

Towards a Conceptual Urban Digital Twin (UDT) Framework for Urban Climate Resilience: Integrating Systems, People, and Polic

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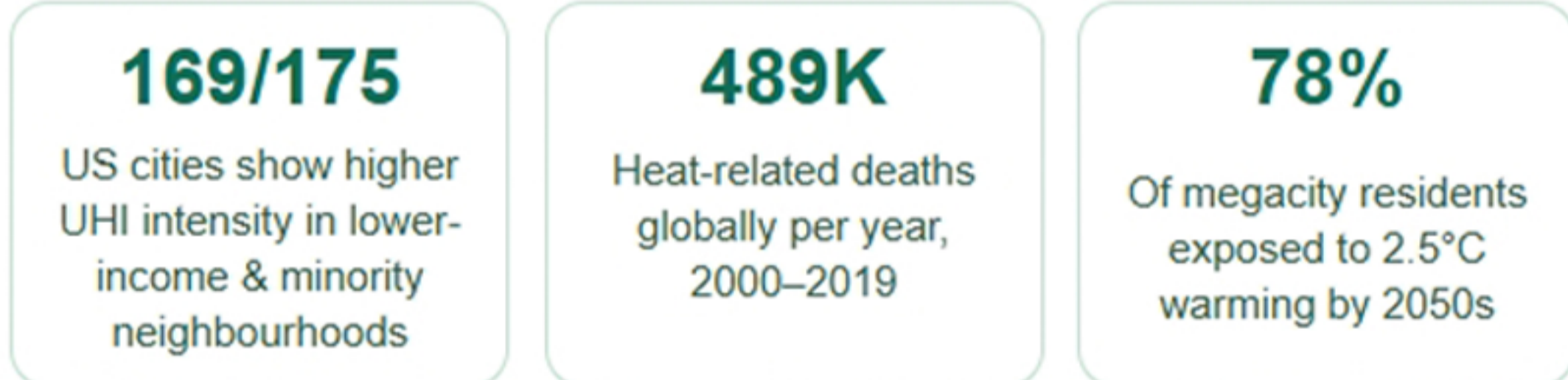
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Overview

Intensifying urban heat significantly exacerbates existing disparities in exposure and coping capacities, creating an urgent need for equity-focused adaptation strategies. Since traditional resilience planning is often fragmented, this paper argues that an Urban Digital Twin (UDT) is essential for integrating these components into a cohesive system.

This paper proposes a reusable minimum UDT architecture specifically designed to enhance climate resilience by testing scenarios in three core areas: physical infrastructure, social dynamics, and institutional governance.

Digital Twins have demonstrated value in infrastructure management, smart cities, and engineering simulation. However, their application to climate resilience planning - particularly with an equity lens - remains conceptually underdeveloped.



Existing UDT frameworks typically address single domains (transport, energy, flood) and rarely incorporate social vulnerability data or participatory governance mechanisms, the two pillars essential for equitable adaptation.

Digital Twin Taxonomy

Following Kritzing et al. (2018), a critical distinction exists between three integration levels:

Concept	Data Flow	Adaptive?
Digital Model	Manual only	X
Digital Shadow	One-directional auto	X
Digital Twin	Bidirectional auto	✓

Framework Development Process

This is a conceptual paper employing systematic literature synthesis and conceptual modelling (following the PRISMA framework with 118 reviewed papers).

The methodology draws on three interdisciplinary bodies of knowledge:

- 1- Digital Twin architecture literature (IoT, data integration, simulation)
- 2- Urban climate resilience and heat vulnerability frameworks
- 3- Social equity theory and urban governance scholarship

The proposed minimum viable UDT architecture is designed to be reusable and adaptable across diverse urban contexts, emphasising interoperability between its three core modules.

References

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The Urban Heat Equity Gap

Urban heat islands and climate shocks do not affect all populations equally. Socially vulnerable residents — the elderly, low-income households, ethnic minorities — face compounded exposure and reduced coping capacity. Yet planning tools rarely surface these distributional dynamics.

The Core Gap

Most standard approaches rely on **temperature and environmental analysis alone**. This paper argues that the distributional equity of interventions must be evaluated as a first-class outcome not an afterthought.

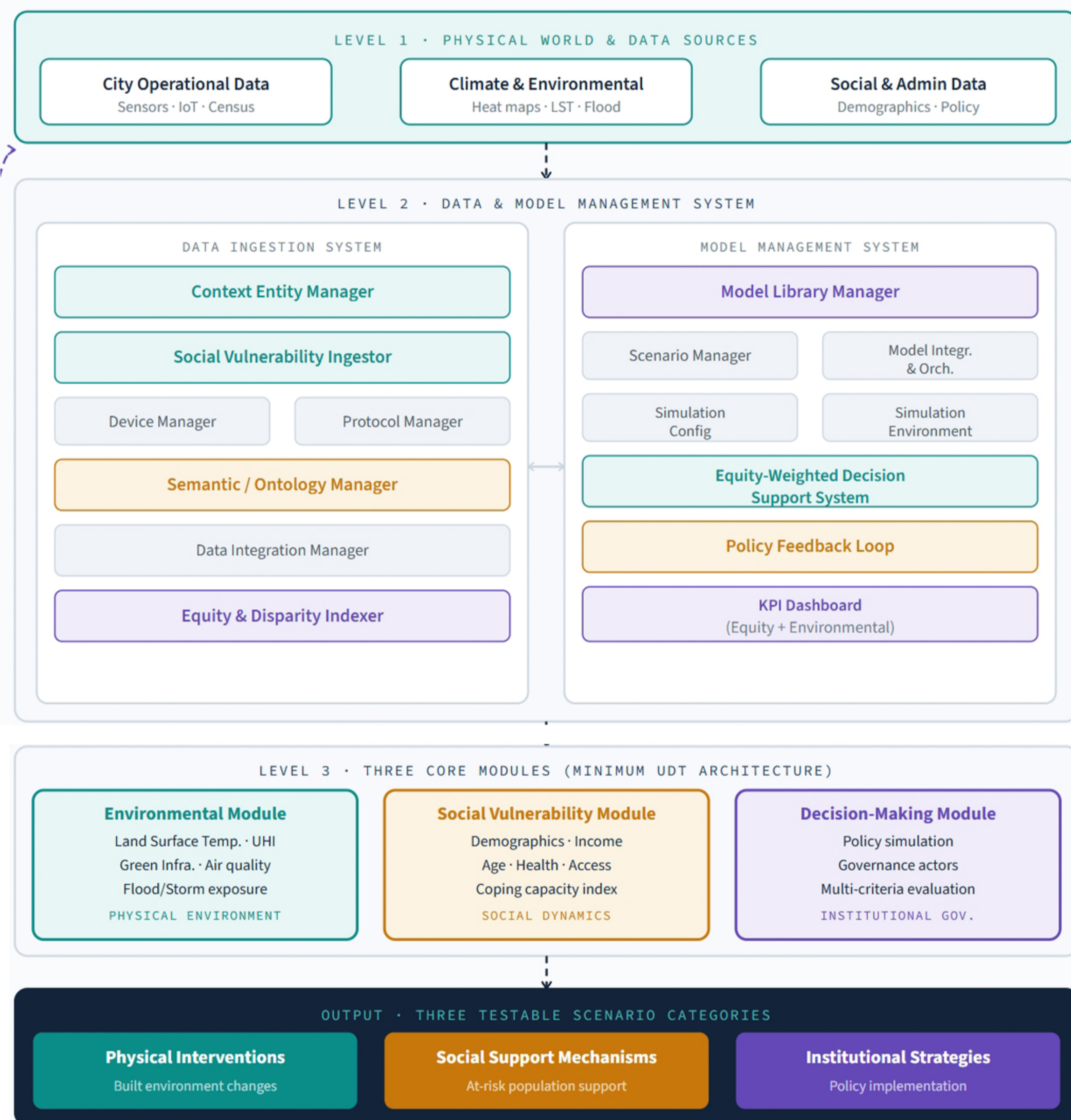
Digital Twin Concept

Unlike digital models (manual data flow) or digital shadows (one-directional), a digital twin provides **automatic bidirectional data synchronisation**, enabling adaptive, real-time policy feedback loops.

Research Objective

To propose a minimum viable UDT architecture that integrates physical, social, and governance components for testing climate resilience scenarios with explicit equity-weighting.

Proposed Framework: Minimum UDT Architecture



Core Equity Argument

Optimising for city-wide temperature averages masks inequality. A just UDT must identify strategies that protect the most vulnerable residents, not merely improve aggregate metrics. This framework places distributional equity at the centre of every scenario evaluation.

Conclusion

This paper presents a minimum viable UDT architecture for urban climate resilience that is genuinely multidimensional. By integrating environmental, social vulnerability, and institutional governance modules in a single adaptive framework, decision-makers gain a tool to identify strategies that protect vulnerable residents and navigate trade-offs fostering lasting social equity and systemic resilience