

Smart and Resilient Infrastructure in the Wake of Climate Change

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Abstract

Climate change and global disruptions such as pandemics are exposing critical vulnerabilities in urban infrastructure. This editorial introduces the thematic issue *Smart and Resilient Infrastructure in the Wake of Climate Change*, which explores how smart technologies, governance frameworks, and community engagement can enhance resilience. The eight contributions span multiple contexts—including transport systems, water infrastructure in South Africa, housing in the Navajo Nation, and coastal towns in the Baltic—demonstrating both the promise and limits of data-driven tools, digital twins, and IoT applications. A recurring theme across the articles is that technological innovation alone is insufficient: resilience depends equally on equity, inclusive governance, and context-sensitive strategies. Together, the studies offer empirical evidence and conceptual frameworks that bridge technical, institutional, and social perspectives. They offer actionable insights for designing infrastructures that are not only smart and adaptive but also inclusive and future-ready in an era of accelerating climate risk.

Keywords

climate change; infrastructure; resilient; smart; strategy; sustainable; technology

1. Introduction

The accelerating impacts of climate change—rising seas, recurrent flooding, extreme heat, intensifying storms, and shifting precipitation patterns—have moved from distant warnings to immediate realities that shape urban life around the globe (C40 Cities, 2020; IPCC, 2014). Cities, as hubs of human activity and economic productivity, depend heavily on infrastructure systems to maintain the functionality and livability of urban environments. However, traditional infrastructure—transport, energy, water, communications, and housing—was rarely designed to cope with the complexity and frequency of contemporary shocks.

Increasingly, urban populations face cascading risks: A single storm, heatwave, or pandemic can disrupt multiple interdependent systems simultaneously, revealing vulnerabilities that are both technical and social in nature.

The Covid-19 pandemic illustrated that infrastructure vulnerabilities are not limited to climate-related shocks. Health crises, economic disruption, and social stressors compound the challenges cities face, highlighting the urgent need for systems that are not only resilient to climate extremes but also adaptive to a wide range of shocks. As the scale and frequency of climate-related and other global disruptions increase, urban planners, policymakers, engineers, and researchers are called to envision infrastructures that are simultaneously smart, resilient, equitable, and sustainable. This thematic issue aims to contribute to this discourse by examining how infrastructure can evolve to meet these multidimensional challenges.

2. Conceptualising Resilience in Urban Infrastructure

Resilience is a concept that transcends engineering to encompass social, institutional, and ecological dimensions. Traditionally, resilience in engineering terms has been understood as the capacity of a system to absorb shocks and recover functionality. Holling (1973, 1996) broadened the notion by introducing resilience as a property of complex adaptive systems, emphasising not only the ability to resist disturbances but also to adapt and transform in the face of change. Modern urban resilience frameworks incorporate four key attributes, often referred to as the “4Rs”: robustness, the ability to withstand stress; redundancy, the existence of backup systems; resourcefulness, the capacity to mobilise resources under stress; and rapidity, the speed of response and recovery (Bruneau et al., 2003; Manyena, 2006).

Emerging smart technologies—from IoT-enabled sensors to AI for predictive modelling—offer new opportunities to enhance these dimensions of resilience. Real-time monitoring, predictive maintenance, and adaptive management can reduce system vulnerabilities and enable proactive responses to impending hazards. However, technical innovation alone is insufficient. Governance, institutional coordination, and community engagement are critical in ensuring that resilience strategies are effective and equitable. Without attention to these social and institutional dimensions, even technologically advanced systems risk reinforcing existing inequalities.

3. Influence of Smart Technologies and Data-Driven Infrastructure

The integration of smart technologies into urban infrastructure is transforming resilience thinking. AI-driven decision-support tools, digital twins, and IoT sensor networks offer the potential to anticipate failures, optimise resource allocation, and dynamically manage urban systems. For example, data-driven urban digital twins (UDTs) allow city managers to simulate infrastructure performance under various climate scenarios, providing actionable insights for planning and investment decisions. However, challenges remain. Interdependencies among infrastructure systems, chronic stresses like water scarcity or heat, and limited citizen participation can constrain the effectiveness of these technologies. Furthermore, data governance and equity concerns must be addressed to ensure that smart systems do not exacerbate disparities (Batty et al., 2012; Kitchin, 2014).

Smart technologies offer powerful tools for resilience, but their value lies in how they are applied within real-world contexts. The contributions from the thematic issue illustrate this complexity, offering insights into

the diverse ways cities and communities are navigating the challenges of climate change through innovation, governance, and equity-driven approaches.

4. Insights From the Thematic Issue Contributions

This thematic issue brings together eight contributions that collectively explore the nexus of climate change, resilience, and smart infrastructure. Each article provides novel insights into different dimensions of resilient urban systems, ranging from technical innovations to governance and equity considerations.

4.1. Public Transport Resilience

The article “Lessons From Climate and Pandemic-Induced Disruptions in Building Public Transport Resilience” by Hirwa and Mostafa (2025) applies the 4R framework to assess how transport systems respond to diverse shocks, including Storm Babet in the UK, flooding in KwaZulu-Natal, and the Covid-19 pandemic in Mexico and the US. Using comparative case studies, it shows that high-capacity systems benefited from early warning systems, institutional coordination, and smart technologies. At the same time, resource-constrained contexts struggled with infrastructural neglect and governance delays. The study’s novelty lies in its integration of climate and pandemic disruptions into a single framework, offering valuable cross-context lessons that bridge technical, institutional, and governance dimensions.

4.2. Resilience in the Global South

“Resilient and Sustainable Urban Infrastructure in the Global South: Strategies to Address Climate Change-Linked Vulnerabilities” by Das (2025) explores strategies for strengthening infrastructure in rapidly urbanising, resource-constrained regions. Combining literature synthesis with case studies, the study highlights adaptive urban planning, renewable energy integration, decentralised infrastructure, and inclusive governance as key levers for resilience. Notably, it reframes the Global South not solely as vulnerable but as a laboratory of innovation, where low-cost, community-centred solutions provide transferable insights for global urban practice.

4.3. Data-Driven Equitable Planning

The article “Data-Driven Equitable Planning for Urban Resilience: Innovation, Risk, and Outcomes in Boston, New Orleans, and Norfolk” by Rosero et al. (2025) examines the role of data in resilience planning, with a particular focus on equity. Comparative case studies show that data practices can either reinforce or mitigate existing inequities depending on governance structures and levels of community participation. By advancing critical data studies alongside urban resilience scholarship, the article emphasises that resilience planning is inseparable from ethical, governance, and accessibility considerations.

4.4. Water Infrastructure and Strategic Frameworks

Water systems are particularly vulnerable to climate stressors. In “Enhancing Sustainable and Resilient Water Infrastructure in South Africa in the Face of Climate Change,” Aiyetan (2025) identifies barriers to resilient

water infrastructure delivery and proposes a five-pronged framework addressing governance, technical capacity, maintenance, funding, and accountability. The combination of surveys, statistical modelling, and case analysis provides both empirical evidence and actionable strategies for infrastructure resilience.

Similarly, “Enhancing Water Infrastructure Resilience in Response to Climate Change: Evidence From South Africa” by Adu (2025) contributes quantitative insights by linking historical (1980–2023) climate stressors to infrastructure performance in South Africa. Using regression and ARIMA forecasting, the study demonstrates that droughts pose greater risks than floods and forecasts an increasing rate of infrastructure failures without intervention. This work underscores the importance of data-driven planning in designing robust resilience strategies.

4.5. Digital Twins and Critical Infrastructure

The review “Data-Driven Urban Digital Twins and Critical Infrastructure Under Climate Change: A Review of Frameworks and Applications” by Zhu and Jin (2025) synthesises scholarship on UDTs and identifies challenges, including system interdependencies, chronic risk factors, and limited stakeholder participation. Its conceptual framework bridges technical, social, and governance gaps, offering a roadmap for inclusive digital twin development that enhances critical infrastructure resilience.

4.6. Housing Resilience in Indigenous Communities

The article “Integrating Emerging Design-Build Technologies for Resilient Housing in the Navajo Nation” by Mostafavi et al. (2025) demonstrates how smart technologies can support culturally appropriate, resilient housing. By combining off-grid renewable energy, locally sourced materials, and participatory design with traditional Navajo values, the study presents a decolonial framework that challenges conventional planning paradigms. Its findings offer transferable insights for Indigenous and marginalised communities globally.

4.7. Coastal Resilience

Finally, Gołędzinowska and Ganczarek (2025), in “Baltic Spas in the Face of Climate Change: In Search of Resilience,” evaluate the vulnerability of Polish spa towns to sea-level rise and flooding. Integrating spatial simulations with policy reviews, the article identifies infrastructure limitations and financial constraints as key risk multipliers. Its holistic assessment, combining spatial, legal, environmental, and socio-economic dimensions, provides practical guidance for small- and medium-sized coastal towns confronting climate change.

4.8. Cross-Cutting Themes

Taken together, the eight articles advance knowledge on smart and resilient infrastructure along multiple dimensions. First, they demonstrate the potential of smart technologies—from IoT and AI to digital twins—to enhance monitoring, predictive analytics, and system optimisation. Second, they underscore the importance of context-sensitive strategies, from retrofitting and material innovations to culturally grounded housing and community engagement. Third, they reveal that governance and equity are central to resilience, showing that even the most advanced technologies risk reproducing inequalities without inclusive planning and data

justice. Finally, they contribute new empirical evidence and conceptual frameworks that bridge technical, institutional, and social perspectives.

Taken together, these eight articles illuminate several key insights:

1. *Technological Innovation*: Smart technologies, from IoT to AI and digital twins, enhance monitoring, predictive analytics, and system optimisation.
2. *Context-Sensitive Strategies*: Resilience approaches must account for local conditions, including urban density, resource availability, cultural values, and socio-economic disparities.
3. *Governance and Equity*: Effective resilience planning requires inclusive governance, data justice, and community engagement. Without these, technological interventions risk exacerbating inequalities.
4. *Empirical Evidence and Conceptual Advancement*: Combining quantitative analysis, comparative case studies, and design experimentation, the contributions offer robust, actionable frameworks for building resilient, adaptive, and sustainable infrastructure.

5. Conclusion

This thematic issue underscores that resilience in the face of climate change is both a technical and social endeavour. Smart technologies and innovative frameworks provide unprecedented opportunities, but their success depends on governance innovation, equity, and community participation. By integrating diverse methodologies—comparative case studies, quantitative analysis, design experimentation, and systematic reviews—these articles collectively chart a roadmap for infrastructures that are intelligent, adaptive, inclusive, and future-ready.

As cities confront the intensifying impacts of climate change, the insights presented here emphasise that resilience cannot be achieved through engineering alone. Instead, it requires a holistic approach that combines technological innovation, social justice, governance reform, and community empowerment. The evidence, frameworks, and case studies in this issue provide not only a state-of-the-art understanding of smart and resilient infrastructure but also practical guidance for policymakers, planners, engineers, and researchers committed to securing urban sustainability in a rapidly changing world.

Conflict of Interests

The authors declare no conflict of interests.

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