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A DECISION-SUPPORT FRAMEWORK FOR SUSTAINABLE URBAN INFRASTRUCTURE MAINTENANCE USING THE ANALYTIC HIERARCHY PROCESS

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Abstract: Urban infrastructure maintenance is critical for ensuring the long-term sustainability, safety, and performance of cities. However, many developing countries continue to rely on traditional maintenance approaches that are reactive and inefficient. Rapid urbanisation, population growth, and climate change have placed significant pressure on infrastructure systems, highlighting the need for more sustainable and proactive maintenance strategies. This study develops a framework for sustainable urban infrastructure maintenance by integrating environmental, economic, resilience, and technological considerations. A qualitative research approach was adopted through a systematic review of secondary data from peer-reviewed literature, policy documents, and infrastructure management studies. Key themes relating to sustainable infrastructure maintenance were identified and synthesised into a decision-support framework. The Analytic Hierarchy Process (AHP) was employed as a multi-criteria decision-making tool to evaluate and prioritise maintenance strategies. The analysis considered four main criteria: environmental impact, economic efficiency, resilience and adaptability, and technology integration. Results from the AHP analysis indicate that environmental impact is the most influential criterion, while climate-resilient infrastructure emerged as the highest-ranked maintenance strategy. The study demonstrates how multi-criteria decision-making techniques can effectively support the development of sustainable infrastructure maintenance frameworks. The proposed framework provides practical guidance for policymakers, engineers, and urban planners seeking to improve infrastructure resilience and sustainability in rapidly urbanising regions.

Keywords: Urban Infrastructure; Sustainable Maintenance; Analytic Hierarchy Process; Infrastructure Resilience; Urban Sustainability

1 INTRODUCTION

Urban infrastructure systems, including transportation networks, water systems, and public facilities, play a fundamental role in supporting economic development and societal well-being. The effective maintenance of these systems is essential to ensure their long-term functionality, safety, and sustainability. However, many cities, particularly in developing countries, continue to rely on reactive maintenance approaches that address infrastructure failures only after they occur, resulting in increased costs, operational inefficiencies, and environmental degradation.Rapid urbanisation, population growth, and climate change have further intensified pressure on infrastructure systems, accelerating deterioration and increasing exposure to environmental risks. These challenges underscore the need for more sustainable, proactive, and resilient maintenance strategies that integrate environmental, economic, and technological considerations.Sustainable infrastructure maintenance has therefore emerged as a critical area of research and practice. It emphasizes lifecycle-based approaches such as predictive maintenance, real-time monitoring, and the integration of smart technologies to enhance infrastructure performance and resilience. Technological innovations, including structural health monitoring and data-driven predictive maintenance systems, have demonstrated significant potential in improving decision-making, reducing maintenance costs, and extending infrastructure lifespan (Hao et al. 2023; Nethamba and Grobbelaar 2022).

Despite these advancements, infrastructure maintenance decision-making remains complex and fragmented. Existing approaches often address individual aspects such as environmental sustainability or technological innovation in isolation, without providing an integrated framework for evaluating competing priorities. Decision-makers are required to balance multiple criteria including environmental impact, economic efficiency, resilience, and technological feasibility yet structured tools for systematically prioritising these criteria in a unified framework remain limited.The absence of an integrated, multi-criteria decision-support framework for sustainable urban infrastructure maintenance limits the ability of policymakers, engineers, and infrastructure managers to make informed and balanced decisions. Current practices lack systematic approaches for prioritising maintenance strategies that simultaneously address sustainability, resilience, and technological integration. The aim of this study is to develop a decision-support framework for sustainable urban infrastructure maintenance using a systematic literature review and the Analytic Hierarchy Process (AHP). This framework will be used to evaluate and prioritise maintenance strategies. The relevance of sustainable infrastructure maintenance has become increasingly significant within digitally enabled and industrialised infrastructure systems associated with smart cities, modular infrastructure delivery, and data-driven asset management practices. In these contexts, resilient maintenance strategies, predictive monitoring technologies, and integrated decision-support systems are essential for improving infrastructure lifecycle performance and long-term sustainability.

To achieve this aim, the study pursues the following objectives:

1. To identify key criteria influencing sustainable infrastructure maintenance through a systematic review of literature.

2. To apply the Analytic Hierarchy Process (AHP) to evaluate and prioritise the identified criteria and maintenance strategies.

3. To rank sustainable maintenance strategies based on their relative importance.

This study contributes to knowledge by developing a structured decision-support framework that integrates sustainability, resilience, economic, and technological considerations within urban infrastructure maintenance prioritisation. Unlike previous studies that apply AHP primarily to isolated infrastructure evaluation problems, this research combines multi-criteria decision-making with sustainability-oriented maintenance strategy assessment within a unified framework. The study further contributes by positioning climate resilience and technology-enabled maintenance approaches alongside traditional economic considerations to support more balanced infrastructure management decision-making. Unlike previous studies that focus on isolated aspects of infrastructure maintenance, this research provides a structured and holistic approach that combines environmental, economic, resilience, and technological considerations. The application of the Analytic Hierarchy Process (AHP) further enhances the study by offering a transparent and systematic method for prioritising maintenance strategies. The proposed framework provides practical guidance for infrastructure managers and policymakers and contributes to advancing sustainable and resilient infrastructure maintenance practices.

2 LITERATURE REVIEW

2.1 Sustainable Infrastructure Maintenance

Sustainable infrastructure maintenance is essential for ensuring the long-term functionality and resilience of urban systems. It involves integrating environmental, economic, and social considerations into maintenance practices to achieve long-term sustainability. The concept is rooted in sustainable development, which emphasizes meeting present needs without compromising future generations (United Nations 1987). In infrastructure management, this requires a shift from short-term, reactive approaches to long-term, lifecycle-based strategies aligned with recognised asset management principles (ISO 2014).

Several studies highlight the limitations of traditional maintenance approaches and the need for sustainable alternatives. O'Farrell et al. (2019) argue that conventional infrastructure practices contribute to environmental degradation and fail to support long-term sustainability goals. Similarly, Hao et al. (2023) emphasize that infrastructure systems must incorporate lifecycle maintenance strategies to reduce costs and prevent structural failures. Jiang et al. (2023) further note that increasing urban demand accelerates infrastructure deterioration, making sustainable maintenance essential for long-term performance. These studies collectively demonstrate that reactive maintenance is no longer sufficient in modern urban environments. Empirical evidence also shows that sustainable maintenance improves infrastructure performance and reduces long-term costs. For example, lifecycle-based maintenance approaches enable early detection of deterioration and reduce the likelihood of catastrophic failures (Hao et al. 2023). These approaches also improve resource efficiency and support environmental sustainability. Overall, the literature indicates that sustainable infrastructure maintenance is a critical requirement for modern cities. It provides a foundation for integrating environmental, economic, and resilience considerations into infrastructure management and highlights the need for structured decision-support frameworks.

2.2 Technological Innovation in Infrastructure Maintenance

Technological innovation plays a significant role in transforming infrastructure maintenance from reactive to proactive systems through predictive analytics, automation, and data-driven monitoring (Carvalho et al. 2019). It enables real-time monitoring, predictive analysis, and data-driven decision-making, which are essential for improving maintenance efficiency and sustainability.Hao et al. (2023) demonstrate that structural health monitoring systems allow engineers to detect structural deterioration early and improve maintenance planning. Nethamba and Grobbelaar (2022) show that predictive maintenance systems, particularly in railway infrastructure, reduce maintenance costs and improve operational efficiency through data-driven insights. Similarly, Jiang et al. (2023) highlight the importance of integrating advanced technologies into infrastructure planning to address increasing demand and system complexity. While these studies focus on different sectors, they collectively show that technological innovation enhances infrastructure reliability and performance. Case-based evidence further supports the role of technology in infrastructure maintenance. Smart infrastructure systems, such as sensor-based monitoring and data analytics platforms, are increasingly associated with Industry 4.0 transformation and intelligent maintenance systems (Lee et al. 2018).These systems improve decision-making by providing accurate and timely information. The significance of these findings lies in the growing importance of technology integration in sustainable infrastructure maintenance. Technological innovation not only improves efficiency but also supports the development of intelligent and adaptive infrastructure systems.

2.3 Climate Change and Infrastructure Resilience

Climate change has become a major factor influencing infrastructure maintenance and sustainability. It increases the exposure of infrastructure systems to extreme weather events, environmental stress, and long-term degradation. Mishra and Sadhu (2023) argue that climate change significantly affects the structural integrity of infrastructure, requiring updated design standards and maintenance strategies. Hao et al. (2023) emphasize that infrastructure must be designed to withstand multi-hazard conditions and adapt to changing environmental conditions. Zhou et al. (2022) further highlight that urban infrastructure in developing regions is particularly vulnerable to climate-related risks due to rapid urbanisation and limited resources. These studies demonstrate that climate change is a critical driver of infrastructure deterioration and maintenance demand. Practical examples show that climate-resilient strategies are essential for ensuring long-term infrastructure sustainability and reducing service disruptions caused by environmental shocks (World Bank 2021). For instance, the use of resilient materials, adaptive design approaches, and environmental monitoring systems can enhance infrastructure durability and reduce maintenance costs. These strategies are particularly important in regions experiencing frequent environmental disruptions. The literature therefore highlights the importance of integrating resilience into infrastructure maintenance frameworks. Climate-resilient strategies are essential for ensuring long-term infrastructure sustainability and reducing service disruptions caused by environmental shocks (World Bank 2021).

2.4 Multi-Criteria Decision-Making in Infrastructure Management

Infrastructure maintenance decision-making involves balancing multiple competing criteria, making it a complex and multidimensional process. Decision-makers must consider environmental, economic, technical, and social factors when selecting maintenance strategies. Navarro, Yepes, and Martí (2019) argue that multi-criteria decision-making (MCDM) methods provide structured approaches for evaluating infrastructure alternatives based on multiple criteria. Saaty (1980) introduced the Analytic Hierarchy Process, which was later further elaborated as a robust decision-making framework for complex choices (Saaty 2008). The AHP method uses pairwise comparisons to determine the relative importance of criteria and alternatives, enabling systematic prioritisation. Similarly, Scope, Vogel, and Guenther (2021) highlight that sustainability assessment in infrastructure requires structured evaluation methods that can integrate multiple criteria. Applications of AHP in infrastructure management demonstrate its effectiveness in prioritising complex decisions, including sustainable transport and infrastructure systems (Kumar and Anbanandam 2020). The method allows decision-makers to evaluate trade-offs between competing criteria and identify the most suitable strategies based on weighted importance. The significance of MCDM methods lies in their ability to provide transparency and consistency in decision-making. They support the development of structured frameworks for sustainable infrastructure maintenance and enable more informed and balanced decisions.

2.5 Synthesis of Key Criteria for Sustainable Maintenance

The literature consistently identifies key criteria that influence sustainable infrastructure maintenance decision-making. These criteria provide a foundation for developing structured decision-support frameworks. Across the reviewed studies, four key criteria emerge: environmental impact, economic efficiency, resilience and adaptability, and technology integration. Navarro, Yepes, and Martí (2019) emphasize the importance of integrating environmental and economic considerations in infrastructure planning. Hao et al. (2023) highlight the role of resilience in ensuring infrastructure durability under environmental stress. Nethamba and Grobbelaar (2022) demonstrate the importance of technology in improving maintenance efficiency and decision-making. These studies collectively show that sustainable infrastructure maintenance requires a holistic approach that integrates multiple criteria. The identification of these criteria is critical for developing a decision-support framework. They provide a structured basis for evaluating and prioritising maintenance strategies using multi-criteria decision-making methods.

2.6 Research Gap

Despite extensive research on sustainable infrastructure maintenance, technological innovation, and decision-making methods, existing studies remain fragmented and often focus on individual aspects in isolation. Many studies emphasize environmental sustainability or technological innovation but do not integrate these aspects into a unified framework. Navarro, Yepes, and Martí (2019) highlight the need for integrated decision-making approaches in infrastructure management. Similarly, O'Farrell et al. (2019) note that current practices fail to address the complexity of sustainability challenges in urban infrastructure systems. While AHP has been widely applied in decision-making, its application in prioritising sustainable infrastructure maintenance strategies remains limited. This gap indicates the need for a structured framework that integrates key sustainability criteria and applies multi-criteria decision-making methods to prioritise maintenance strategies. This study addresses this gap by developing a decision-support framework using the Analytic Hierarchy Process to evaluate and rank sustainable urban infrastructure maintenance strategies. While previous studies such as Navarro, Yepes, and Martí (2019) and Kumar and Anbanandam (2020) demonstrate the usefulness of multi-criteria decision-making approaches in infrastructure evaluation, their focus is largely directed toward infrastructure design and transportation prioritisation. Limited attention has been given to integrating sustainability, resilience, and technology-oriented maintenance strategies within urban infrastructure maintenance decision-support frameworks.

2.7 Literature Review Conclusion

The reviewed literature demonstrates that sustainable infrastructure maintenance is a multidimensional concept that integrates environmental sustainability, economic efficiency, infrastructure resilience, and technological innovation. Studies such as Hao et al. (2023) and Nethamba and Grobbelaar (2022) emphasize the role of technology in improving maintenance efficiency and enabling predictive strategies. In contrast, O'Farrell et al. (2019) and Mishra and Sadhu (2023) highlight the environmental and resilience challenges associated with traditional infrastructure maintenance practices. While these studies provide valuable insights, they often address individual aspects of infrastructure maintenance rather than offering a comprehensive and integrated perspective. As a result, the existing body of knowledge remains fragmented, with limited alignment between sustainability, resilience, and decision-making frameworks. Furthermore, although multi-criteria decision-making methods such as the Analytic Hierarchy Process (Saaty 1980) have been widely applied in infrastructure planning, their integration with sustainable infrastructure maintenance remains limited. Studies such as Navarro, Yepes, and Martí (2019) demonstrate the effectiveness of MCDM approaches in infrastructure evaluation but do not fully incorporate the combined influence of environmental, economic, resilience, and technological criteria within a single framework. This gap highlights the need for a structured and integrated decision-support approach. Therefore, this study addresses this limitation by applying the Analytic Hierarchy Process to systematically evaluate and prioritise sustainable maintenance strategies, thereby providing a holistic framework that supports informed decision-making in urban infrastructure maintenance. Table 1 summarises the key areas covered in existing literature, the identified gaps, and how this study addresses these limitations.

Table 1: Literature Gaps and Study Contribution

Key Area	What Literature Covers	Identified Gap	How This Study Addresses It
Sustainable maintenance	Focus on environmental and economic aspects	Lack of integration with technology and resilience	Integrates all four criteria into one framework
Technological innovation	Focus on SHM, IoT, predictive maintenance	Limited application in decision frameworks	Applies technology as a decision criterion
Climate resilience	Focus on environmental risks and adaptation	Not linked to prioritisation models	Incorporates resilience into AHP framework
Decision-making methods	Use of AHP and MCDM in infrastructure	Limited application to sustainable maintenance strategies	Applies AHP specifically to rank maintenance strategies
Framework development	Conceptual frameworks exist	Lack of operational prioritisation tools	Develops a decision-support prioritisation framework

The summary presented in Table 1 highlights that, while existing studies provide valuable insights into sustainability, resilience, and technological innovation in infrastructure maintenance, they largely address these elements in isolation. There remains a lack of integrated and operational decision-support frameworks that combine these dimensions within a unified structure. By addressing this gap, the present study develops and applies an AHP-based framework to systematically evaluate and prioritise sustainable maintenance strategies, thereby providing a more holistic and practical approach to infrastructure maintenance decision-making.

3. RESEARCH METHODOLOGY

This study aims to develop a decision-support framework for sustainable urban infrastructure maintenance by applying a systematic literature review (SLR) and the Analytic Hierarchy Process (AHP) to evaluate and prioritise maintenance strategies. A qualitative research approach was adopted to synthesise existing knowledge and support the development of a structured decision-making framework. The study followed a three-stage process involving literature identification, thematic analysis, and multi-criteria evaluation. Secondary data were collected from peer-reviewed journal articles, academic publications, and relevant infrastructure reports. The systematic literature review followed a structured screening and selection process to ensure transparency and relevance. Literature searches were conducted using Scopus, Web of Science, Google Scholar, and ScienceDirect databases covering publications from 2014 to 2025. Search terms included combinations of keywords such as "sustainable infrastructure maintenance", "urban infrastructure resilience", "predictive maintenance", "smart infrastructure", "Analytic Hierarchy Process", and "multi-criteria decision-making". The inclusion criteria focused on peer-reviewed studies addressing sustainable infrastructure maintenance, resilience, technological innovation, or decision-support methods within urban infrastructure contexts. Studies unrelated to infrastructure maintenance, lacking sustainability relevance, or presenting insufficient methodological detail were excluded. Figure 1 presents the PRISMA-based literature screening and selection process adopted for this study.

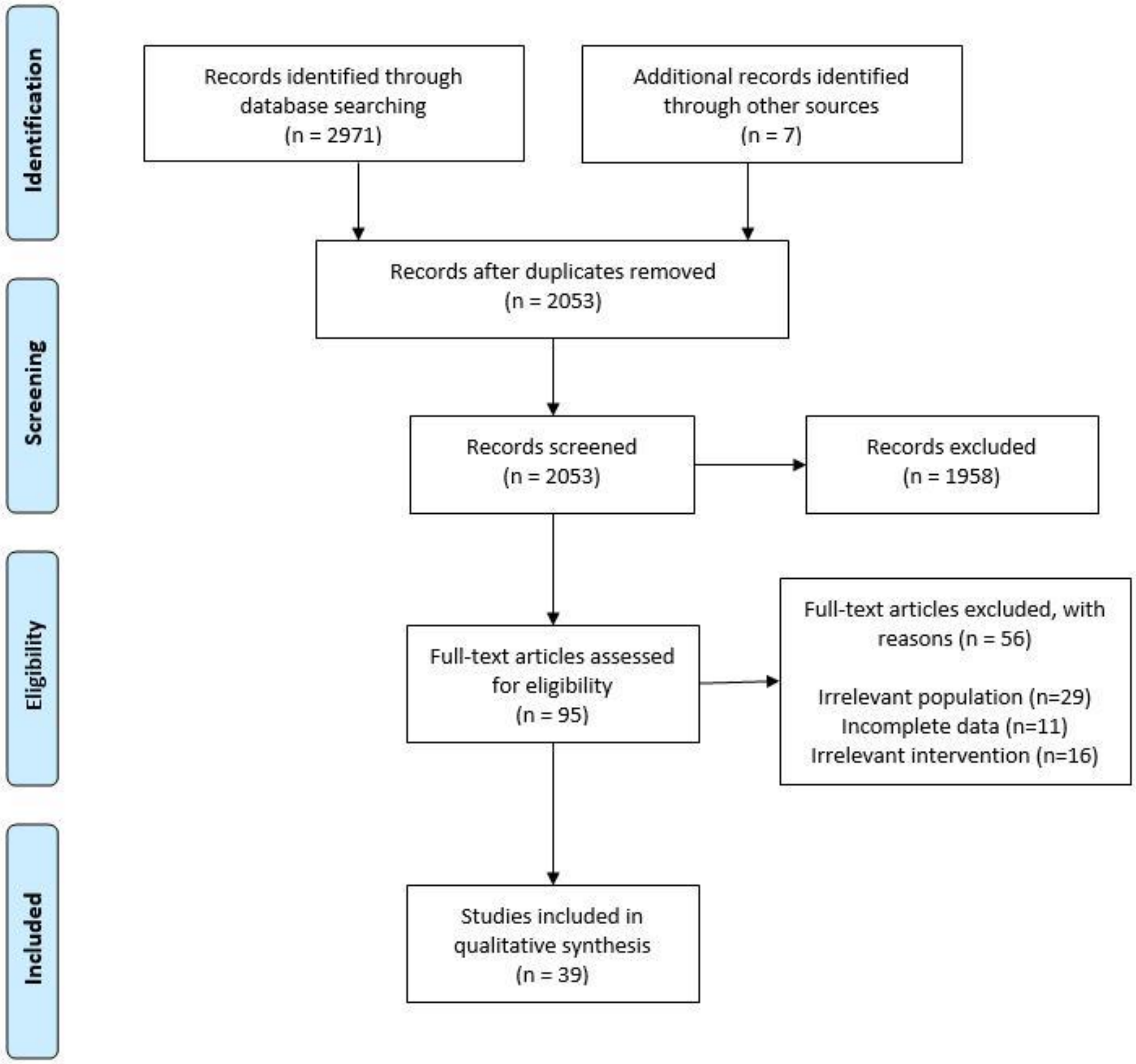

Figure 1: PRISMA-Based Literature Screening and Selection Process

Table 2 summarises the inclusion and exclusion criteria adopted during the literature screening and selection process.

Table 2: Inclusion and Exclusion Criteria for Literature Selection

Criterion	Inclusion Criteria	Exclusion Criteria
Relevance	Studies focused on sustainable urban infrastructure maintenance, management, resilience, or decision-support systems	Studies unrelated to infrastructure maintenance or urban infrastructure systems
Focus Area	Studies addressing sustainability, resilience, technology integration, predictive maintenance, smart infrastructure, or multi-criteria decision-making	Studies not addressing sustainability, resilience, technology integration, or decision-support approaches

Criterion	Inclusion Criteria	Exclusion Criteria
Publication Type	Peer-reviewed journal articles, conference papers, and reputable institutional reports	Editorials, opinion papers, news articles, and non-peer-reviewed publications
Methodological Quality	Studies with clear methodology, Analytic framework, or empirical contribution	Studies with insufficient methodological clarity or weak Analytic relevance
Time Frame	Publications from 2014–2025	Publications published before 2014
Language	Studies published in English	Non-English publications
Accessibility	Full-text accessible studies	Studies without accessible full text

A systematic search strategy was employed using keywords such as *sustainable infrastructure*, *maintenance*, *urban engineering*, and *decision-making*. The selected studies were screened based on relevance to sustainability, infrastructure maintenance, and decision-support methods. The identified literature was analysed using thematic analysis to extract recurring patterns and key concepts. The analysis of the literature resulted in the identification of four key criteria influencing sustainable infrastructure maintenance: environmental impact, economic efficiency, resilience and adaptability, and technology integration. These criteria formed the basis for the development of the decision-support framework. In addition, three maintenance strategies were identified as alternatives, namely performance-based contracts, integration of smart infrastructure, and climate-resilient infrastructure. These alternatives were conceptualised as strategic maintenance approaches representing procurement-driven, technology-enabled, and resilience-oriented pathways for sustainable urban infrastructure maintenance. The Analytic Hierarchy Process (AHP), developed by Saaty (1980), was employed to evaluate and prioritise the identified criteria and alternatives. AHP is a widely used multi-criteria decision-making method that structures complex decision problems into hierarchical levels consisting of a goal, criteria, and alternatives. The method enables systematic comparison of multiple factors and supports transparent decision-making (Navarro, Yepes, and Martí 2019). Pairwise comparisons were conducted using the AHP nine-point scale to assess the relative importance of the criteria and alternatives. The scale, which ranges from equal importance to extreme importance, allows for consistent evaluation of competing factors (Saaty 1980). The comparison matrices were used to derive criteria weights using the eigenvalue method, and consistency checks were performed to ensure reliability of the results. The evaluated alternatives were then ranked by combining the criteria weights with the corresponding scores from the pairwise comparisons. This process enabled the identification of the most suitable maintenance strategy based on multiple sustainability criteria. Microsoft Excel was used to perform the calculations, ensuring transparency and reproducibility of the analysis. To systematically operationalise the research design, a structured methodology framework was developed, integrating systematic literature review procedures with multi-criteria decision-making using the Analytic Hierarchy Process (AHP), as illustrated in Figure 2.

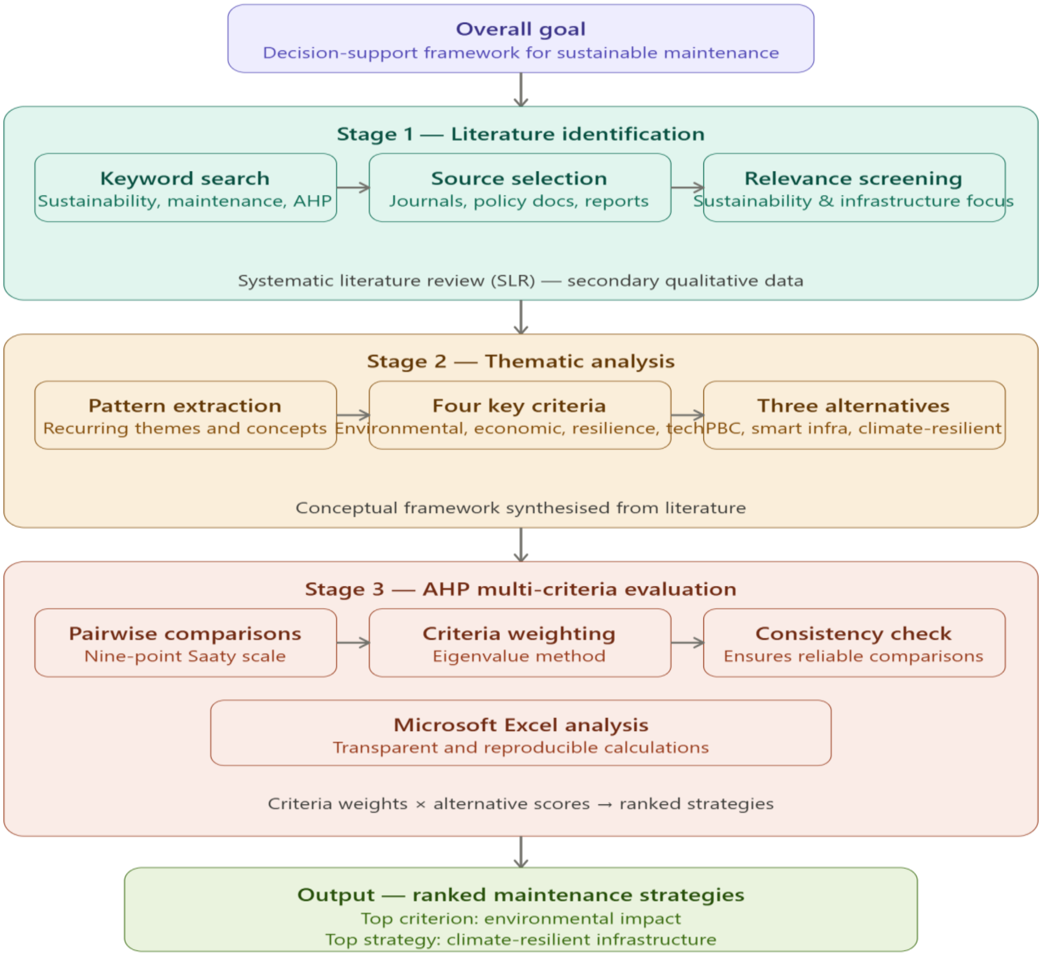

Figure 2: Research Methodology Framework for Sustainable Urban Infrastructure Maintenance Using SLR and AHP

Figure 2 presents the structured research methodology adopted in this study. The process begins with a systematic literature review, where relevant studies on sustainable urban infrastructure maintenance were identified, screened, and selected. This is followed by thematic analysis to extract key concepts and identify critical sustainability criteria, namely environmental impact, economic efficiency, resilience and adaptability, and technology integration. In parallel, feasible maintenance strategies were defined as decision alternatives. The identified criteria and alternatives emerged from recurring themes and strategic approaches consistently discussed across the reviewed literature. Environmental impact, economic efficiency, resilience and adaptability, and technology integration were selected due to their strong representation within sustainable infrastructure management studies. Similarly, performance-based contracts, smart infrastructure integration, and climate-resilient infrastructure were categorised as strategic maintenance approaches reflecting procurement-driven, technology-enabled, and resilience-oriented pathways for sustainable infrastructure maintenance delivery.Subsequently, the Analytic Hierarchy Process (AHP) was employed to structure the decision problem into hierarchical levels comprising the overall goal, evaluation criteria, and alternative strategies. Pairwise comparisons were conducted using Saaty's nine-point scale to determine the relative importance of each criterion and alternative. The pairwise comparison judgments were developed through literature-informed comparative assessment based on the recurring importance of sustainability-related criteria identified across the reviewed studies. The weighting process was guided by established AHP procedures to support a structured conceptual evaluation of sustainable maintenance strategies. The derived weights were validated through consistency checks to ensure reliability. Finally, the alternatives were ranked based on their composite scores, leading to the development of a robust decision-support framework for sustainable urban infrastructure maintenance.

4. RESULTS AND DISCUSSION

The results of the study are based on the application of the Analytic Hierarchy Process (AHP) to evaluate and prioritise sustainable urban infrastructure maintenance strategies. The analysis focused on four key criteria identified from the literature: environmental impact, economic efficiency, resilience and adaptability, and technology integration. Table 3 presents the pairwise comparison matrix developed for evaluating the relative importance of the sustainability criteria within the AHP framework.

Table 3: Pairwise Comparison Matrix for Evaluation Criteria

Criteria	Environmental Impact	Resilience & Adaptability	Economic Efficiency	Technology Integration
Environmental Impact	1	2	3	5
Resilience & Adaptability	1/2	1	2	4
Economic Efficiency	1/3	1/2	1	2
Technology Integration	1/5	1/4	1/2	1

Table 3 presents the pairwise comparison matrix developed for evaluating the relative importance of the sustainability criteria within the AHP framework.

Table 4: Criteria Weights Derived from Analytic Hierarchy Process

Criteria	Weight	Rank
Environmental Impact	0.42	1
Resilience & Adaptability	0.30	2
Economic Efficiency	0.18	3
Technology Integration	0.10	4

As shown in Table 4, the pairwise comparison results indicate that environmental impact is the most influential criterion, with the highest weighting, followed by resilience and adaptability, economic efficiency, and technology integration. The dominance of environmental impact reflects the growing importance of sustainability considerations in infrastructure maintenance. This finding aligns with existing studies which emphasise the need to minimise environmental degradation and promote resource efficiency in infrastructure systems (O'Farrell et al. 2019; Mishra and Sadhu 2023). The high ranking of resilience and adaptability further highlights the increasing need for infrastructure systems to withstand environmental stresses and climate-related risks. This supports the argument that infrastructure maintenance strategies must incorporate resilience to ensure long-term performance and reliability (Hao et al. 2023). Economic efficiency, although important, was ranked lower than environmental and resilience considerations. This suggests a shift from traditional cost-driven maintenance approaches towards more sustainability-oriented decision-making. While cost remains a critical factor, the findings indicate that decision-makers are increasingly prioritising long-term sustainability over short-term economic gains. Technology integration received the lowest weighting among the criteria, which may reflect challenges associated with implementation costs, technical expertise, and institutional readiness.

Table 5: Consistency Ratio Test

Measure	Value
Λmax	4.12
CI	0.04
RI	0.90
CR	0.044

The consistency ratio shown in Table 5 is below the acceptable threshold of 0.10, indicating reliable expert judgments. A basic sensitivity assessment was conducted by observing potential ranking variations under moderate adjustments to criteria importance. The analysis showed that climate-resilient infrastructure consistently remained the highest-ranked strategy under reasonable weighting variations, indicating relative robustness of the prioritisation outcomes.

Table 6: Ranking of Maintenance Strategies

Alternative Strategy	Score	Rank
Climate-resilient infrastructure	0.46	1
Smart infrastructure integration	0.33	2
Performance-based contracts	0.21	3

The ranking of maintenance strategies presented in Table 6 shows that climate-resilient infrastructure is the highest-ranked alternative, followed by smart infrastructure integration, while performance-based contracts ranked third. The high ranking of climate-resilient infrastructure indicates that strategies aimed at improving infrastructure adaptability to environmental conditions are considered most effective in achieving sustainable maintenance. This finding is consistent with literature highlighting the importance of climate adaptation in infrastructure planning and maintenance (Mishra and Sadhu 2023).

Performance-based contracts ranked third, suggesting that aligning contractor incentives with sustainability outcomes can improve maintenance efficiency and long-term performance. This approach encourages accountability and promotes the adoption of sustainable practices in infrastructure management. Smart infrastructure integration, which ranked second, remains an important component of modern maintenance strategies. Technologies such as sensors and data analytics enable real-time monitoring and predictive maintenance, which improve operational efficiency (Nethamba and Grobbelaar 2022). The findings demonstrate that sustainable infrastructure maintenance requires a balanced integration of environmental, resilience, economic, and technological considerations. The results also confirm the effectiveness of the Analytic Hierarchy Process in supporting complex decision-making by providing a structured approach to prioritising competing criteria and strategies. Overall, the study highlights the importance of adopting a holistic approach to infrastructure maintenance that prioritises sustainability and resilience while leveraging technological advancements. The developed framework provides a practical tool for decision-makers to evaluate maintenance strategies and supports more informed and effective infrastructure management. The findings suggest that infrastructure maintenance decision-making is increasingly shifting toward resilience-oriented and sustainability-driven priorities rather than purely cost-based considerations. Although technology integration received the lowest weighting, this does not imply limited importance; rather, it may reflect practical implementation challenges such as high initial investment requirements, institutional readiness limitations, and technical capacity constraints commonly experienced in developing urban infrastructure systems.

5. CONCLUSION

This study developed a decision-support framework for sustainable urban infrastructure maintenance by integrating a systematic literature review with the Analytic Hierarchy Process (AHP). The study identified four key criteria influencing maintenance decision-making: environmental impact, economic efficiency, resilience and adaptability, and technology integration. The application of AHP supported the structured evaluation and prioritisation of these criteria and the ranking of alternative maintenance strategies.The conceptual analysis indicates that environmental impact is the most influential criterion, followed by resilience and adaptability, economic efficiency, and technology integration. Among the evaluated strategies, climate-resilient infrastructure emerged as the highest-ranked approach, highlighting the importance of incorporating environmental sustainability and adaptive capacity into infrastructure maintenance planning. These findings suggest a gradual shift from traditional cost-driven approaches toward more sustainability-oriented and resilience-focused decision-making.

This study contributes to knowledge by proposing a structured and integrated decision-support framework aligned with emerging sustainable asset management approaches for urban systems (Love et al. 2020). The application of AHP provides a transparent and systematic approach for prioritising maintenance strategies and supporting more informed infrastructure management decision-making. However, the study is limited by its reliance on secondary data and the absence of empirical validation. Future research should incorporate primary data through expert consultation, case studies, or empirical applications to further validate and refine the proposed framework. Additional studies may also explore the integration of advanced digital technologies and real-world infrastructure applications to enhance sustainable maintenance decision-making.

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