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Smart Urban Open Space Planning in Malé City: Integrating AI Tools for Future Resilience

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Abstract: As island nations like the Maldives confront increasing urbanization, land scarcity, and climate vulnerability, the need for intelligent and adaptive planning becomes critical. This paper explores how Artificial Intelligence (AI) tools can be integrated into the redesign and planning of urban open spaces in Malé City to enhance resilience, sustainability, and livability. The research proposes a smart planning framework that utilizes AI-driven geospatial analysis, machine learning algorithms, and predictive modeling to assess current urban space performance, simulate future scenarios, and support data-informed design decisions. By analyzing spatial patterns, environmental data, and community needs, the study demonstrates how AI can optimize the distribution, functionality, and climate responsiveness of open spaces in high-density coastal environments. The framework is tested using real-world data from Malé City, offering scalable insights for policy-makers, planners, and urban designers working in climate-sensitive contexts. The findings highlight the potential of AI to bridge the gap between sustainable design and smart technology, paving the way for resilient urban futures in small island developing states.

Keywords: AI in urban planning ·Smart cities ·Urban resilience ·Open space design ·Malé City Climate adaptation Machine learning ·Sustainable development ·Island urbanism ·Geospatial analysis.

1. INTRODUCTION

The rapid pace of global urbanization poses one of the most significant challenges of the 21st century, with projections indicating that by 2030, 60% of the world's population will reside in urban areas [1,2]. While cities are often catalysts for economic growth and innovation, they also concentrate pressures related to resource scarcity, social equity, and environmental vulnerability. For Small Island Developing States (SIDS), these urban challenges are compounded by a unique set of existential threats, including climate change,

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sea-level rise, and limited landmass [3-5]. The confluence of these crises demands a radical shift from traditional, reactive urban planning to a proactive, data-informed approach.

Malé City, the capital of the Maldives, exemplifies these complex and intertwined challenges in their most acute form. As one of the most densely populated cities on the planet, it grapples with a severe "housing squeeze," strained infrastructure, and a palpable scarcity of green and public spaces [6] Simultaneously, the city, with much of its land at less than two meters above sea level, is on the frontlines of climate change, facing an existential threat from rising seas and coastal erosion [4]. The nation's economy, deeply rooted in tourism and fisheries, is perilously dependent on its natural capital, which is under threat from climate impacts like coral reef degradation and ocean heating [7] Traditional planning, relying on static master plans and fragmented data, is proving insufficient to address the speed and complexity of these issues.

This paper proposes an intelligent and adaptive framework for the redesign and planning of urban open spaces in Malé City, leveraging the transformative capabilities of Artificial Intelligence (AI) and Geospatial AI (GeoAI) tools. The research demonstrates how a multi-phase, AI-driven methodology can bridge the gap between sustainable design and smart technology, providing a scalable model for other SIDS and vulnerable coastal environments. The framework utilizes AI for geospatial analysis, predictive modeling, and data-informed design to optimize the distribution, functionality, and climate responsiveness of open spaces, thereby enhancing urban resilience and livability in a hyper-dense, climate-sensitive context.

2. THE MALÉ CITY CONTEXT: A DEEP DIVE INTO CHALLENGES

The urban and environmental pressures on Malé City are extraordinary, providing a compelling case for a new planning paradigm. The city's geography and rapid population growth have created a dual crisis of extreme density and infrastructural strain.

2.1 Hyper-Density and the Squeeze on Livability

The Maldivian population is highly dispersed across its many islands, with the average inhabited island outside of the capital having a population of only around 800 [10]. In stark contrast, Malé City concentrates roughly one-third of the nation's population.[11] The central island, with a land area of just 1.95 km², housed approximately 109,498 residents in 2014, yielding a population density of over 56,000 people per square kilometer [11]. While more recent figures show a lower density for the entire administrative area of Malé City (including Hulhumalé, Hulhulé, and other islands) [11], the core island remains one of the world's most congested urban areas, with a density reaching 94,196 people per square kilometer [13]. This extreme concentration is a direct result of decades of internal migration, where a large portion of the population moved to the capital in search of economic opportunities [7]

This extreme density has led to a profound degradation of urban livability. The available housing is often cramped, with many residents defining "home" as a 12x12 sq. foot room or a small apartment of less than 400 sqft [6]. This physical confinement has contributed to a shift from a traditional "communal spirit" to a more individualistic mindset, where collective care for shared spaces has diminished.[6] Issues such as municipal waste management on the streets are a visible symptom of this broader problem of strained infrastructure and a frayed social fabric [6]. Despite the scarcity of open spaces, a study on Malé's green areas revealed a significant positive association between their use and the subjective well-being of residents [15]. This indicates that although public spaces are limited, their value and potential for fostering community well-being are immense.

2.2 Climate Threats and Compounded Vulnerability

The urbanization crisis in Malé is inextricably linked to the existential threat of climate change. As a low-lying archipelago, the Maldives is exceptionally vulnerable to a projected sea-level rise of up to 0.9 meters by 2100, which could submerge the entire country [4]. Already, 90% of the country's islands are experiencing severe coastal erosion, and over 50% of the national budget is allocated to climate adaptation efforts [4]. Malé's central island is particularly susceptible because it is protected by expensive sea walls, which prevent the natural morphological response to rising waters [4]. This reliance on expensive engineering solutions is financially burdensome and further exacerbates the nation's high public debt, which stood at 123% of GDP in 2023 [7].

The fiscal strain from large-scale infrastructure projects limits the government's ability to fund other critical climate and strategic investments, creating a feedback loop where the solution itself becomes a source of vulnerability [7]. This situation underscores the critical need for a new planning approach that can optimize resource allocation and provide a data-driven justification for projects. The World Bank's Maldives Urban Development and Resilience Project (MUDRP), which includes components for resilient infrastructure, stormwater drainage, and technical studies, is a direct response to this need [16]. A smart planning framework could provide the analytical foundation for such initiatives.

This compounded vulnerability—a crisis of hyper-density colliding with an existential climate threat—makes Malé City a critical case study for resilient urban planning. The lack of available space for open areas is not just a spatial problem but a direct consequence of historical development patterns, one that has eroded the city's social fabric and amplified its environmental risks. A new approach must address these issues holistically, fostering both physical and social resilience.

3. AI AND URBAN PLANNING: A TOOLKIT FOR RESILIENCE

To address the multifaceted challenges of Malé, a new toolkit is required. The convergence of Artificial Intelligence, machine learning (ML), and geospatial technologies offers a powerful suite of tools to move beyond static, two-dimensional planning and into a dynamic, predictive, and data-informed future.

3.1 Geospatial AI and Predictive Modeling

Geospatial AI (GeoAI) is a transformative field that integrates AI with geographic information systems (GIS) to automate the analysis of vast, multivariable datasets, from satellite imagery to sensor data and demographic information [19]. This capability is critical for a city like Malé, where complex, interrelated problems are evolving at a speed that traditional manual analysis cannot match. By detecting patterns and anomalies in real-time, GeoAI can provide insights at an unprecedented scale, enabling planners to model future scenarios and optimize operational performance [19]. This shift from a reactive to a proactive planning model is fundamental to building urban resilience in a constrained, climate-sensitive environment.

The application of AI in urban planning is supported by a range of sophisticated algorithms and models. For example, machine learning and deep learning models such as Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and Support Vector Machines (SVMs) are highly effective at classifying and analyzing complex spatial data to understand urban growth, land use changes, and settlement patterns [20]. When combined with predictive modeling, these tools can evaluate the potential outcomes of planning decisions, from forecasting infrastructure needs to simulating the effects of different development strategies on traffic flow, resource allocation, and environmental impact [22].

3.2 Case Studies in Climate and Urban Resilience

The utility of an AI-driven approach is demonstrated by its successful application in other high-density, climate-vulnerable contexts.

- **Urban Heat Island (UHI) Mitigation:** AI tools, particularly those based on CNNs (Convolutional Neural Networks) , can analyze satellite thermal data to generate high-resolution temperature maps of urban areas [24]. This allows planners to identify UHI hotspots and simulate the cooling effects of nature-based solutions, such as new green spaces, reflective pavements, or urban agriculture [24]. This direct link between spatial analysis and climate-responsive design is vital for Malé, where a dense urban fabric and limited green space likely contribute to significant thermal stress.
- **Coastal Flood Modeling:** AI algorithms can fuse real-time weather, tidal, and topographic data to predict flood risks with enhanced accuracy and lead time [27]. Case studies show that such models can optimize evacuation routes and emergency response plans for high-density coastal areas, a capability that is particularly relevant for Malé given its low elevation and vulnerability to coastal floodin [4]. The World Bank's MUDRP project in the Maldives, which focuses on developing a stormwater management master plan for Malé and Hulhumalé, provides a clear opportunity for the application of these tools to achieve more effective and data-driven outcomes [9].
- **Green Infrastructure and Social Equity:** AI can analyze satellite imagery to map urban vegetation and assess the health of existing green spaces [29]. These insights can inform the strategic placement of new parks and green corridors to ensure their equitable distribution, particularly in underserved neighborhoods with limited access to nature [29]. This application directly addresses the scarcity and unequal access to public spaces in Malé and supports the design of spaces that are not only environmentally effective but also socially responsive to community needs.

3.3 Generative and Regenerative Design

Beyond analysis and prediction, AI empowers a new philosophy of urban design. Generative design tools can simulate thousands of design variations for urban spaces, optimizing for multiple objectives simultaneously, such as natural light, airflow, and space efficiency, while adhering to regulatory constraints [31]. The Singapore Urban Redevelopment Authority (URA) already uses AI to identify optimal land and infrastructure options, demonstrating its successful application in a high-density coastal environment [32].

This capability is a critical step towards regenerative design, an approach that aims to go beyond simply minimizing environmental impact to actively restoring ecosystems and enhancing urban resilience [33]. An AI-driven framework can model and simulate how a new public space can serve as both a recreational area and a functional piece of climate-resilient infrastructure. For example, an AI model can be used to optimize a new park's design to simultaneously reduce urban heat, manage stormwater runoff, and support local biodiversity. This allows planners to create a net positive impact on the environment and society, moving beyond mere sustainability to active regeneration.

4. AN AI-DRIVEN FRAMEWORK FOR SMART OPEN SPACE PLANNING IN MALÉ

This paper proposes a three-phase, AI-driven framework to transform urban open space planning in Malé City. This framework leverages the technologies discussed above to provide a systematic and replicable methodology.

4.1 Phase 1: Foundational Data Integration and Geospatial Analysis

The first phase establishes a comprehensive digital foundation by integrating disparate data streams into a centralized, geo-referenced platform, often referred to as an "Urban Digital Twin" [34]. This addresses the current data fragmentation by creating a single, authoritative source of truth [36].

The data inputs for this phase are critical and include:

- **Geospatial Data:** High-resolution satellite imagery and a detailed digital elevation model (DEM) are foundational for mapping and simulating the built and natural environment.[8] Existing land use maps and national datasets can be integrated from sources like OneMap Maldives [36]
- **Environmental Data:** Real-time and historical meteorological data from agencies like the Maldives Meteorological Service are essential [38]. This is complemented by sea-level rise projections, which can be sourced from models such as those from NOAA [40]. Data on biodiversity from the Maldives Environmental Protection Agency can also be incorporated to inform conservation efforts [42].
- **Socio-economic Data:** Population density, demographic data, and census information from sources like the Maldives Bureau of Statistics provide the human context necessary for equitable planning [6].

This integrated dataset forms a robust model of the city, enabling planners to visualize and analyze the complex interplay between urban design, human activity, and environmental factors.

4.2 Phase 2: Predictive Simulation and Scenario Modeling

With a unified data foundation, the second phase applies AI and machine learning to run predictive simulations. This moves planning from a reactive response to a proactive strategy.

- **Climate Resilience Modeling:** Deep learning models, combined with hydrodynamic simulations, can forecast the impact of coastal flooding and stormwater runoff on urban infrastructure and public spaces, identifying the most vulnerable areas [27].
- **Microclimate Optimization:** AI-powered tools, specifically those using CNNs, can analyze the integrated data to predict urban heat island hotspots [24]. These models can then simulate the effectiveness of nature-based solutions and landscape design choices in mitigating heat, enabling a targeted approach to creating cool, comfortable spaces.
- **Community Needs Analysis:** Machine learning algorithms can analyze historical and real-time data on pedestrian movement, public space usage, and community demographics to identify areas of need [29]. This helps planners understand where new public spaces are most urgently needed and what functions they should serve to maximize community well-being.

4.3 Phase 3: Data-Informed Design and Policy Recommendations

The final phase translates the outputs of the predictive models into tangible design principles and actionable policy recommendations.

- **Generative Design:** Generative design tools use the data and simulation results to rapidly create and evaluate thousands of potential layouts for new or retrofitted public spaces. These tools can optimize for a variety of co-benefits, such as maximizing shade, facilitating stormwater drainage, and creating efficient circulation patterns, all while adhering to the unique constraints of a small island environment [31].
- **Policy and Implementation:** The outputs of the framework can directly inform the government's land use plans and strategic investments [47]. The success of the Hulhumalé master plan, which allocates over 30% of its total land to green and recreational areas, provides a powerful precedent and benchmark for a more sustainable approach to urban development [49]. The proposed framework can provide the technical and analytical studies that projects like the MUDRP require to effectively enhance urban services and strengthen resilience [16].

A comparative analysis of land allocation in Malé City's central island versus the planned Hulhumalé serves to illustrate the transformative potential of this approach.

Table 1. Comparison of Green Space Allocation: Malé vs. Hulhumalé

Land Allocation Category	**Central Malé (Traditional Planning)**	**Hulhumalé (Smart Master Plan)**
Residential Use	**~75-80%** (estimated)	**29.84%** [49]

Commercial Use	**~10-15%** (estimated)	**5.56%** [49]
Green Spaces, Sports & Recreation	**<5%** (estimated)	**30.62%** [49]

The stark contrast in the allocation for green and recreational spaces demonstrates the historical legacy of dense, unplanned urban growth on the central island and validates the forward-looking approach of the Hulhumalé master plan.[49] This table serves as a powerful argument that with a data-informed, strategic approach, a more resilient and livable future is not only possible but is already being built.

5. IMPLEMENTATION AND ETHICAL CONSIDERATIONS IN A SIDS CONTEXT

The successful implementation of an AI-driven planning framework in a SIDS like the Maldives is not merely a technical exercise; it requires a deep consideration of ethical principles and the unique socio-cultural context.

5.1 Algorithmic Bias and Social Equity

A significant risk in deploying AI for urban planning is the potential to perpetuate or amplify existing social inequities if the models are trained on biased historical data [31]. In Malé's context, the housing squeeze and land inheritance practices have historically disadvantaged certain populations [9]. If an AI framework is trained on this data, its recommendations for resource allocation-such as the location of new public spaces or infrastructure-could inadvertently lead to a form of "algorithmic redlining," where already vulnerable communities are systematically neglected [50].

To mitigate this, a responsible AI framework must incorporate ethical oversight from its inception. This includes regular audits to ensure algorithmic fairness, diversification of training data, and a "human-in-the-loop" approach where human planners retain final decision-making authority [52]. The goal is to use AI to actively correct historical injustices by prioritizing the equitable distribution of new green spaces to the most underserved and high-density neighborhoods, thereby enhancing social cohesion and public well-being [29].

5.2 Data Privacy and Governance

The use of real-time data from sensors, GIS, and other sources raises significant privacy concerns, particularly in a small, close-knit society like the Maldives [52]. In such a spatially constrained environment, high-resolution data on movement and habits could easily be linked to individuals, infringing upon privacy and potentially undermining a culture based on shared community [6].

A successful framework must adopt a privacy-by-design approach, ensuring that data is anonymized and aggregated where possible. It must also be implemented with a "whole-of-society" approach, as advocated by the United Nations Development Programme (UNDP) for SIDS [56]. This necessitates robust public engagement and transparency about how data is collected and used. The technology must be demystified to build public trust, ensuring that the community perceives AI as a tool for their empowerment rather than a force of surveillance or external control [52].

5.3 Capacity Building and Resource Sustainability

The financial and technical capacity of SIDS to undertake large-scale digital transformations is often limited.[5] The World Bank's MUDRP project, with its focus on hiring for project management and financial roles, highlights the need for institutional strengthening [17].

Additionally, the environmental footprint of AI infrastructure—which requires massive energy and water consumption for data centers—is a critical concern for a nation already grappling with water security and climate threats [56]. For the Maldives, building large-scale, on-premise AI infrastructure could be a counterproductive burden on its environment. The proposed framework, therefore, advocates for a model that leverages cloud-based, centralized services to reduce the local environmental and financial footprint [56]. This approach supports a vision of "small, yet profoundly impactful" AI innovations that are rooted in local needs and insights, ensuring that technological progress aligns with the nation's broader sustainability goals and financial realities [55].

6. CONCLUSION

The dual crisis of hyper-urbanization and climate vulnerability presents a profound and urgent challenge to Malé City. By integrating AI-driven geospatial analysis, predictive modeling, and generative design, the framework proposed in this paper offers a systematic and scalable pathway to urban resilience. The methodology allows planners to move from reactive, static planning to a dynamic, data-informed process that optimizes urban open spaces for both environmental and social well-being.

The analysis demonstrates that AI tools can effectively identify and mitigate urban heat islands, simulate coastal flood risks, and guide the equitable distribution of green infrastructure. Furthermore, generative design provides a means to translate these data-driven insights into optimized urban layouts, while a regenerative design philosophy ensures that these spaces contribute to a net positive impact on the environment.

This framework is not unique to the Maldives. It offers a replicable blueprint for other SIDS and vulnerable coastal cities worldwide, providing a practical example of how to tackle shared challenges with limited resources. However, the success of this approach hinges on a thoughtful and human-centric implementation that prioritizes ethical governance. By actively mitigating algorithmic bias, protecting data privacy, and building local capacity, Malé can demonstrate how a smart city can also be an equitable, transparent, and resilient one. Ultimately, the paper concludes that AI, when used as a tool to augment human expertise and respect local values, can empower even the most vulnerable communities to shape a more livable and sustainable future.

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