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Innovative Urban Futures: Smart City Strategies for Disaster Resilience in Songdo, South Korea, an Environment-Behaviour Perspective

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Abstract

Rapid urbanization and intensifying climate hazards have increased interest in smart city technologies for disaster risk reduction (DRR). This paper examines Songdo International Business District in Incheon, South Korea, through an environment–behaviour (E–B) framework. Using qualitative thematic analysis of planning documents, literature, and observations, it finds that while smart DRR systems improve risk awareness and emergency response, their behavioural potential is constrained by top-down governance, underused public spaces, digital inequality, and ecological disconnection from tidal flat reclamation. The study proposes an E–B evaluation framework and offers recommendations for cities pursuing inclusive, adaptive resilience aligned with the Sendai Framework.

Keywords: smart cities, disaster risk reduction, environment-behaviour studies, climate adaptation

1.0 Introduction

The twenty-first-century city faces an unprecedented convergence of demographic pressure and environmental risk. With the United Nations (2022) projecting that approximately 70 per cent of the global population will reside in urban areas by 2050, the exposure of human settlements to climate-induced disasters—including coastal flooding, tropical storms, extreme heat events, and subsidence—is growing at a rate that conventional urban infrastructure is structurally ill-equipped to absorb. Floods alone affected over 1.6 billion people globally between 2000 and 2019 (UNDRR, 2020), while the economic costs of urban disasters are escalating alongside climate volatility. Against this backdrop, the concept of the "smart city"—an urban environment that deploys digital technologies, networked sensors, artificial intelligence, and data-driven governance to optimise urban systems—has emerged as a widely promoted paradigm for embedding resilience into the built fabric of cities (Lee et al., 2016; Kim et al., 2023).

Smart city frameworks promise to transform disaster risk reduction from a reactive to a proactive enterprise. By enabling real-time environmental monitoring, predictive risk modelling, automated early warning dissemination, and coordinated emergency response, smart technologies offer municipalities the capacity to detect hazards before they become catastrophes. Yet the transformative potential of these systems is not self-executing. Technologies embedded in the built environment operate through human intermediaries: they succeed or fail depending on how residents perceive, trust, interpret, and respond to the information and affordances they provide. This is the domain of environment-behaviour (E-B) studies, a field that examines the reciprocal relationships between the physical and social dimensions of built environments and the psychological and behavioural responses they elicit (Gifford, 2014).

This paper is structured around three core objectives. First, it documents and critically evaluates Songdo's smart city DRR framework. Second, it applies E-B theory to assess how this framework influences key behavioural constructs relevant to disaster resilience, including risk perception, place attachment, pro-environmental behaviour (PEB), and community preparedness. Third, it identifies structural challenges that limit the behavioural efficacy of Songdo's smart DRR systems and derives human-centred recommendations applicable to smart city development globally. The analysis is situated within the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR, 2015) and within the broader E-B literature.

2.0 Literature Review

2.1 Smart Cities and Disaster Risk Reduction

The conceptual foundations of the smart city draw on convergent traditions in urban informatics, sustainable urbanism, and governance theory. Early formulations (Caragliu et al., 2011; Albino et al., 2015) emphasized the deployment of ICT to improve urban service delivery, economic competitiveness, and resource efficiency. Over subsequent decades, the smart city concept expanded to encompass environmental sustainability, climate adaptation, and disaster resilience (Yigitcanlar et al., 2019). Lee et al. (2016) identify four core pillars of smart city systems relevant to DRR: IoT and AI integration for real-time data collection; institutional policy frameworks for multi-agency coordination; mechanisms for citizen engagement; and adaptive real-time responsiveness to environmental change. In South Korea, these pillars were operationalized through the "u-City" initiative, with Songdo as its flagship greenfield exemplar (Kim et al., 2023; World Bank, 2022).

The relationship between smart city systems and DRR has received growing scholarly attention. Kitchin (2016) argues that smart urbanism offers a new spatial epistemology for disaster management. Batty et al. (2012) similarly contend that networked urban intelligence enables a shift from post-disaster response to pre-disaster preparedness. Empirical studies from Asian contexts document measurable improvements in early warning accuracy and emergency response coordination associated with IoT-enabled urban management (Kim et al., 2023). However, critics caution against techno-deterministic framings: Vanolo (2014) argues that the "smart city" concept has been deployed primarily as a neoliberal urban development strategy, while Hollands (2008) challenges the assumption that technological sophistication translates into social resilience.

2.2 Environment-Behaviour Theory and Disaster Resilience

Environment-behaviour (E-B) studies examine how physical and social environments influence—and are influenced by—human cognition, affect, and behaviour (Gifford, 2014). In the context of DRR, E-B theory offers a distinctive analytical lens that foregrounds the behavioural mechanisms through which built environments either enable or constrain disaster resilience. Three constructs are particularly salient.

First, risk perception refers to the subjective assessment of hazard threats, which research consistently identifies as a primary determinant of preparedness behaviour (Slovic, 2000). Smart city systems that translate real-time sensor data into accessible public information can function as powerful modulators of risk perception. Second, place attachment—the affective and cognitive bonds individuals develop with specific locations—has been identified as a significant predictor of protective behaviours (Scannell & Gifford, 2013) and post-disaster recovery capacity (Brown & Perkins, 1992). Green infrastructure plays a particular role in cultivating place attachment in dense urban environments. Third, pro-environmental behaviour (PEB) encompasses voluntary actions that individuals undertake to contribute to environmental sustainability and resilience (Steg & Vlek, 2009). The Sendai Framework implicitly affirms an E-B orientation to DRR by centring risk understanding and community preparedness as primary priorities (UNDRR, 2015).

2.3 Songdo in Context

Scholarly engagement with Songdo as a smart city case study has been substantial but predominantly focused on governance, infrastructure, and economic development dimensions rather than behavioural outcomes. Lee et al. (2016) provide a comprehensive inventory of Songdo's smart city systems. The World Bank (2022) offers a critical assessment, noting persistent challenges related to the PPP framework's prioritization of commercial development over community needs. Yigitcanlar et al. (2019) situate Songdo within a comparative analysis of global smart city exemplars, concluding that its technological sophistication has not translated into a superior quality of life compared with less technologically intensive cities. Kuecker (2018) characterizes Songdo as a "city of ghosts"—technologically impressive but socially thin.

Critically for this paper, Ayral and Cha (2024) provide the most direct empirical engagement with behavioural outcomes in Songdo's public spaces, reporting that parks are consistently underutilised, with resident satisfaction scores in the range of 3.6 to 4.1 out of 5 and usage patterns characterised by brief transitory visits rather than sustained engagement. Huh et al. (2024) further documents significant disparities in smart city service access between central and peripheral neighbourhoods. Together, these studies establish a research gap in the systematic application of E-B theory to the evaluation of smart city DRR systems, which this paper seeks to address.

3.0 Methodology

This study employs a qualitative case study methodology, following Yin's (2018) framework for in-depth, context-sensitive urban analysis. The analysis draws on primary planning and technical documents, a systematic review of the literature, published empirical behavioural data from a prior observational study of Songdo's public spaces, and climate and environmental data, rather than on new primary data collection, such as interviews or surveys conducted specifically for this study.

Songdo is selected as the case site on theoretical grounds: as one of the most comprehensively documented greenfield smart cities, it represents an extreme case (Flyvbjerg, 2006) that illuminates the dynamics and tensions inherent to smart city DRR. Data collection drew on four primary sources: (1) primary planning and technical documents including Lee et al. (2016), the World Bank (2022) assessment, and technical specifications from Incheon's U-City governance framework; (2) peer-reviewed scholarly literature on E-B studies, DRR governance, green infrastructure behaviour, and place attachment; (3) empirical behavioural data from Ayral and Cha's (2024) study of public space utilization in Songdo; and (4) climate and environmental data from Korea Meteorological Administration sources.

Thematic analysis (Braun & Clarke, 2006) was applied to identify, develop, and interpret patterns across data sources. Four a priori thematic categories structured the analytical framework: risk perception and alert responsiveness; place attachment and green infrastructure use; pro-environmental behaviour and community preparedness; and equity and access in smart DRR systems. Analytical limitations include reliance on secondary data sources, the pre-completion status of several Songdo development phases, and the absence of longitudinal behavioural tracking data.

4.0 Songdo's Smart City Ecosystem and DRR Architecture

4.1 Urban Development Context and Ecological Trade-offs

Songdo International Business District occupies approximately 6 km² of land reclaimed from the Yellow Sea adjacent to Incheon, forming the core of a broader 53.4 km² Songdo development zone, approximately 65 kilometres west of Seoul. Estimates suggest that the reclamation of Songdo and adjacent industrial areas reduced Yellow Sea tidal flat area by approximately 4,000 to 5,000 hectares in the Incheon region alone, with Lee et al. (2023) documenting the loss of wetland habitats that had provided critical storm surge attenuation, carbon sequestration, and shorebird foraging functions. This ecological transformation constitutes the foundational contradiction of Songdo's identity as an "eco-city."

Korea Meteorological Administration data indicate an annual average temperature of 14.55°C at the Incheon coastal station, approximately 0.95°C above the national average. Annual precipitation averages approximately 1,200 mm, concentrated in a summer monsoon season (June through September) that typically delivers 60 to 70 percent of annual rainfall. These intense episodic events are associated with the East Asian monsoon and tropical cyclones tracking northward through the Yellow and East China Seas. Combined with the artificial soil conditions of reclaimed land—which exhibit higher liquefaction risk and differential settlement than natural geological substrates—these climatic characteristics create a specific DRR context in which flood management, subsidence monitoring, and wind-resistant infrastructure are primary concerns. The targeted resident population of approximately 300,000 by 2030 had reached roughly 220,000 by 2024. The following thermal image is used to justify how urban greening minimises Songdo's heat island effect to ensure a healthy living environment.

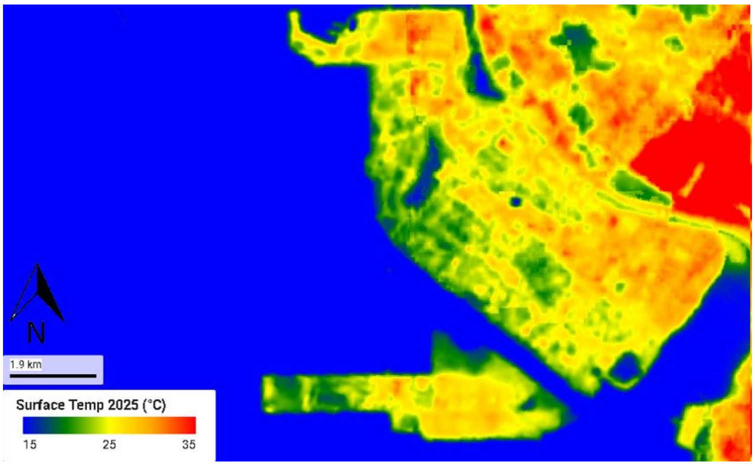

Fig. 1: Land surface and change of temperature over the year in Songdo.

4.2 Smart DRR Infrastructure: Sensors, Monitoring, and Early Warning

Songdo's smart DRR architecture centres on a network of over 10,000 sensors integrated through the Integrated Operations and Control Centre (IOCC), a 24-hour command facility that aggregates data streams from environmental monitoring, traffic management, utility systems, and emergency services into a unified operational picture. The U-Disaster Prevention system incorporates six primary monitoring modalities: ground subsidence sensors; water level monitoring cameras; environmental quality monitors; automated weather stations; seismic monitoring sensors; and a closed-circuit television (CCTV) network (Lee et al., 2016).

These sensor inputs feed AI-supported GIS dashboards that enable IOCC operators to visualize current hazard conditions, identify anomalies indicative of developing risk situations, and model projected flood inundation patterns. When hazard thresholds are exceeded, the system triggers a multi-channel alert cascade disseminated through variable message signs (VMS) on major roadways, audio announcements through speakers in parks and public spaces, emergency alerts pushed to resident smartphones via dedicated applications, and digital media boards in commercial areas. This multi-channel approach recognizes that effective emergency communication must reach residents through multiple modalities appropriate to their location and activity at the time of alert.

4.3 Green Infrastructure as Multifunctional DRR

Alongside its digital infrastructure, Songdo incorporates an extensive network of green and blue infrastructure that functions as a complementary, nature-based component of its DRR strategy. Green spaces account for 32.4 percent of total land area—significantly above the national urban average—and are designed with explicit multifunctionality: parks serve simultaneously as recreational amenities, stormwater retention and attenuation systems, urban heat mitigation zones, and potential emergency assembly areas. Central Park, the 100-acre (approximately 40-hectare) flagship open space, incorporates a tidal channel connected to the adjacent waterway and hydrological design elements that allow it to accept and temporarily store significant volumes of stormwater runoff during intense precipitation events.

This multifunctional design philosophy draws on international precedents in green infrastructure for DRR, including Copenhagen's cloudburst management plan, New York City's post-Hurricane Sandy coastal resilience investments, and the "sponge city" paradigm (Chan et al., 2018). From an E-B perspective, the significance of this approach lies not only in its biophysical flood attenuation performance but in its potential to cultivate pro-environmental behaviours and place attachment among residents who engage with green infrastructure in everyday, non-emergency contexts.

5.0 Analysis: Environment-Behaviour Outcomes of Smart DRR in Songdo

5.1 Risk Perception and Alert Responsiveness

Songdo's smart monitoring and early warning systems represent a significant advance over conventional municipal emergency communication in their speed, granularity, and multi-channel reach. From an E-B perspective, the system's design aligns with key principles for effective risk communication: it provides timely, specific, actionable information through channels familiar to residents; it maintains consistent messaging across modalities; and it integrates alerts with the physical environment through speaker systems and VMS that make hazard warnings spatially immediate (Slovic, 2000; Gibson, 1979; Gifford, 2014).

Nevertheless, the behavioural efficacy of alert systems is constrained by several well-documented phenomena. Alert fatigue—the progressive desensitization of residents to warning signals that are experienced as frequent or inconvenient—is a particular risk in densely monitored environments. Kuecker (2018) observes that Songdo residents have reported normalised relationships with the IOCC's monitoring presence, suggesting a habituation dynamic that may attenuate behavioural responsiveness to genuine emergency alerts. The risk of "techno-dependency"—the erosion of personal hazard awareness as individuals defer to automated systems—is further identified as a behavioural risk that Songdo's top-down system may inadvertently promote (Benedikt, 2016). The digital divide dimension of alert responsiveness also warrants attention, as Huh et al. (2024) document meaningful disparities in access to smart services, with direct implications for equitable DRR outcomes.

Table 1. Songdo Smart DRR Systems: E-B Intended Outcomes and Observed Challenges

Smart DRR System / Feature	Intended E-B Outcome & Observed Challenge
10,000+ Sensor Network & IOCC	Intended: Enhanced risk perception, faster alert response. Observed: Alert fatigue risk; techno-dependency eroding personal vigilance
Multi-channel Early Warning (VMS, apps, speakers)	Intended: Equitable, accessible hazard communication. Observed: Digital divide limits reach to elderly, migrant, and low-income populations
Multifunctional Green Infrastructure (32.4% land)	Intended: Place attachment, social resilience, PEB cultivation. Observed: Underutilization; brief transit visits rather than social engagement
Central Park Canal & Stormwater Retention	Intended: Visible ecological function building environmental identity. Observed: Ornamental character limits ecological legibility for residents
Smart Energy & Water Monitoring Systems	Intended: Behavioural nudges toward resource conservation. Observed: Feedback mechanisms not systematically deployed for resident PEB
PPP Governance & Citizen Apps	Intended: Engaged, co-producing community. Observed: Top-down model produces passive users; limited co-creation and ownership
Tidal Flat Reclamation (ecological loss)	Intended: N/A (development necessity). Observed: Reduced nature contact weakens environmental identity and long-term PEB motivation

5.2 Place Attachment and Green Infrastructure Utilization

Perhaps the most striking E-B finding in the Songdo context is the gap between the ecological and recreational ambitions of the city's green infrastructure and its actual utilization patterns. Ayral and Cha (2024) report that parks including Sunrise Park, Haenuri Park, and several neighbourhood green spaces are consistently underutilized by residents, with usage characterized by brief transitory visits—walking through as a route between destinations—rather than sustained recreational or social engagement. Resident satisfaction surveys return scores in the range of 3.6 to 4.1 out of 5, indicating moderate but not strong positive experiences, with qualitative data suggesting that residents perceive parks as visually attractive but socially thin.

These utilization patterns carry significant implications for DRR. Place attachment research consistently identifies the strength of affective bonds between residents and specific locations as a predictor of protective behaviour, community cohesion, and recovery capacity following disasters (Scannell & Gifford, 2013). Parks experienced primarily as visual amenities or transit corridors provide these social infrastructure functions much less effectively than parks experienced as valued social spaces. Multiple factors contribute to this underutilization: the top-down design process that characterizes Songdo's development; the city's lower-than-projected population density; and the absence of a locally rooted historical and cultural identity. The following map shows the urban land use of Songdo and indicates that almost 40 per cent of urban land is designated and preserved as green space for DRR purposes and for better built-environment design for healthy living.

Fig. 2: Land-use map of Songdo, built environment and Green space ratio.

5.3 Pro-Environmental Behaviour and Community Preparedness

Pro-environmental behaviours relevant to DRR in the Songdo context include voluntary participation in emergency preparedness training, compliance with stormwater management guidelines, engagement with community resilience programs, and support for green infrastructure maintenance. The literature on PEB identifies perceived behavioural control, social norms, and environmental identity as primary predictors of voluntary environmental action (Steg & Vlek, 2009). Songdo's infrastructure provides the technical capability for behavioural feedback systems, but the evidence suggests these affordances have not been systematically deployed to cultivate resident PEB.

The ecological disconnection resulting from tidal flat reclamation is a particularly consequential constraint on PEB. Research consistently demonstrates that direct, positive experiences of natural systems strengthen environmental identity and the intrinsic motivation to protect environmental quality (Nisbet et al., 2009). Songdo's residents inhabit an environment from which the most ecologically significant natural system—the tidal flat—has been permanently removed. The canal waterways and ornamental water features that partially substitute for this natural blue infrastructure provide aesthetic amenity but do not convey the ecological complexity and biodiversity that tidal flat environments offer, potentially contributing to a thinner environmental identity among Songdo residents.

5.4 Equity, Access, and the Limits of Technocentric Resilience

A fundamental challenge confronting Songdo's smart DRR model is the distribution of both risks and resilience resources across socio-economically differentiated urban populations. Disaster risk research consistently demonstrates that vulnerability to hazard impacts is concentrated among populations with lower economic resources, weaker social networks, and more limited access to protective infrastructure (UNDRR, 2020). Smart city systems that require digital literacy, compatible devices, and reliable connectivity to access their full benefits may inadvertently reproduce or amplify these vulnerability patterns.

In Songdo's case, Huh et al. (2024) document significant spatial inequalities in smart city service provision between the fully built-out central business district and peripheral neighbourhoods. Migrant workers and foreign residents face additional barriers related to language, administrative status, and unfamiliarity with Korean emergency management protocols. These equity dimensions represent not merely social justice concerns but functional resilience deficits: communities with the highest barriers to accessing smart DRR systems are frequently those with the fewest alternative resources for managing disaster risk.

6.0 Conclusions and Recommendations

The Songdo case suggests that achieving behavioural resilience through smart city systems requires attention to at least four dimensions that technocentric approaches tend to underweight. The first is the governance dimension. Participatory co-creation of smart DRR systems generates the sense of ownership, familiarity, and trust that converts technological capability into behavioural compliance. The World Bank's (2022) assessment notes the limited mechanisms for genuine citizen participation in city governance. Living lab approaches, which embed community co-design into governance, offer a promising alternative (Colding et al., 2013).

The second dimension is the ecological dimension. The loss of tidal flat ecosystems has removed a natural infrastructure layer that provided both biophysical DRR services and the experiential conditions for the development of environmental identity and nature-motivated PEB. Hybrid approaches combining smart monitoring with active ecological restoration could partially restore the nature-society relationships that support long-term environmental stewardship. The third is the equity dimension: smart DRR systems that are not universally accessible leave the most vulnerable populations outside the protective perimeter of the smart city's risk management architecture. The fourth is the behavioural measurement dimension: current evaluations of Songdo's DRR performance focus predominantly on technical metrics while neglecting behavioural outcomes. Incorporating E-B metrics into DRR evaluation frameworks would provide a more comprehensive and actionable picture of smart city resilience performance.

These conclusions support recommendations organized around four dimensions. On governance, Songdo's administrators should invest in structured participatory mechanisms—living labs, resident advisory panels, co-design workshops—that incorporate community knowledge and agency into the ongoing refinement of smart DRR systems. On ecology, feasibility studies for tidal flat restoration at the urban fringe of Songdo should be commissioned, and constructed wetland systems and enhanced biodiversity planting in existing green spaces should be pursued. On equity, targeted investment in multilingual emergency communication, digital literacy programs for underserved populations, and participatory design processes should be treated as DRR priorities. On measurement, a comprehensive E-B monitoring framework incorporating longitudinal surveys, behavioural observation, and social network analysis should be developed.

Songdo stands at an inflection point: its technological infrastructure positions it as a global leader in smart DRR capability, while the behavioural and social dimensions of its resilience remain works in progress. Closing this gap—making Songdo not only a smart city but a resilient community—offers a model for the rapidly urbanizing world confronting the compound crises of climate change and social inequality.

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Paper Contribution to Related Field of Study

This paper advances environment-behaviour research by proposing a systematic E-B evaluation framework for assessing smart-city disaster risk-reduction systems, bridging a gap between the technocentric urban resilience literature and behavioural outcome measurement. By applying E-B constructs—risk perception, place attachment, and pro-environmental behaviour—to the Songdo case, it offers a replicable analytical model for researchers and practitioners seeking to embed human-centred metrics into smart city governance and Sendai Framework implementation.

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