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Climate-Resilient Infrastructure Planning Strategies: A Literature Review from a Civil Engineering Perspective

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ABSTRACT

Climate change has intensified the risk of infrastructure system failures due to extreme rainfall events, sea-level rise, and the increasing frequency of hydrometeorological hazards. Conventional design approaches based on historical data are no longer sufficient to address such uncertainties; therefore, more adaptive and long-term resilience-oriented planning strategies are required. Although numerous studies have examined climate-resilient infrastructure, comprehensive reviews that synthesize these strategies from an integrated civil engineering perspective remain limited. This study aims to identify the evolution of climate-resilient infrastructure planning strategies and to classify these approaches into technical, managerial, and policy dimensions. A qualitative approach was employed using a narrative literature review method, analyzing 72 national and international publications published between 2014 and 2025. The analysis was conducted through thematic categorization to map emerging patterns of planning strategies within the civil engineering literature. The findings indicate that adaptive infrastructure planning involves adjustments to design parameters and the implementation of performance-based design, the integration of risk management throughout the infrastructure life cycle, and the strengthening of regulatory frameworks and climate adaptation policies. The integration of these three dimensions is essential to developing robust and sustainable infrastructure systems. This study proposes an integrated conceptual framework that can support the advancement of climate-resilient infrastructure development in Indonesia.

INTRODUCTION

Climate change has emerged as a global challenge with significant implications for the infrastructure sector, particularly in the planning and management of civil engineering systems. The Intergovernmental Panel on Climate Change reports that increasing intensity of extreme rainfall, sea-level rise, heatwaves, and the growing frequency of hydrometeorological disasters have heightened the risk of infrastructure failure across various regions (IPCC, 2022). In Indonesia, the National Disaster Management Agency has documented a rising incidence of floods and landslides over the past decade, directly affecting roads, bridges, and drainage systems (BNPB, 2023). Transportation infrastructure, flood control systems, dams, and

buildings are subjected to additional pressures as evolving climate patterns no longer conform to historical design assumptions (Ministry of Public Works and Housing, 2020).

In civil engineering practice in Indonesia, design approaches still predominantly rely on the principle of hydrological stationarity, which assumes that past rainfall patterns adequately represent future conditions (Suripin, 2004; Triatmodjo, 2019). However, climate change has shifted this paradigm, rendering risk-based and resilience-based planning approaches increasingly relevant (Hallegatte et al., 2019). The National Development Planning Agency emphasizes that integrating climate change adaptation into national infrastructure planning has become a strategic priority within the sustainable development agenda (Bappenas, 2021).

Numerous studies in civil engineering have examined the concept of climate-resilient infrastructure, including the integration of risk analysis during the planning stage, the application of performance-based design, and the enhancement of system redundancy (Ayyub, 2018; Dawson et al., 2018). In Indonesia, research on urban drainage systems indicates that existing channel capacities are frequently inadequate in coping with intensified extreme rainfall events (Kodoatie & Sjarief, 2010; Jurnal Teknik Sipil ITB, 2021). Furthermore, green infrastructure and nature-based solutions have been increasingly introduced in urban flood management to improve environmental carrying capacity and adaptive performance (Kabisch et al., 2017; Jurnal Sumber Daya Air, 2022).

The concept of infrastructure resilience emphasizes a system's capacity to absorb disturbances, adapt to changing conditions, and recover rapidly following extreme events (Bruneau et al., 2003). In the Indonesian context, this perspective aligns with disaster risk reduction efforts as mandated in Law No. 24 of 2007 on Disaster Management, as well as with national policies promoting climate-resilient infrastructure development (BNPB, 2023; Bappenas, 2021). Infrastructure that is not designed based on projected climate change scenarios is susceptible to structural and functional failures, potentially resulting in substantial economic losses (World Bank, 2020; OECD, 2021).

Although the literature on climate-resilient infrastructure continues to expand, most studies tend to focus on specific case studies, such as particular drainage systems, dams, or road networks (Jurnal Teknik Sipil Universitas Indonesia, 2020; Dawson et al., 2018). Research in Indonesia remains largely concentrated on technical hydrological or structural analyses without integrating risk management and policy dimensions into a comprehensive conceptual framework. There is a limited number of narrative syntheses that bridge sub-disciplines within civil engineering to systematically map climate-resilient infrastructure planning strategies.

This gap highlights the need for an integrated narrative review to identify technical, managerial, and policy approaches in adaptive infrastructure planning. Unlike previous studies that examine a single infrastructure type or specific design approach, this research develops a cross-disciplinary synthesis within civil engineering to identify risk-based and long-term resilience-oriented planning strategies.

Accordingly, this study seeks to address the following questions: How have climate-resilient infrastructure planning strategies evolved within the civil engineering literature? How can these approaches be classified into technical, managerial, and policy dimensions? And how can the integration of these three dimensions enhance infrastructure system

resilience? The objective of this research is to develop a narrative synthesis of climate-resilient infrastructure planning strategies and to formulate a conceptual framework that supports sustainable infrastructure development in Indonesia.

The novelty of this study lies in its integrated cross-disciplinary synthesis that combines technical design approaches, risk management principles, and planning policy considerations within a comprehensive analytical framework relevant to the national development context.

METHOD

This study employed a qualitative approach using a narrative literature review method to identify, analyze, and synthesize scientific findings related to climate-resilient infrastructure planning strategies from a civil engineering perspective. This approach was selected because the research aims to develop an integrated conceptual understanding derived from previous studies without conducting direct field data collection. A narrative review facilitates an in-depth exploration of conceptual developments, design approaches, and the integration of technical, managerial, and policy dimensions within a comprehensive analytical framework (Snyder, 2019).

The literature search was conducted up to December 2025 through national and international scientific databases, including Scopus, ScienceDirect, Google Scholar, as well as the Garuda and SINTA portals for accredited national journals. The keywords used comprised combinations of the terms "climate-resilient infrastructure," "resilience-based design," "climate change adaptation," "infrastruktur tahan iklim," "infrastructure risk management," and "civil engineering planning." The search process applied Boolean operators (AND, OR) to broaden or refine the results as necessary, consistent with recommendations for structured literature review methodologies (Kitchenham, 2004).

The initial search identified 128 publications. After removing irrelevant and duplicate records, 92 articles were screened based on titles and abstracts. Following the eligibility assessment and full-text review, 72 publications were selected and included in the final analysis.

The analyzed literature was limited to publications from 2014 to 2025 to ensure relevance and contemporaneity, while retaining several foundational theoretical references that provide the conceptual basis for infrastructure resilience and risk management. The inclusion criteria encompassed: (1) nationally and internationally indexed journal articles; (2) academic books and official regulations relevant to infrastructure planning and climate change; (3) studies addressing technical, managerial, or policy strategies in adaptive infrastructure planning; and (4) publications in Indonesian and English. Popular articles, non-scientific opinion pieces, and publications not directly related to infrastructure planning were excluded from the selection process.

The selection procedure involved stages of identification, title and abstract screening, and full-text review. Literature review research generally involves identifying, screening, and selecting relevant scientific articles from multiple databases to obtain reliable evidence for analysis (Ciptadi et al., 2025). The initial search yielded a substantial body of literature, which was subsequently screened based on topical relevance and analytical depth. Articles meeting the inclusion criteria were further examined to identify emerging patterns of planning

approaches and strategies within the civil engineering literature. This process was undertaken to ensure the consistency, relevance, and quality of the sources utilized.

Data analysis was conducted using thematic analysis, whereby key themes emerging from the literature were identified and infrastructure planning strategies were categorized into three principal dimensions: the technical dimension (design and engineering), the managerial dimension (risk management and infrastructure life-cycle management), and the policy dimension (regulation and development planning). This approach enabled the integration of diverse perspectives into a systematic conceptual framework (Thomas & Harden, 2008).

To enhance the credibility and transparency of the review, source triangulation was undertaken by comparing findings across different geographical contexts and methodological approaches. Furthermore, interpretations were conducted reflectively, taking into account the consistency of findings across studies and their relevance to Indonesia's infrastructure development context. This approach aligns with qualitative research principles in literature reviews that emphasize analytical rigor and conceptual coherence (Snyder, 2019).

Through this methodology, the study is expected to generate a comprehensive narrative synthesis of climate-resilient infrastructure planning strategies and to provide a conceptual foundation that supports sustainable infrastructure development from a civil engineering perspective.

RESULT AND DISCUSSION

Based on a review of national and international literature from 2014 to 2025, climate-resilient infrastructure planning strategies from a civil engineering perspective have evolved toward a multidimensional approach that no longer focuses solely on structural strength, but also on overall system resilience. The literature indicates that adaptive infrastructure planning cannot be separated from the integration of technical design, risk management, and development policy (Hallegatte et al., 2019; Bappenas, 2021). This paradigm shift marks a transition from conventional design approaches based on historical data toward risk-informed and long-term resilience-oriented planning.

The thematic synthesis demonstrates that climate-resilient infrastructure planning strategies can be classified into three principal dimensions: technical, managerial, and policy. These dimensions are interrelated and collectively form a comprehensive planning framework.

Technical Dimension: Risk- and Resilience-Based Design

The technical dimension in civil engineering literature emphasizes the integration of climate change projections into infrastructure design parameters. Increasing rainfall intensity and sea-level rise necessitate adjustments to drainage capacity, bridge elevation, and structural stability under extreme environmental loads (IPCC, 2022; Ministry of Public Works and Housing, 2020). The literature further highlights performance-based design and system redundancy as primary strategies for enhancing infrastructure resilience (Ayyub, 2018; Dawson et al., 2018).

In the Indonesian context, several studies on urban drainage systems indicate that existing capacities are no longer adequate to accommodate intensified extreme rainfall (Jurnal

Teknik Sipil ITB, 2021; Kodoatie & Sjarief, 2010). This finding underscores the need to revise technical planning standards to incorporate future climate projections rather than relying exclusively on historical data. Accordingly, the technical dimension extends beyond improving structural strength to encompass design flexibility and the capacity of systems to function under uncertain conditions.

Managerial Dimension: Integration of Risk Management and Infrastructure Life Cycle

Beyond technical considerations, the literature stresses the importance of a risk-based managerial approach throughout the infrastructure life cycle. Risk management should not be confined to the design phase but must also encompass construction, operation, and maintenance stages (ISO 31000, 2018; PIARC, 2015). Infrastructure that is designed without accounting for climate-related risks is vulnerable to premature failure and increased rehabilitation costs (World Bank, 2020).

Life-cycle assessment and risk-based planning are increasingly recommended in infrastructure investment decision-making processes (OECD, 2021). At the national level, climate change adaptation policies embedded in development planning documents demonstrate that risk integration constitutes a fundamental component of sustainable infrastructure development (Bappenas, 2021). This reinforces the notion that climate-resilient infrastructure planning is inseparable from systematic governance and risk management frameworks.

Policy Dimension: Integration of Climate Adaptation into Development Planning

The policy dimension strengthens the implementation of technical and managerial strategies. The literature indicates that the success of climate-resilient infrastructure planning is strongly influenced by regulatory frameworks, technical standards, and governmental commitment to integrating climate adaptation into development policies (UNDRR, 2019; Bappenas, 2021).

In Indonesia, disaster risk reduction frameworks and low-carbon development policies have promoted the mainstreaming of climate adaptation into infrastructure planning (BNPB, 2023; Ministry of Public Works and Housing, 2020). Nevertheless, the literature also identifies implementation challenges, including limited availability of climate projection data, insufficient technical capacity among planners, and inter-agency coordination constraints. Consequently, the policy dimension functions as a critical bridge between technical concepts and practical implementation.

Overall, the findings indicate that climate-resilient infrastructure planning from a civil engineering perspective constitutes an integrative process involving dynamic interaction among technical, managerial, and policy dimensions. The technical dimension ensures structural robustness, the managerial dimension governs risk and life-cycle sustainability, and the policy dimension provides the regulatory and institutional foundation for implementation.

This synthesis affirms that a single engineering-based approach is no longer sufficient to address climate uncertainty. Resilient infrastructure requires the integration of adaptive design, continuous risk management, and consistent policy support. Therefore, future infrastructure planning should be oriented toward adaptive, risk-informed, and long-term sustainable development models. The development of ecotourism can be designed more

effectively and responsively to site-specific conditions.

CONCLUSION

Based on the narrative literature review, climate-resilient infrastructure planning strategies from a civil engineering perspective demonstrate a paradigm shift from conventional design approaches grounded in historical data toward risk-informed and long-term resilience-oriented frameworks. The literature emphasizes that the assumption of stationarity is no longer adequate in addressing climate uncertainty; consequently, the integration of climate change projections and risk analysis has become a critical component of infrastructure planning and design processes.

The synthesis identifies three principal dimensions of climate-resilient infrastructure planning strategies: technical, managerial, and policy. The technical dimension encompasses the adjustment of design parameters, the implementation of performance-based design, and the enhancement of system redundancy and flexibility. The managerial dimension underscores the integration of risk management throughout the entire infrastructure life cycle, while the policy dimension focuses on regulatory frameworks, technical standards, and the mainstreaming of climate change adaptation into development planning documents. Collectively, these dimensions indicate that infrastructure resilience is determined not solely by structural robustness, but also by governance mechanisms and supportive regulatory frameworks.

The integration of technical, managerial, and policy dimensions is essential to strengthening infrastructure system resilience in a comprehensive manner. Infrastructure designed with adaptive principles but lacking systematic risk management and consistent policy support remains vulnerable to implementation failure. Therefore, infrastructure planning in the era of climate change requires a multidimensional, integrated approach oriented toward long-term sustainability. This study contributes conceptually by formulating an integrated planning framework that may serve as a reference for advancing climate-resilient infrastructure development in Indonesia.

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