Integrated Design and Modeling of Coupled Mangrove and Urban Ecosystems

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ABSTRACT

Perhaps the greatest challenge facing humanity is how to sustainably manage human-dominated ecosystems. This challenge is particularly evident on coastlines, where high density urban development is degrading fragile coastal ecosystems at alarming rates. Currently, the world's natural protective buffers, mainly coral reef, seagrass and mangroves, are being lost at a rate that exceeds the rainforests. Urban development standards conflict with the requirements of these ecosystems, both in terms of the spatial and temporal dynamics critical to their functioning and in the economic valuation of their roles in human health and well-being. The loss of protective services from these ecosystems is progressively exposing urban populations to risk of catastrophe from increasing storm activity, rising sea levels, and tsunamis. Engineered structures, such as breakwaters, bulkheads and seawalls, have been previously accepted as a method to protect people from risk of wave impact, while natural buffer structures, such as mangrove forests, have only recently gained attention for their protective value to communities exposed to these hazards. Although there are major initiatives underway to account for the value of ecosystem services to human well-being, these initiatives focus on large scale ecosystems and the immediate consequences of human appropriation of natural systems. There is a critical need for research methods and models that span across scales and disciplines and couple the large-scale analysis of ecological services and human well-being with the mechanistic functions of human-altered environments.

This research couples architectural and engineering models with a mangrove vegetation model to evaluate the impact of urban and architectural design decisions on long-term environmental processes and the resulting ecosystem services. This novel approach to design and planning integrates fields of knowledge within a collaborative framework to utilize the feedback of multiple species and environmental systems in the development of urban guidelines for future growth and retrofit. The present thesis is a seed to a larger field of inquiry, and as such, develops the modeling infrastructure for interdisciplinary collaboration that will extend beyond the current scope of work. In the present thesis, the collaborative methodology is executed within a series of simulations that use the conflict between coastal urban development and tropical mangrove forests as case study. More specifically, the research parametrically-links the dimensions of large-

scale buildings and associated urban structures with a solar simulation tool and forest growth model to determine the 'best case' scenario(s) with regards to establishing viable cohabitation between urban and mangrove landscapes. Mangrove forests, unlike other vegetation forms, need to be continuous over large swaths of terrain, and the structural and concomitant light requirements of the ecosystem across the landscape gave rise to new urban morphologies that engage the spatial and temporal dynamics of coupled human and environmental systems. The computational framework to develop these structures utilizes multi-objective algorithms and model databases to analyze the relationships across economics (rentable space), constructability and ecosystem restoration.

The research focuses on parameters derived from large-scale vertical construction and land reclamation in order to address the existing pressures to develop coastlines with these types of structures. In this regard, the aim is to capitalize on economic growth to implement a regenerative landscape. The proposition for a structurally-enhanced mangrove wavebreak was schematically explored within the thesis, and recommendations for further work are suggested. Finally, the modeling approach was applied to a test site in Miami, FL to investigate the restoration strategy within a severely degraded mangrove shoreline and to develop design recommendations for future growth within medium to high density urban areas.

Although the context for this research is the performance of 'built ecologies' along tropical coastlines, the research has broader implications for interdisciplinary frameworks where urgency to address large-scale environmental challenges has required simplified models to transfer information across scales and disciplines. The experimental structures will ultimately engage environmental questions and requirements that span large ranges of physical and temporal scales, questions that have been disregarded in the development of conventional coastline structures, due to the previous inability to process the complex ecological and environmental performance parameters attendant to such landscapes. The long-term goal of the research is to develop methods to understand the impact of large-scale urban structures on the growth and habitat requirements of integrated ecosystems, such that urban forestry can be viably sustained within a variety of city densities and geographical contexts.