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Reimagining the Coastline: A Digital-Intelligence Framework for Ecological Governance and Aesthetic Reconstruction of Dalian's Tourism Landscape

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ABSTRACT
Coastal cities worldwide are grappling with the dual pressures of ecological degradation and the demand for high-quality tourism experiences. Dalian, a prominent coastal city in China, epitomizes this challenge, facing issues such as shoreline erosion, wetland degradation, and aesthetic homogenization of its cultural tourism landscapes. While existing research often addresses these problems through either a technical governance lens or a humanistic aesthetic critique, a significant theoretical gap exists in integrating these perspectives. This paper bridges this gap by proposing a novel synergistic framework that combines digital-intelligence, ecological governance, and aesthetic reconstruction. Methodologically, the study employs an interdisciplinary approach, integrating landscape ecology, scenes theory, and the philosophy of technology. The core argument is that the fusion of digital technologies (e.g., digital twins, AI, IoT) with ecological principles and aesthetic strategies can foster a new paradigm for sustainable coastal development. The primary innovation lies in the construction of a "Digital-Ecological-Aesthetic" three-dimensional analytical model. This model provides an actionable pathway for transforming coastal landscapes from passive scenic backdrops into dynamic, resilient, and culturally resonant ecosystems. Ultimately, this research offers a replicable strategy for Dalian and other similar coastal cities to achieve ecological restoration, enhance cultural identity, and create immersive tourism experiences in the digital era.

KEYWORDS
Coastal landscape; Ecological governance; Aesthetic reconstruction; Cultural tourism

1 Introduction

The world's coastlines are critical yet fragile zones of convergence, where ecological systems and human settlements meet. These interfaces are increasingly under threat from the combined forces of rapid urbanization, industrial activity, and climate change, leading to pervasive challenges of shoreline erosion, habitat loss, and declining biodiversity. In this global context, cities like Dalian, a major port and tourism hub in Northeast China, find themselves at a critical juncture. The city is compelled to balance its economic ambitions with the urgent need for environmental stewardship, an agenda strongly supported by national policies such as the "Beautiful China" initiative. Concurrently, the strategic push towards "smart tourism" encourages the adoption of advanced data and communication technologies to enhance managerial efficiency and enrich visitor experiences, setting a new digital context for urban development (Gretzel et al., 2015).

Despite these positive drivers, Dalian's celebrated coastal landscape faces a persistent and complex paradox. On one hand, it is endowed with remarkable natural beauty and a rich industrial heritage. On the other, it suffers from significant ecological stress, with long-term studies confirming substantial shoreline alteration and the replacement of natural coastlines with artificial structures to accommodate decades of urban growth. This physical degradation is mirrored by a growing aesthetic and cultural dilemma. In the pursuit of modernization, some waterfront developments have succumbed to a form of "placelessness," characterized by standardized promenades, generic real estate projects, and formulaic public art that fail to resonate with the city's unique history. This situation exposes a critical gap within existing academic discourse. Current research is often siloed into two distinct camps: one focusing on the techno-solutionist paradigms of the "smart city," which apply digital tools for monitoring and management but can overlook the humanistic and aesthetic dimensions of place (Kitchin, 2014); the other engaging in cultural and heritage studies, which adeptly critique the loss of local identity but frequently lack technologically informed, actionable strategies for intervention. This paper aims to bridge this divide by addressing a central question: How can the integration of digital intelligence forge a synergistic relationship between ecological governance and aesthetic reconstruction to cultivate a sustainable, resilient, and culturally vibrant coastal tourism landscape in Dalian?

2 Theoretical Underpinnings and The Proposed Framework

To construct a robust analytical model capable of addressing this question, this study builds on an interdisciplinary theoretical foundation. It begins with the principles of landscape ecology, particularly Richard T.T. Forman's (1995) seminal "patch-corridor-matrix" model. This theory provides a scientific vocabulary for analyzing spatial structure, where coastal wetlands can be understood as critical "patches" of biodiversity, tidal creeks as "corridors" for nutrient flow, and encroaching urban development as the fragmenting "matrix." This ecological lens is then complemented by Scenes Theory. Developed by Terry N. Clark (2004), this sociological framework offers a powerful tool for analyzing the aesthetic

and experiential qualities of a landscape by conceptualizing it as a dynamic "scene" —a place defined by a unique confluence of amenities, cultural meanings, and social activities that attract specific audiences. To ensure that technology serves these ecological and cultural ambitions ethically and effectively, a critical perspective is drawn from the philosophy of technology. This incorporates Bernard Stiegler's (1998) work on the dual nature of technics as both a potential remedy and a threat, and Yuk Hui's (2016) concept of "cosmotechnics," which argues against a universal, one-size-fits-all model of technology and calls for developing technologies that are in harmony with specific local worldviews and environments.

Building upon this theoretical synthesis, we propose a three-dimensional synergistic framework for analysis and intervention. The first dimension, digital intelligence, maps the technological process from data acquisition to public interaction. It progresses from the Perception Layer, where IoT sensors and remote sensing platforms gather real-time environmental data, through the Cognition Layer, where AI algorithms analyze patterns and predict future trends, to the Decision Layer, where digital twins are used to simulate and evaluate the consequences of different policy and design choices. It culminates in the Presentation Layer, where augmented reality (AR) and interactive media are used to communicate complex information and engage the public. The second dimension, ecological governance, outlines a management cycle rooted in the concept of "nature-based solutions" (IUCN, 2020). This cycle moves from a comprehensive Diagnosis of ecosystem health and stressors, through targeted Restoration of degraded habitats, to long-term adaptive Maintenance and the fostering of system-wide Adaptation and resilience to future shocks. The third dimension, aesthetic reconstruction, details a hierarchy of aesthetic experience. It begins with an Ecological Aesthetics that derives beauty from visible natural processes, evolves into a Cultural Aesthetics that embeds and celebrates local history and identity, advances to an Immersive Aesthetics that engages multiple senses to create rich, interactive experiences, and ultimately achieves a Sustainable Aesthetics, where the form and beauty of the landscape explicitly reflect and reinforce ecological limits and cycles. The convergence of these three dimensions is the locus of innovation, defining the pathway to a truly integrated and high-value cultural tourism landscape.

3 An Integrated Diagnosis of Dalian's Coastal Landscape Challenges

Applying this integrated framework to Dalian reveals deeply interconnected problems that a siloed approach cannot solve. Ecologically, the coastline suffers from severe structural imbalances born from its rapid development history. Long-term remote sensing analysis provides clear evidence that decades of port construction, land reclamation, and urban expansion have systematically replaced natural shorelines with artificial revetments and seawalls (Ma et al., 2020). In the language of landscape ecology, this has fragmented or destroyed critical "patches" like salt marshes and intertidal flats, which serve as vital nursery grounds for marine life and natural buffers against storm surges (Forman, 1995). This reliance on "gray infrastructure" has led to a cascade of negative consequences, including diminished biodiversity, impaired water quality, and a reduction in the coast's overall ecological resilience.

This physical degradation is inextricably linked to an aesthetic and cultural crisis. The push for a modern, globalized urban image has, in many areas, resulted in a form of aesthetic homogenization. This manifests as a new kind of urban placelessness, where the unique narratives of Dalian's maritime and industrial history are often obscured by generic commercial real estate and standardized public spaces that could exist in any city (Wang, 2007). From a Scenes Theory perspective, this approach fails to cultivate the authentic, unique, and engaging "scenes" that attract cultural tourists and foster a strong sense of local pride (Clark, 2004). Compounding these issues are significant bottlenecks in the application of digital intelligence. While various government departments may collect environmental or tourism data, they often operate in isolation. The persistence of these data silos—a result of bureaucratic inertia and a lack of interoperable technical standards—prevents the integrated analysis needed for holistic governance and innovative, context-aware design (Kitchin, 2014).

4 Strategies for Synergistic Governance and Reconstruction

To address these multifaceted challenges, our framework guides an integrated strategic approach that weaves together technology, ecology, and aesthetics. The initial and foundational strategy is the development of a digital-intelligence-driven ecological governance system. This would be operationalized through a "Coastal Digital Brain," an integrated data platform that serves as a central nervous system for the coastline. This platform would fuse multi-source data—from high-resolution satellite imagery and drone-based LiDAR scans to real-time water quality data from IoT sensors—to create a dynamic, comprehensive understanding of the ecosystem. This rich dataset would then fuel the creation of urban digital twins. These are not static 3D models but high-fidelity virtual replicas of the coastline where managers can simulate the long-term impacts of different restoration scenarios, such as testing the efficacy of a restored mangrove forest versus a constructed wetland for nutrient absorption and coastal protection (Batty, 2018). This process allows for the precision deployment of nature-based solutions, optimizing their design and placement for maximum ecological benefit while minimizing risks and costs. Moreover, such a platform can democratize governance by incorporating citizen science applications, allowing residents to report pollution or monitor biodiversity, thereby fostering

a more adaptive and transparent management model.

Parallel to this technological and ecological overhaul is a strategy for aesthetic reconstruction rooted in the principle of digital-ecological fusion. This approach purposefully rejects the traditional separation of engineering and artistry. Instead of concealing ecological functions, it seeks to translate the processes of restoration into powerful aesthetic and educational narratives. For instance, a restored salt marsh is designed not just for its ecological function but as a living landscape exhibit, with boardwalks and interpretive digital overlays that explain its role in carbon sequestration and habitat provision. Digital tools become crucial for reactivating Dalian's dormant cultural heritage. A visitor pointing their smartphone at a derelict shipyard crane could see a ghostly AR overlay of it in operation during the 1970s, hear archival audio of shipyard sounds, and access oral histories from former workers. This moves beyond the purely visual to craft immersive, multi-sensory scenes. Bio-acoustic sensors in a restored wetland could translate the diversity of bird calls into ambient light patterns along a pathway, creating a beautiful and intuitive visualization of ecosystem health. The ultimate aim is to establish a sustainable aesthetic order. Guided by a critical understanding of technology as a "pharmakon" (Stiegler, 1998), this approach carefully avoids energy-intensive "tech spectacles." Instead, it uses digital tools elegantly and subtly to reveal and reinforce the natural rhythms, ecological limits, and unique cultural stories of the Dalian coastline.

5 Conclusion and Future Prospects

The complex challenges facing Dalian's coastline are emblematic of a global struggle to reconcile ecological health with cultural vibrancy and economic development. This paper has argued that a viable path forward lies not in piecemeal solutions, but in the deep and synergistic integration of digital intelligence, ecological governance, and aesthetic reconstruction. The primary contribution of this research is the "Digital-Ecological-Aesthetic" framework, which offers a theoretical synthesis and a practical methodology for bridging the persistent divide between technocratic management and humanistic design. By weaving together insights from landscape ecology (Forman, 1995), urban sociology (Clark, 2004), and a critical philosophy of technology (Stiegler, 1998; Hui, 2016), the framework provides a robust model for intervention. For Dalian, this translates into a concrete and inspiring vision: a coastline governed by a smart ecological brain, where restored habitats become living classrooms, industrial heritage is reanimated through digital storytelling, and tourism evolves from passive consumption to active, meaningful engagement.

The implementation of this ambitious vision is not without challenges. It demands unprecedented levels of inter-departmental collaboration, significant investment in data infrastructure, and careful navigation of ethical issues such as data privacy and algorithmic transparency (Kitchin, 2014). This paper, therefore, serves as a conceptual starting point. Future research should focus on longitudinal empirical studies to validate and refine the framework through pilot projects, developing clear metrics to assess the combined ecological, social, and economic benefits of such integrated interventions. Further work is also needed to explore the policy and institutional innovations required to support this new paradigm of governance. Ultimately, by embracing this holistic and synergistic vision, Dalian has the opportunity to not only solve its own pressing challenges but also to transform its coastline into a celebrated international model of sustainable urbanism—a place where the digital future and the natural world collaboratively create a landscape of deep resilience and enduring value.

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