. By developing a robust framework for tree species selection that accounts for urban stressors, infrastructure compatibility, and long-term sustainability, cities can better harness the full range of benefits provided by urban trees while minimizing the associated risks. This approach will not only improve the quality of urban life but also contribute to the broader goals of environmental sustainability and climate resilience.

In conclusion, solving the research problem of street tree selection is essential for optimizing the benefits of urban trees while minimizing their negative impacts on infrastructure and safety. This research is of paramount importance for developing sustainable urban forestry practices that enhance the livability, resilience, and economic efficiency of cities. By addressing this issue, local authorities can make more informed decisions that support the long-term health and vitality of urban environments.

Developing Theoretical Model

The development of a street tree species selection model holds significant potential for mitigating tree conflicts and optimizing the benefits that urban trees provide. Developing a robust selection model is crucial for maximizing the positive impacts of urban trees while minimizing their drawbacks. A well-designed tree species selection model can significantly enhance urban planning and landscape architecture by providing a systematic approach to choosing the right trees for specific urban environments. This approach involves considering various tree morphological factors such as tree growth patterns, root structures, canopy size, and species resilience to local climatic conditions and pests (Alvey, 2006). By integrating these factors, the model can help landscape architects and urban planners select species that are less likely to cause infrastructure damage or pose safety hazards, thus reducing the frequency and costs associated with tree removal and maintenance (Ramly Hasan et al., 2017).

Furthermore, the implementation of a selection model supports sustainable urban development by promoting biodiversity and ecological resilience. By ensuring a diverse and appropriate selection of tree species, the model can help urban areas maintain ecological balance and resilience, thereby enhancing the overall sustainability of urban ecosystems (Speak et al., 2020).

A Framework for Street Tree Planning in Urban Areas in Israel by S. Amir and A. Misgav (1990).

This study offers a comprehensive approach to urban street tree planning, tailored specifically to the needs and challenges of Israeli cities. The framework as shown in Figure 7, emphasizes the importance of systematically planning street tree systems to achieve specific urban goals such as environmental enhancement, aesthetic improvement, and public welfare. It provides guidelines for setting clear objectives in street tree planning, including the selection of appropriate tree species based on these objectives.

One of the key strengths of this framework is its focus on establishing well-defined goals and criteria for urban tree systems. Amir and Misgav (1990) argue that urban planners should consider a range of factors when selecting tree species, such as the tree's environmental benefits (e.g., shade provision, air quality improvement), its aesthetic contribution to the urban landscape, and its compatibility with the surrounding infrastructure. By doing so, planners can ensure that street trees fulfil multiple roles within the urban environment, contributing to both the ecological and social fabric of the city.

However, the framework also has limitations, particularly in its lack of a detailed model path for tree species selection. While the framework sets out broad goals and criteria, it does not provide specific guidance on how to choose the most suitable tree species for different urban contexts. This gap can create challenges for urban planners who need more concrete recommendations to make informed decisions about tree selection. As a result, the framework, while valuable in setting overarching objectives, may fall short in offering the practical tools needed for effective implementation (Amir & Misgav, 1990).

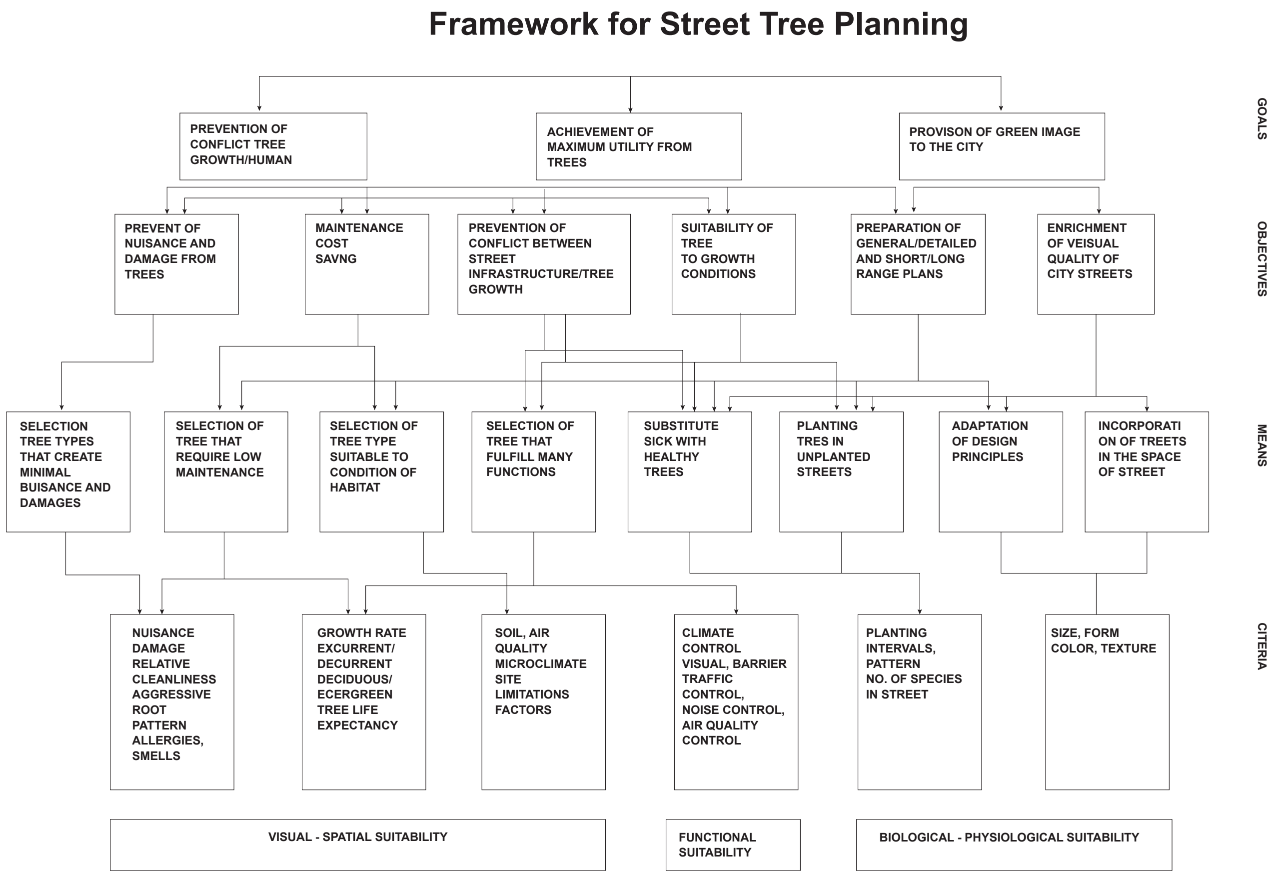

Figure 7: Selection Model by S.Amir and A.Misgav, 1990

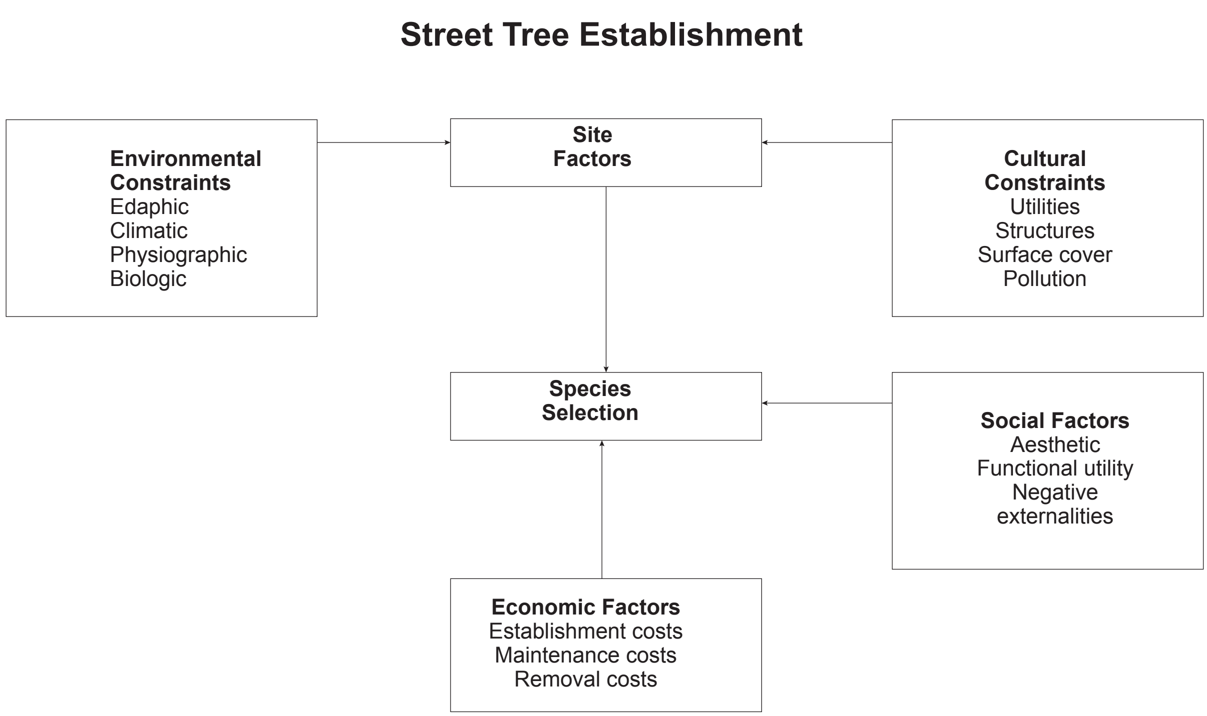

Figure 8: Selection Model by Robert W. Miller, 1997

Urban Forestry: Planning and Managing Urban Greenspaces by Robert W. Miller (1997).

As shown in Figure 8, Miller's (1997) seminal work provides a robust framework for planning and managing urban forestry, emphasizing the integration of urban trees into broader urban planning processes. By positioning urban forestry as an integral part of urban infrastructure, Miller underscores its ecological, social, and economic importance in enhancing the sustainability and livability of cities. His framework considers diverse factors influencing tree selection and management, including environmental conditions, cultural values, economic constraints, and social needs, offering urban planners a holistic approach to decision-making.

One of the key strengths of Miller's framework is its emphasis on the multifunctional role of urban trees. He underscores how trees contribute to urban environments by improving air quality, reducing the urban heat island effect, enhancing aesthetic appeal, and increasing property values. This multifunctionality makes urban trees invaluable assets for sustainable urban development. However, Miller also acknowledges the challenges inherent in urban tree management, particularly the need to balance competing demands from various stakeholders and address the practical difficulties of maintaining trees in often harsh urban environments.

Despite its comprehensive nature, Miller's framework faces limitations. The need to compromise among environmental, cultural, and economic factors can complicate the formalization of tree selection criteria, potentially leading to conflicts or suboptimal outcomes. Urban planners must carefully navigate these trade-offs, which can be challenging in practice (Miller, 1997). Nevertheless, Miller's work remains a cornerstone in urban forestry, offering critical insights and guidance for sustainable planning and management of urban greenspaces.

Factors Influencing Australian Local Governments' Street-Tree Species Selection by Sudipto Roy (2015)

This study provides an in-depth analysis of the various factors that influence the selection of street tree species by local governments in Australia. The study is particularly focused on understanding how these factors vary across different regions and how local governments make decisions that balance environmental, social, and economic considerations. Figure 9 represents Roy's (2015) extension of earlier urban forestry frameworks, such as those developed by Miller (1997), by incorporating additional biophysical and socio-economic factors that are specifically relevant to the Australian context. For example, the study highlights the importance of tree characteristics, such as drought resistance and adaptability to local soil conditions, which are critical in the diverse and often harsh Australian climates. Additionally, Roy emphasizes the role of ecosystem services provided by street trees, such as carbon sequestration, air quality improvement, and urban cooling, which are increasingly important in the context of climate change.

A key contribution of Roy's (2015) framework is the integration of resident expectations and socio-economic factors into the tree selection process. Unlike previous models that may have focused predominantly on environmental factors, Roy acknowledges that local governments must also consider the preferences and needs of their communities. This includes aesthetic considerations, maintenance costs, and the impact of trees on property values. By incorporating these factors, the framework provides a more holistic approach to street-tree species selection that aligns with both ecological sustainability and community well-being. However, the study also identifies potential challenges with this integrated approach. One such challenge is the overlap between the new factors proposed by Roy and the existing factors from earlier models, such as those proposed by Miller (1997). This overlap could lead to redundancy or conflict in decision-making, making it more difficult for local governments to prioritize certain criteria over others. Additionally, the study suggests that the complexity of balancing these diverse factors may pose practical difficulties for local governments, particularly in areas with limited resources or expertise.

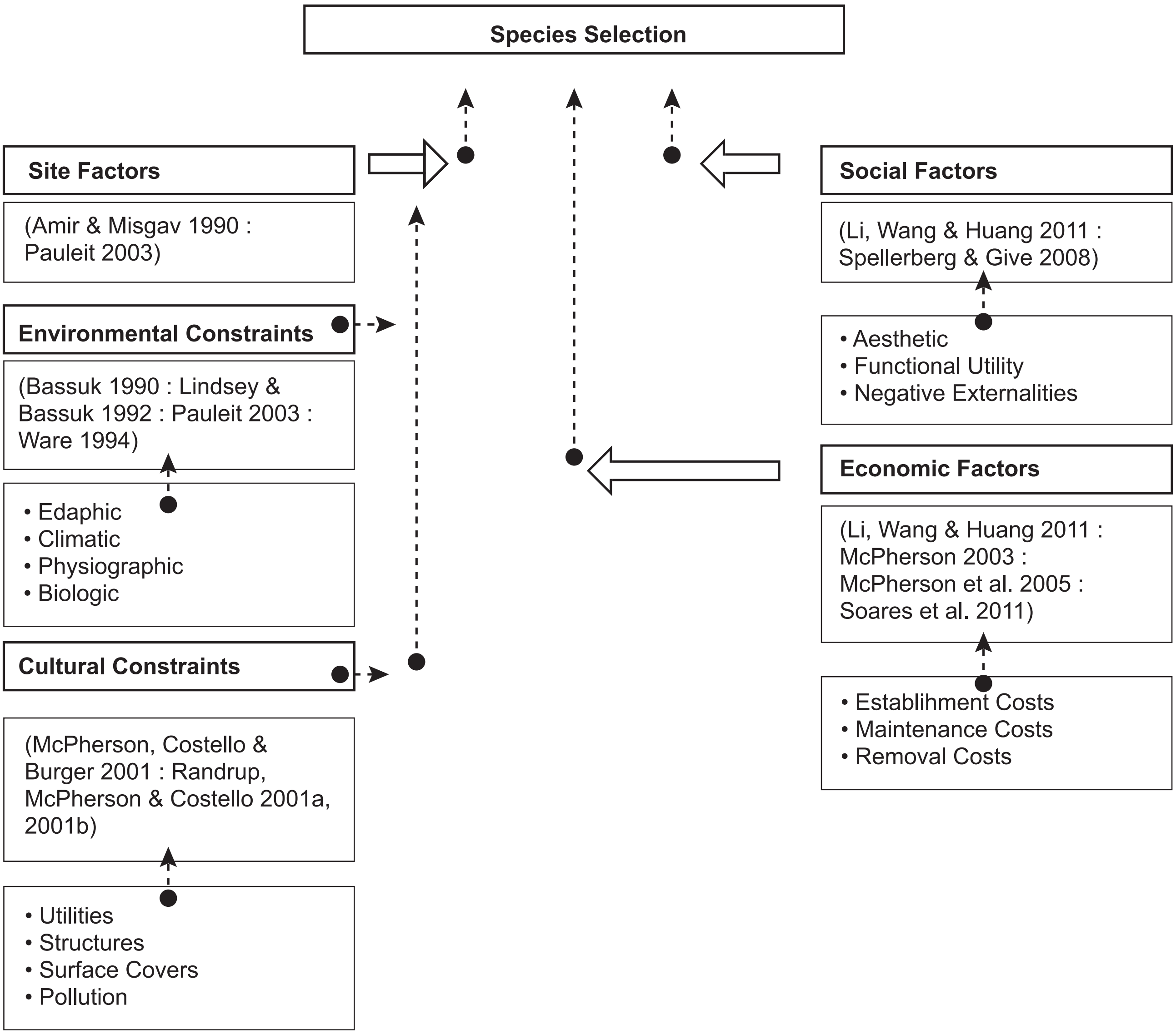

Figure 9: Selection Model by Roy, Sudipto, 2015

Developing Malaysian Roadside Tree Species Selection Model in Urban Areas by Ramly Hasan, Noriah Othman, and Faridah Ismail (2018)

This study focuses on creating a comprehensive model for selecting tree species specifically for roadside planting in Malaysian urban areas. This study is particularly significant as it addresses the unique environmental, cultural, and infrastructural challenges faced by urban planners in Malaysia, providing a tailored approach that considers the specific needs of the local context.

The framework developed by Hasan et al. (2018) builds upon earlier models, such as those by Miller (1997) and Roy (2015), but it introduces new factors and methodologies that are pertinent to the Malaysian context as shown in Figure 10 below. These include considerations of local climatic conditions, soil types, and the specific urban infrastructure found in Malaysian cities. The model integrates various factors like site conditions, social and cultural influences, economic constraints, and institutional regulations, providing a holistic approach to tree species selection. Hasan et al. (2018) emphasize that this model is designed to optimize the benefits of urban trees, such as enhancing biodiversity, providing shade, and improving air quality, while also minimizing conflicts with urban infrastructure, such as root damage to roads and sidewalks. However, the study also notes certain limitations. While the model introduces new factors specific to the Malaysian context, these have not yet been extensively tested in real-world scenarios.

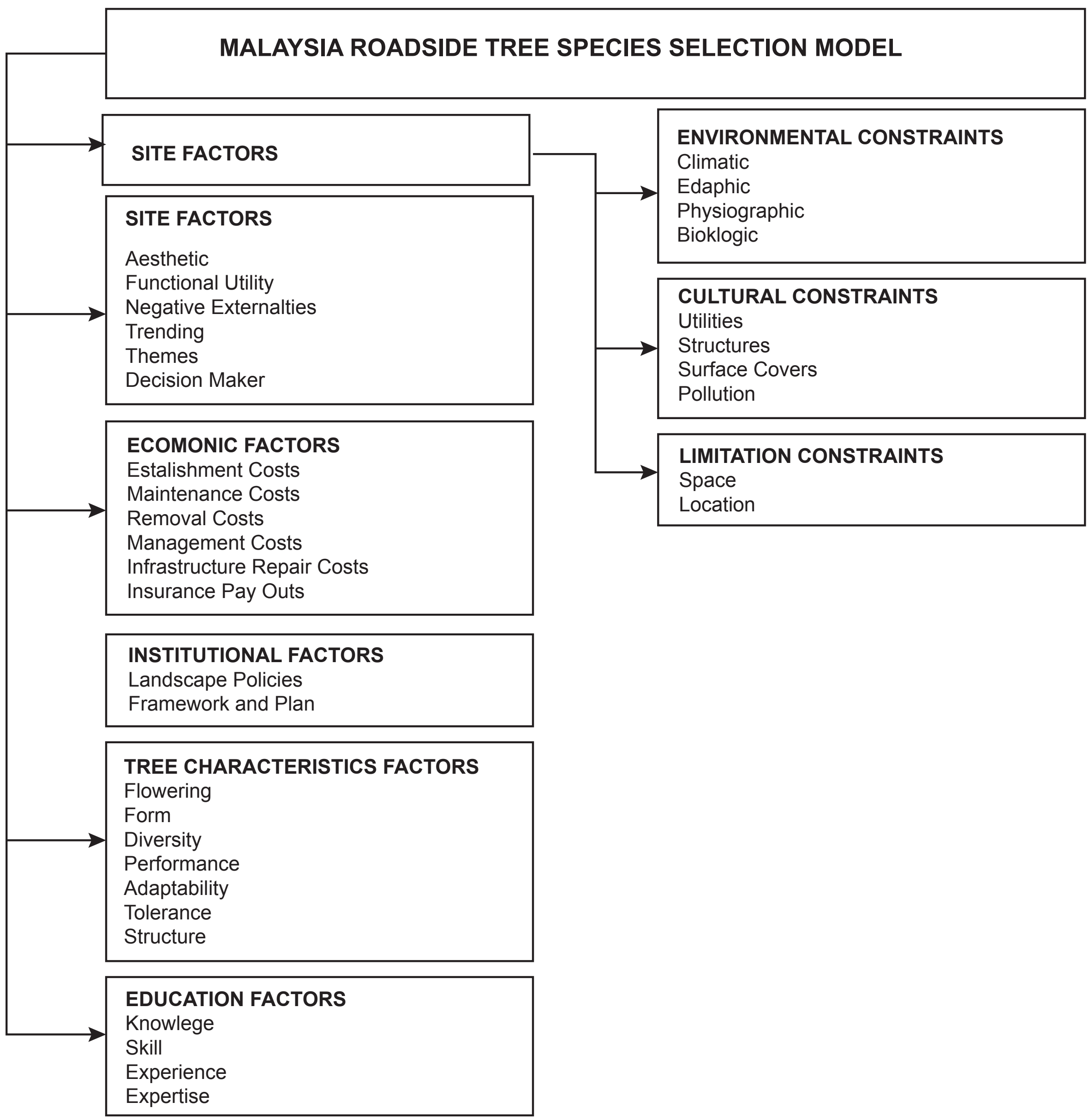

Figure 10: Selection Model by Ramly Hasan, Noriah Othman and Faridah Ismail, 2018

Other Related Models in the Street Tree Selection

The development of street tree selection models tailored to urban environments can benefit significantly from insights provided by existing frameworks and models that address various aspects of urban forestry. Some models indirectly related to street tree selection modeling can support the development of such a model. These models provide insights and data that, while not explicitly focused on tree species selection, offer valuable information to enhance the development of street tree selection models tailored to urban environments. For instance, Kendal, Dobbs, and Lohr (2014) propose the 10/20/30 rule to enhance urban forest resilience through species diversity, recommending that no single species exceed 10%, no genus exceed 20%, and no family exceed 30% of the urban forest composition. This approach underlines the importance of diversity in mitigating risks from pests, diseases, and climate change. Similarly, Hirons and Sjöman (2019) offer a framework for selecting climate-resilient species by assessing their responses to stressors such as heat and drought, emphasizing the role of phenotypic plasticity and genotypic variation in adapting to urban conditions.

Regional considerations are addressed in models such as Sjöman, Nielsen, and Östberg (2012), which focus on species selection for Scandinavian cities by accounting for cold climates and urban stressors. Pauleit, Ennos, and Golding (2005) further highlight the role of tree species in urban microclimates, evaluating their shading potential, cooling effects, and contributions to air quality improvement. Building on this, Nowak and Dwyer (2010) present a cost-benefit approach to urban forestry, guiding species selection based on ecosystem services like carbon sequestration, air quality enhancement, and cost-effective maintenance.

Specific applications are detailed in models like Salmond et al. (2013), which examine how trees influence pollution distribution in street canyons, and Vogt et al. (2017), whose database, Citree, aids species selection based on environmental tolerances and service provision. Hirons and Thomas (2018) focus on species suitability for green infrastructure, offering guidelines that integrate ecological benefits and maintenance needs. Together, these models underscore the multifaceted considerations necessary for street tree selection, including diversity, climate adaptability, ecosystem services, and regional suitability. Integrating these insights can support sustainable urban forestry planning and the development of context-sensitive tree selection strategies.

Overall Insights from the Combined Models

The evolution of urban tree selection models reflects a shift toward holistic approaches that balance environmental, social, economic, and cultural factors to enhance urban forestry's sustainability and functionality. Foundational models, such as those by Miller (1997) and Roy (2015), highlight the need to integrate diverse criteria, including environmental benefits, social acceptance, economic feasibility, and cultural relevance. This multifaceted approach ensures urban forestry programs can address the complex demands of urban ecosystems, contributing to sustainable urban environments (Miller, 1997; Roy, 2015).

Context-specific adaptations have become a crucial component of tree selection models, emphasizing the importance of tailoring species to local conditions. Models by Ramly Hasan (2018) demonstrate how incorporating regional factors, such as climate, soil, and socio-economic conditions, can enhance the relevance and success of urban forestry initiatives. This localized focus aligns with sustainability goals, promoting biodiversity, and improving the adaptability and performance of urban forests (Ramly Hasan, 2018).

Climate resilience and species diversity are increasingly prioritized to ensure urban forests can withstand stressors such as extreme weather, pests, and diseases.

Models like those developed by Kendal et al. (2014) and Pretzsch et al. (2015) advocate for species diversity to provide sustained ecosystem services, including temperature regulation and carbon sequestration. By selecting adaptable, resilient species, these models promote long-term urban forest health and ecological balance (Kendal et al., 2014; Pretzsch et al., 2015).

Socio-cultural integration and community engagement are now central to urban forestry planning. Participatory models by Roy (2015) and Davis (2021) emphasize stakeholder involvement, ensuring tree selection reflects community preferences and values. This participatory approach fosters public support, strengthens social benefits, and encourages a sense of ownership over urban green spaces (Roy, 2015; Davis, 2021).

Additionally, minimizing conflicts with infrastructure remains a critical objective. Models by Sjöman and Nielsen (2010) and Ramly Hasan (2018) focus on selecting species that reduce maintenance challenges, such as root damage to pavements, enhancing infrastructure compatibility and reducing long-term costs (Sjöman & Nielsen, 2010; Ramly Hasan, 2018).

Integrating Tree Morphology Characteristics into the Selection Model

Integrating tree morphology characteristics into tree selection models is essential for the development of resilient and sustainable urban forests. Tree morphology encompasses various attributes such as tree size, form, leaf structure, flowers, fruits, growth rate, root system architecture, elasticity, timber type, natural habitat, soil preference, and microhabitat adaptability. These characteristics play a critical role in determining the suitability of tree species for specific urban conditions, directly influencing their survival, functionality, and contribution to the urban environment.

As shown in Figure 11, titled ‘Framework for Street Tree Selection: Integrating Morphological, Environmental, and Management Criteria,’ the model provides a comprehensive framework that guides the selection of appropriate tree species for urban street planting, emphasizing the importance of aligning tree characteristics with specific urban needs. This model is structured into several concentric layers, each representing key criteria that influence the choice of street trees. At the core of the model is the principle of “Selecting the Right Tree for the Right Place,” which serves as the guiding objective. Surrounding this core is the Road Hierarchy, highlighting different street types (A, B, C, etc.), which suggests that tree selection should be adapted to the specific requirements of various road categories.

Figure 11: "Framework for Street Tree Selection: Integrating Morphological, Environmental, and Management Criteria"(200 Malaysia's Native Trees for Street Planting, 2024)

Tree Morphology Characteristics as Mediating Variables

Mediating variables play a pivotal role in the development of tree selection models, as they help elucidate the mechanisms through which independent variables (e.g., environmental, economic, and cultural factors) influence dependent variables such as tree adaptability, functionality, and ecosystem services. In the context of street tree morphology, mediators such as tree size, form, leaves, root systems, and growth rate bridge the relationships between external constraints and desired outcomes. For instance, tree size and root systems mediate the influence of urban space limitations on tree growth and functionality, while leaf characteristics and growth rate mediate the impact of environmental constraints on urban cooling and air quality enhancement (Hair et al., 2017). Similarly, factors like natural habitat and soil type mediate the adaptation of tree species to specific urban microhabitats, ensuring ecological resilience. By incorporating these mediators, tree selection models can better capture the complex interactions among variables, facilitating more precise and context-specific urban forestry decisions. Measurement items, such as tree size, form, leaves, flowers, fruits, growth rate, root systems, and environmental attributes like soil type or microhabitat, can be assessed for their relationship with tree selection factors in urban contexts. This design allows researchers to evaluate these factors' importance and influence decision-making in a systematic and time-efficient manner.

Table 3: Measurement Items of Street Tree Morphology

No.	Items
1	The tree size has a relationship with tree species selection factors
2	The tree form has a relationship with the tree selection factors
3	The leaves have a relationship with the tree selection factors
4	The flower has a relationship with the tree selection factors
5	The fruits have a relationship with the tree selection factors
6	The growth rate has a relationship with the tree selection factors
7	The root system has a relationship with the tree selection factors
8	The elasticity has a relationship with the tree selection factors
9	The timber type has a relationship with the tree selection factors
10	The natural habitat has a relationship with the tree selection factors
11	The soil type has a relationship with the tree selection factors
12	The microhabitat has a relationship with the tree selection factors

The mediating variable, Street Tree Morphology as shown in Table 3, encompasses a range of physical and biological attributes that influence the selection and performance of tree species in urban environments. Tree size and form are critical determinants, affecting shade provision, aesthetic appeal, and spatial compatibility with urban infrastructure (McPherson et al., 2007). The characteristics of leaves, such as their density and surface area, contribute to air purification and cooling effects, enhancing urban microclimates (Hirons & Sjöman, 2019).

Flowers and fruits influence the ecological and cultural value of street trees, supporting biodiversity while aligning with public preferences for ornamental features (Wolf, 2005). Growth rate plays a significant role in determining maintenance needs and long-term functionality, as faster-growing species often require more frequent pruning and management (Mullaney, Lucke, & Trueman, 2015). The root system is another crucial factor, directly affecting tree stability and its interactions with underground utilities. Trees with non-invasive roots minimize conflicts with infrastructure, ensuring their structural integrity (Pauleit et al., 2005). Elasticity and timber type further mediate species selection by influencing resilience to mechanical stress and environmental pressures. Natural habitat and soil type compatibility are essential for ensuring species adaptability to local conditions, including soil fertility and urban pollution. Finally, the microhabitat, encompassing localized environmental conditions, plays a key role in determining species success in constrained urban spaces (Dobbs, Kendal, & Nitschke, 2014). These morphological traits serve as mediators by bridging the relationship between environmental, social, and functional factors, ultimately influencing the success of tree selection and management practices in urban forestry.

The next layer focuses on Selection Criteria related to Adaptability and Environmental Tolerance, such as tolerance to microclimate changes, pest and disease resistance, and resistance to soil weaknesses and mechanical damage. These factors ensure that the selected tree species can thrive in urban environments, withstand environmental stresses, and contribute to sustainable urban forestry. Botanical Morphological Features form the outermost layer of the model, encompassing tree characteristics like size, form, leaves, flowers, and fruit. These features are crucial for achieving the desired aesthetic and functional outcomes in urban landscapes.

Conceptual Tree Selection Model

The findings from the confirmatory factors survey support the development of an objectives-driven tree selection model that integrates ecological, social, and economic considerations in alignment with urban planning goals. Existing urban forestry frameworks—such as those by Amir and Misgav (1990), Miller (1997), and Ramly et al. (2018)—primarily emphasize environmental constraints but often lack integration of tree morphological traits with socio-economic factors essential to urban contexts. Addressing this gap, Research Objective 4 focuses on formulating a species selection model that reduces potential conflicts while optimizing the benefits of street tree planting.

By incorporating tree morphology into a wider framework of environmental, cultural, economic, and social factors, the proposed model enhances its applicability across diverse urban scenarios. For instance, selecting species that are both climate-resilient and culturally appreciated can enhance community support, while species with low maintenance requirements contribute to long-term economic sustainability (Roy et al., 2015).

The Proposed Conceptual Tree Selection Model as shown in Figure 12 offers a structured framework that balances these dimensions, ultimately evolving into an Optimized Street Tree Selection Model. This integrative approach ensures species are selected not only for their ecological suitability but also for their compatibility with urban infrastructure and public needs. The model thus advances sustainable urban forestry by aligning species selection with multiple stakeholder priorities and long-term urban resilience strategies.

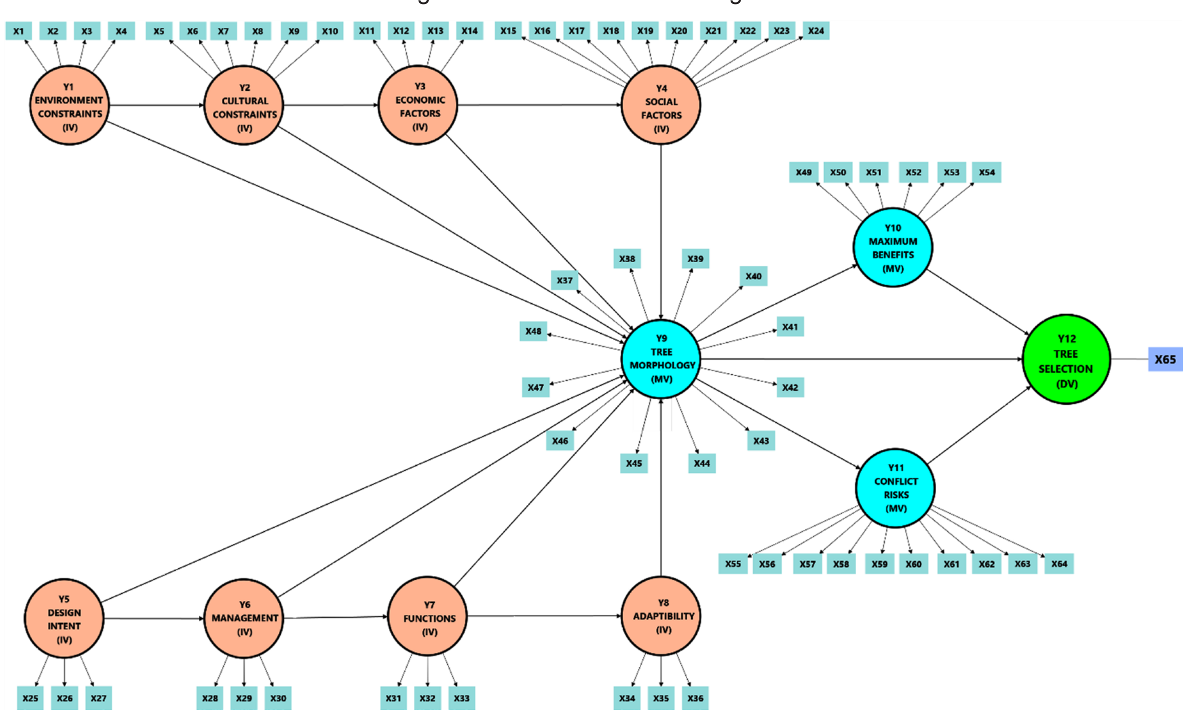

Figure 12: Proposed Conceptual Tree Selection Modelling

The hypotheses in this study were derived from the proposed conceptual framework designed to examine factors influencing street tree species selection. Each hypothesis reflects a theorized cause-effect relationship between constructs, informed by literature, expert input, and urban forestry theory. The study tests both direct and indirect effects, particularly the mediating role of tree morphology, using the PLS-SEM method to evaluate statistical significance and model validity. This structured approach allows for a comprehensive assessment of the complex decision-making processes in urban tree planning.

Table 4: Research Model Hypotheses

No.	Hypotheses Testing	
H1	**Street Tree Planting Objectives → Street Tree Species Selection**	
	H1a	The objective of optimizing maximum benefits positively influences the selection of street tree species.
	H1b	The objective of conflict risks positively influences the selection of street tree species.
H2	**Street Tree Planting Objectives → Tree Morphology**	
	Street tree planting objectives positively influence the selection of tree morphological characteristics.	
H3	**Tree Morphology → Street Tree Species Selection**	
	Tree morphological characteristics positively influence the selection of street tree species.	
H4	Tree Morphology as a Mediator	
	Tree morphology mediates the relationship between street tree planting objectives and street tree species selection.	
H5	**Street Tree Selection Criteria → Street Tree Species Selection**	
	H5a	Adaptability and tolerance to the environment positively influence the selection of street tree species.
	H5b	Functional attributes of trees positively influence the selection of street tree species.
	H5c	Ease of plant management positively influences the selection of street tree species.
	H5d	Compatibility with planting design positively influences the selection of street tree species.
H6	**Street Tree Selection Factors → Street Tree Species Selection**	
	H6a	Environmental factors positively influence the selection of street tree species.
	H6b	Cultural factors positively influence the selection of street tree species.
	H6c	Economic factors positively influence the selection of street tree species.
	H6d	Social factors positively influence the selection of street tree species.

Conclusion

In conclusion, the optimization of street tree selection is a complex process that involves balancing the benefits of trees with the prevention of conflicts between tree growth and human activities. This methodological rigor adds a layer of scientific credibility to the model, ensuring that it is not only theoretically sound but also practically applicable. By integrating tree morphology into factors such as cultural, economic, social, and environmental constraints, urban planners can develop objective-driven models that enhance the sustainability and liveability of urban areas. While this is an important and timely research topic, presents several limitations that must be acknowledged. One of the primary challenges is the limited availability of localized data on tree species performance under specific urban conditions in Malaysia. Many studies on urban forestry and street tree selection are based on data from temperate climates, which may not be directly applicable to the tropical context of Malaysia. As a result, researchers often have to rely on international literature, which might not accurately reflect the unique environmental and cultural factors at play in Malaysian urban areas.

Limitations

The geographic concentration of the study in Malaysia limits its global generalizability. While Malaysia's urban forestry context is rich and relevant, biophysical variables (e.g., climate, soil) and socio-cultural values differ across regions. Cultural preferences, religious symbolism, and regulatory standards vary and influence species selection practices. Therefore, applying the model in other contexts without adaptation could lead to misalignment with local conditions and stakeholder expectations.

Even within Malaysia, significant variation exists across urban centres. For example, Kuala Lumpur is heavily urbanized with dense infrastructure and policy-driven greening agendas, Penang emphasizes heritage-sensitive landscapes and community aesthetics, while Kuching reflects Bornean biodiversity and cultural diversity. These city-specific contexts highlight that generalization of the model across Malaysia must be done cautiously, with adaptations to local ecological settings, governance frameworks, and socio-cultural priorities.

Secondly, the study employs an entirely quantitative methodology, relying on PLS-SEM. While statistically robust, this approach lacks the depth to capture qualitative aspects of urban forestry, such as emotional attachment to species, local symbolism, or historical memory. Excluding perspectives from interviews, community dialogues, or expert workshops limits understanding of why certain species are favored or rejected in practice.

To overcome these limitations and strengthen the robustness and usefulness of the STSS model, several future research directions are suggested. First, testing the model in different regions and climates is important to ensure it works beyond the Malaysian context and adapts to various ecological and urban settings. Second, future studies should include socio-political and institutional factors—such as governance, stakeholder roles, and policies—to reflect real-world decision-making. Third, using mixed methods, including interviews, focus groups, and workshops, can reveal local cultural values and preferences, making the model more socially relevant for future studies.

Research Contribution

The 'Conceptual Tree Selection Model' presents a structured approach to optimizing street tree selection by integrating tree morphology into various constraints and factors that influence urban tree planting decisions. The framework aims to balance environmental, cultural, economic, and social factors to achieve the dual objectives of maximizing street tree benefits and minimizing conflicts with human activities. The integration of tree morphology and these constraints leads to the development of an Optimized Street Tree Selection Model aimed at maximizing the benefits of urban trees while preventing conflicts with human activities and urban infrastructure. The proposed model emphasizes a balanced approach that aligns tree selection with ecological, cultural, economic, and social requirements, ultimately contributing to more sustainable and harmonious urban environments. The proposed models are valuable for urban planners, policymakers, and environmental managers, promoting the development of resilient and sustainable urban forests that enhance urban livability and ecological health. The practical contributions include offering context-specific and informed decisions that urban planners and local authorities can directly apply to optimize the sustainability and resilience of urban green spaces. In real projects, local authorities or landscape consultants can use the model as a decision-support tool to screen potential species, evaluate site-specific constraints, and justify selection choices in planning submissions or design guidelines.

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