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Ecological Designed Experiment Method Based on Pragmatism: A Case Study of Haizhu Wetland Restoration Project in Guangzhou, China

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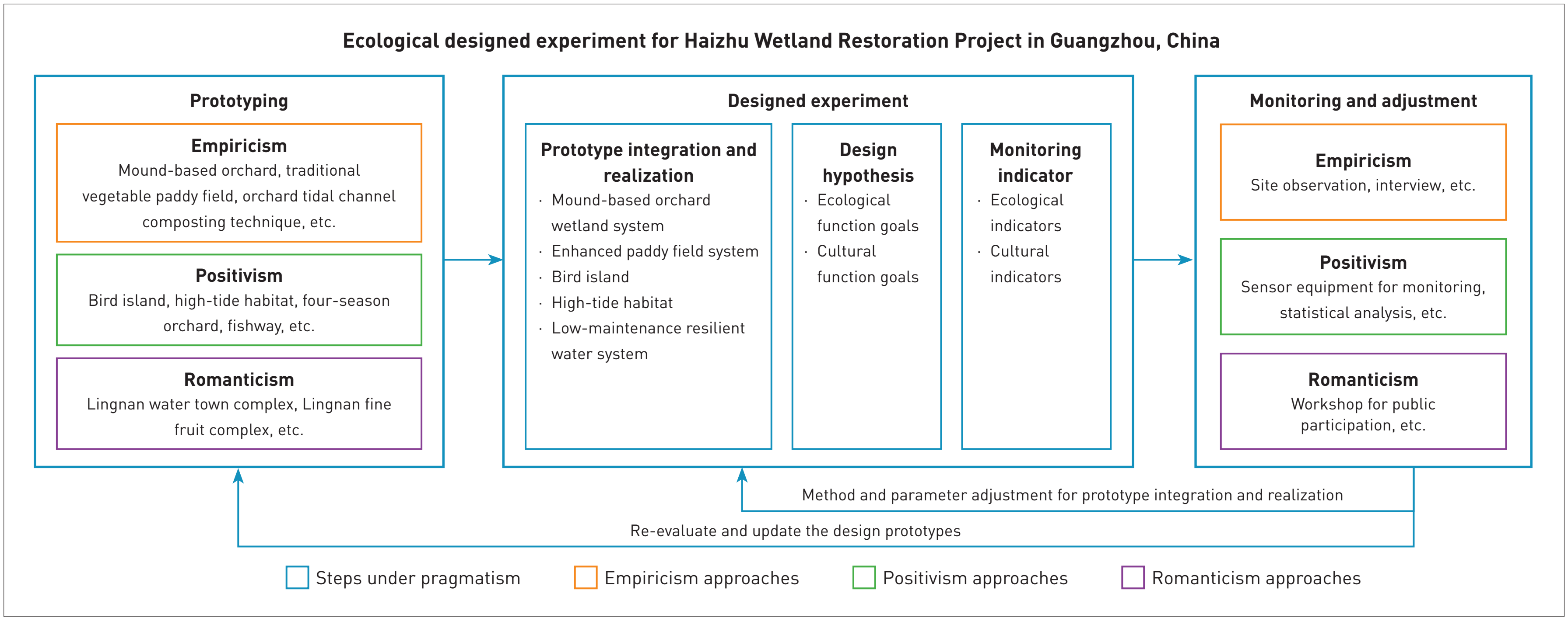
GRAPHICAL ABSTRACT



ABSTRACT

Exploring the effect ecological design methods is a critical issue for sustainable development, yet a gap still exists between the research and practices of ecological landscape design. This study employed pragmatic designed experiments as its core method, integrating methodologies from empiricism, positivism, and romanticism to propose a semi-empirical ecological design framework that emphasizes learning by doing and research through practice. The framework encompasses three steps: prototyping, designed experiments, and monitoring and adjustment. The study further took the restoration project of Haizhu Wetland in Guangzhou as an example by proposing five designed experiments based on the analysis of form prototypes suitable for the site: the mound-based orchard wetland system, enhanced paddy field system, bird island, high-tide habitat, and a low-maintenance resilient water system. Corresponding design hypotheses and monitoring and adjustment evaluation indicators were also offered. The results showcase the feasibility of integrating ecological research with practical application to steer ecological design optimization and enhance the resilience of anthropogenic ecosystems. Although the wetland renovation project has initially shown ecological benefits and social welfare, the effectiveness of this design framework still requires further tracking and validation.

KEYWORDS

Novel Ecosystem; Urban Wetlands; Pragmatism; Design Prototype; Designed Experiment; Monitoring and Adjustment

HIGHLIGHTS

- Constructs a learning-by-doing and semi-empirical ecological design framework based on pragmatism to facilitate effective learning through practices
- The ecological design framework includes three main steps of prototyping, designed experiment, and monitoring and adjustment
- Enhances the analytical capabilities regarding ecological knowledge and prototypes and establishes routines of monitoring and assessing the effectiveness of ecological design, thus increasing the flexibility of design process

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1 Introduction

The advancement of urbanization and globalization has impacted every corner of the Earth, ushering in a new era known as the Anthropocene[1][2]. Presently, human activities have transformed over one-third of the planet's ecosystems, including agricultural lands and urban areas[3]. Each year, nearly half of the biological productivity of terrestrial ecosystems[4] and renewable freshwater resources[5] are consumed by humans, which is altering the global biogeochemical cycle[6]. This has led to the emergence of novel ecosystems in the Anthropocene, characterized by human influence and exhibiting three characteristics: 1) they surpass natural ecological thresholds; 2) their species composition significantly diverges from natural ecosystems; and 3) they have established self-sustaining mechanisms[7][8]. Despite their widespread presence, these systems often exhibit conflicts between their social and natural functions due to the short evolutionary history. Without balancing these dual functions, the planet may suffer extensive adverse effects. Thus, there is an urgent need to define and achieve the equilibrium of novel ecosystems.

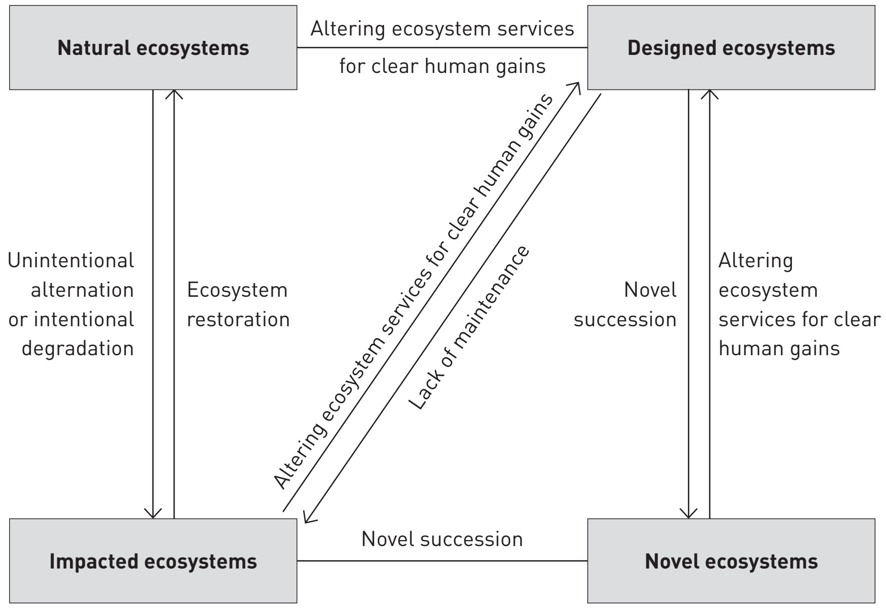
Since the 1970s, the global academic community has embarked on exploring modern ecological design methods[9], while China initiated the exploration into urban and landscape ecological design at the onset of the 21st century[10][11]. Despite the rapid development of modern ecology, marked by the rise of Landscape Ecology and Global Ecology at the macro scale, and a focus on organs, cells, organelles, and molecules at the micro scale[12], a persistent gap exists between ecological research and landscape design practices[2]~[5]. The concepts of ecological design have largely remained theoretical, lacking practical application and thus falling short in guiding formative design[12].

This gap can be primarily attributed to two aspects. Firstly, the deconstructive nature of modern ecological research does not align with the holistic nature of ecological practices[13]. Secondly, ecological practices encompass subjective processes that cannot be fully explained by the purely rational paradigm of modern ecological research. Landscape architects should employ the improvisation ability, which is rooted in irrationality, imagination, and mystique[14], to integrate fragmented, abstruse, and generalized scientific findings with specific demands, thereby realizing those findings in spatial forms. Consequently, this study seeks to diverge from the mainstream scientific positivism methodology and take pragmatic designed experiments as the main framework, while combining the technical methods of empiricism, positivism, and romanticism. This practical ecological design approach was proposed to enhance ecosystem resilience, exemplified through the Haizhu Wetland restoration project in Guangzhou, China led by the authors' team.

2 Pragmatic Ecological Designed Experiment

Broadly speaking, ecological design refers to purposeful manipulation of the structure and function of ecosystems to meet predetermined goals[2]. These designed ecosystems mark a deliberate shaping of the Anthropocene ecosystems, distinguished by human-directed management and interventions[15]. When contrasting these two types of ecosystems (Fig. 1)[8], the former emerges from intensive human intervention, necessitating ongoing maintenance and management, while the latter does not need; the former is purpose-built and caters to explicit human needs, while the latter is shaped by unconscious human activities. However, the designed ecosystems cannot replicate the untouched state of natural ecosystems, considering existing human desires, environmental conditions, and level of knowledge and technology. Instead, they incorporate human influences as inherent components, optimizing ecosystem services within coupled nature-human ecosystems, steering clear an idealized return to unspoiled nature[16]. Across both urban and rural contexts, the optimized ecosystem services are pivotal in bolstering ecosystem resilience[17]~[19].

Such designed ecosystems demand a novel pragmatic paradigm that fuses design with science, elevating the role of design with ecological sciences and positioning landscape architects as key contributors to research[20]. Derived from diverse philosophical underpinnings, present-day ecological design is developed based on methodologies including positivism, empiricism, pragmatism, and romanticism (Table 1)[9]. Among them, the "adaptation" concept of pragmatism advocates for learning by doing, which involves multiple experimental scheme implementation, scale control of individual experiments, and monitoring and adjustment for ecological design. On this basis, this study proposes a pragmatism-



1. Transformation between different types of ecosystems (adapted from: Ref. [8]).

Table 1: Comparison of ecological design approaches based on different methodological foundations

	Positivism	Empiricism	Pragmatism	Romanticism
Ecological view	Equilibrium paradigm Complexity paradigm	Equilibrium paradigm Complexity paradigm	Complexity paradigm Anthropocene ecosystem	Open ecological view
Methodology	Scientific deduction	Empirical induction	Dialectic Practical retroductive	Artistic abstraction Philosophical speculation
Starting point	Ecology (main) Ecological ethics (secondary)	Ecological ethics (main) Ecology (secondary)	Ecological ethics Ecology	Ecological aesthetics Ecological ethics
Typical topic	Ecosystems, landscape ecology, urban ecology, modeling and assessment, etc.	Ecological wisdom, ecological practical wisdom, local knowledge, vernacular landscape, cultural landscape, etc.	Adaptive planning, designed experiment, designed ecology, public participation, social equity, etc.	Land art, ecological aesthetics, environmental perception, environmental education, etc.

centered comprehensive framework that unfolds through prototyping, designed experiment, and monitoring and adjustment, combining different ecological design methods and stakeholders together (Fig. 2).

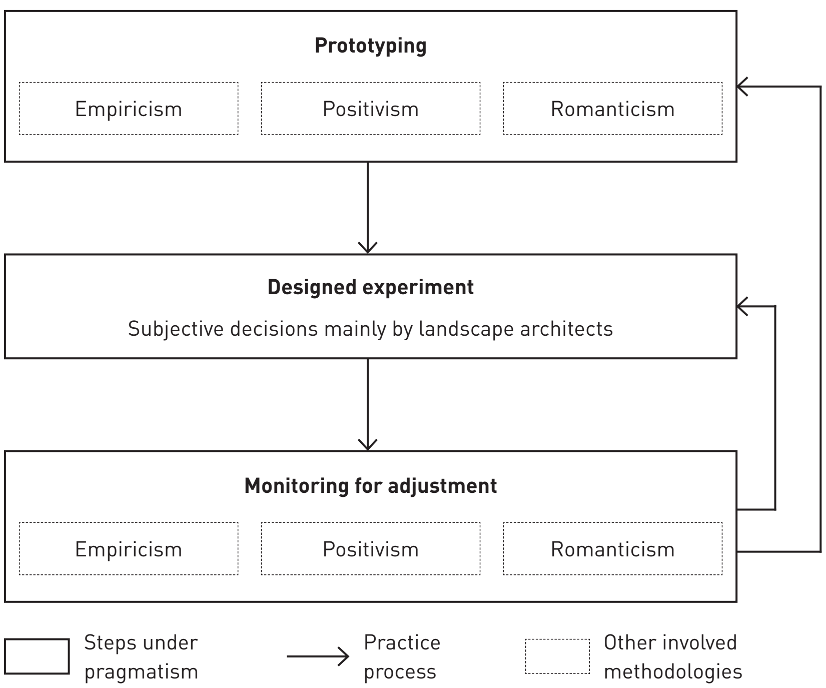
2.1 Prototyping

The initial step in ecological design involves selecting form prototypes that resonate with ecological significance for subsequent designed experiments. Ecological significance here implies forms that deliver tangible ecological benefits or convey beneficial ecological notions, or both.

Form prototypes that offer tangible ecological benefits can be derived from positivistic design simulations and empirical design collaborations. Design simulation leverages ecological knowledge to forecast the functional outcomes of specific design forms, employing methods such as computational tools. Through variable parameter settings, this process spawns diverse design prototypes, evaluates their ecological performance, and identifies suitable form prototypes. Examples include parametric design and performative design for small- and medium-scale sites[21][22], and scenario analysis for large-scale landscapes[23][24]. Such simulations enable the visualization of ecological functions on three-dimensional site models, fostering a meaningful dialogue between landscape architects and ecologists. Concurrently, the indigenous practices reflective of local knowledge offer invaluable insights[13][25][26]. The local knowledge, born from the deep-rooted interaction between communities and their environments over generations, embodies a repository of ecological wisdom, even though such empirical indigenous practices may not always adhere to scientific, precise standards[27]~[29]. Through collaborative efforts, landscape architects can assimilate local knowledge, translating it into form prototypes. These two approaches can blend universal knowledge with indigenous insights, enriching landscape architects' grasp of the local ecological culture, consciousness, current conditions, and basic data.

Form prototypes capable of conveying beneficial ecological notions can be extracted from romanticism design collaboration. This philosophy emphasizes conveying ecological consciousness and inspiring public ecological aesthetics and contemplation through artistic endeavors, rather than addressing specific environmental problems directly[30]. Through collaboration with artists and the public, landscape architects can craft formative expressions that enhance public perception and understanding on ecological processes and environmental issues to provoke environmental reflection and awareness, thus serving as a conduit for environmental experience and education.

2. Framework of ecological design based on pragmatism.



2 © Hong Yun

2.2 Designed Experiment

Designed experiment frames design projects as repeatable ecological experimental units, aiming to validate ecological hypotheses while achieving functional and aesthetic goals[31][32]. This method has been applied to forefront topics such as climate adaptation[33], biodiversity enhancement[34], and Nature-based Solutions[35]. The implementation strategy primarily involves three steps: 1) translating abstract knowledge into tangible form prototypes to achieve specific functions; 2) fine-tuning the parameters of a given form prototype to optimize its functionality; 3) integrating various form prototypes to realize multifaceted functions. Designed experiment relies on landscape architects' subjective judgment, rather than specific ecological knowledge①,

① The essence of this process blends empiricism with a stronger inclination towards pragmatism. The difference of these two methodologies lies in whether there is sufficient argumentation beforehand. Empiricism is grounded in observable facts, while pragmatism depends more on subjective judgement. Whether it is about transforming abstract and profound knowledge into specific forms or integrating diverse prototypes, landscape architects usually lack direct empirical evidence, relying more on subjective inference, which is in line with the "trial and error correction" feature of pragmatism.

to refine prototypes, necessitating the formulation of design hypotheses and post-construction evaluation frameworks. This iterative process of hypothesis validation and form refinement, known as "retroductive"[36], gradually leads to the development of rational and effective design solutions.

Designed experiment is an ecological experiment with hypotheses[37], inherently embracing the possibility of failure. To manage this risk and enhance outcome predictability, certain principles should be adhered to: 1) full-cycle involvement—in addition to early consultation and post-construction evaluation, researchers should engage throughout the design process, especially in formulating design hypotheses and post-construction evaluation methods[38]; 2) multifaceted objectives—designed experiments should consider various goals, including urban functionality, human engagement, ecological benefits, and aesthetics[31], to ensure partial success even if not all objectives are met; 3) safe to fail—experiments should be conducted at scales where potential negative outcomes are manageable, thus not jeopardizing the broader ecosystem and habitats[37]; 4) adaptability—designed experiments are innovative and iterative processes, for which even proven design solutions may require adjustments when applied in new contexts[39].

2.3 Monitoring and Adjustment

The monitoring and adjustment phase is pivotal for the continuous optimization of design forms, acting as the foundation for effective ecosystem design and management[40]. This phase involves the collection and analysis of primary data against the pre-established evaluation criteria to test hypotheses and summarize outcomes, both successful and unsuccessful. These insights inform immediate adjustments in design masterplan, form, materials, or will be applied to future design. The evaluation methods should be tailored to the specific site and design challenges, with options ranging from green energy metrics like the Leadership in Energy and Environmental Design (LEED) and Building Performance Evaluation, to sustainability benchmarks like the Landscape Performance Series, Post Occupancy Evaluation, and Sustainable Sites Initiative, and ecological restoration indices such as the National Ecological Observatory Network and National River Restoration Science Synthesis project.

Monitoring and tracking extends beyond immediate outcomes, assessing the enduring impact of ecological designs. Previous evaluation methods often lack this long-term perspective, focusing on single-time snapshots of landscape performance[41]. Today, leveraging advancements in big data and the Internet of Things (IoT), researchers are increasingly capable of conducting extended monitoring and assessment[42]~[44]. Establishing ongoing collaborations with site stakeholders, including local governments, operating companies or management organizations, and residents, can enhance the feasibility of sustained, high-frequency monitoring. This may involve integrating evaluation-related data collection into routine operations, installing monitoring sensors with management approval, or scheduling regular site visits to gather longitudinal data.

3 Ecological Designed Experiment for Haizhu Wetland

3.1 Research Area

Haizhu Wetland, located in the central urban area of Guangzhou, covers an area of 1,100 hm^2 (Fig. 3). It epitomizes an Anthropocene ecosystem, where natural and artificial elements converge, including the natural tidal river network of the Pearl River Delta, Lingnan area's traditional agricultural system, recreational parks, water management and storage infrastructures, and the scientific research and education system. In 2019, the launch of the Guangzhou Haizhu Wetland Biodiversity Conservation and Restoration Project marked a significant step towards creating an urban central life community, along with objectives to foster diverse river networks, productive wetlands, minimal-intervention habitats, complete ecological cycles, and enduring societal support. This project is a venture into designing coupled nature-human ecosystems for multiple goals.

The project navigates through multiple restoration goals and an intricate process, with existing ecological knowledge falling short of meeting the design demands. Therefore, a pragmatic ecological

3. Distribution of the 5 designed experiments.

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design method was adopted for the designed experiments. Aligning with the four foundational principles of designed experiments, the project devised the following specific strategies. 1) Multi-stakeholder engagement throughout the whole process: this involved collaboration with landscape architects, researchers, and local residents from the outset, such as consulting with the Institute of Zoology, Guangdong Academy of Sciences for expert zoological insights and monitoring frameworks for performance assessment, and incorporating local agricultural wisdoms shared by local residents. 2) Multiple objectives: this included enhancing urban stormwater storage and flood control, restoring habitats for key species, preserving agricultural heritage, and enriching public activities. 3) Acceptable experimental scale: only a 146-hectare portion of the wetland was designated for experimental interventions to minimize the risk of irreversible damage to the overall ecosystem. 4) Adaptive adjustment: while drawing from biodiversity restoration techniques and traditional Lingnan agricultural practices, the project remained open to novel design methods that resonate with the site's unique context and the social and demographic backdrop, venturing beyond tried and tested models.

3.2 Prototyping

The form prototypes of this project are derived from three distinct sources (Table 2).

1) Empiricism prototype. Inspired by local agricultural heritage, this project introduced the mound-based (duoji) orchard, a practice with roots in the Qin and Han dynasties and reaching its zenith in the Ming and Qing dynasties. This system, foundational to the Haizhu Wetland, combines wide mounds (8 ~ 10 m in width) for orchard planting and narrow orchard tidal channels, leveraging the tidal river network to sustain the agricultural ecosystem with nutrients and transport. Despite its historical significance, this prototype is primarily geared towards agricultural productivity with limited functional diversity.

2) Positivism prototype. Grounded in the ecological principles outlined in the *General Plan for Wetland Restoration of Guangzhou Haizhu National Wetland Park*, as well as insights into the behaviors of waterbirds, insects, and aquatic animals from Institute of Zoology, Guangdong Academy of Sciences, this project envisioned a variety of habitat scenarios, including natural embankment, bird islands, fishways, high-tide habitats, and micro-wetland clusters. However, these prototypes remain untested in practice, with their physical forms and functional efficacy pending further exploration.

3) Romanticism prototype. The project was inspired by the deep connection local residents have with their environment, particularly the affinity for the Lingnan water town complex (distinguished water town heritage) and Lingnan fine fruit complex (distinguished fruit heritage). The Lingnan water town complex reflects a lifestyle and traditions that revolve around the waterways of the Pearl River Delta, including water-based living and travel, and dragon boat celebrations. The Lingnan fine fruit complex stems from the tradition of cultivating premium fruits such as longan (*Dimocarpus longan*), lychee (*Litchi chinensis*), and yangtao (*Averrhoa carambola*), which were historically exported abroad. However, escalating land values and deteriorating water quality have gradually eroded the agricultural viability of the Haizhu Wetland and its associated cultural practices, with a communal aspiration to restore its historical splendor.

3.3 Designed Experiment and Monitoring Plan

To achieve the five sub-goals while considering the specific conditions of each plot, this project combined form prototypes

Table 2: Overview of the design prototypes

Methodological basis	Prototype No.	Prototype name	
Empiricism	1	Mound-based orchard	
	2	Traditional vegetable paddy field	
	3	Orchard tidal channel composting technique	
Positivism	4	Bird habitat	Bird island
	5		High-tide habitat
	6		Four-season orchard
	7	Fish habitat	Fishway
	8		Natural embankment
	9		Micro-wetland cluster
	10	Insect habitat	Insect house
	11	Water purification system	Purification measures for Class III water bodies
Romanticism	12	Lingnan water town complex	
	13	Lingnan fine fruit complex	
	14	Other local complex	

with different ecological effects to ultimately establish 5 designed experiments (Table 3, Fig. 3). These experiments include mound-based orchard wetland system, enhanced paddy field system, bird island, high-tide habitat, and low-maintenance resilient water system, aiming to realize the compound socio-ecological functions.

3.3.1 Mound-based Orchard Wetland System by Integrating Local Knowledge and Ecological Theoretical Wisdom

The mound-based orchard wetland system integrates prototypes of mound-based orchard under empiricism, the positivistic bird and fish habitat construction, and the romanticism-inspired Lingnan

Table 3: Overview of designed experiments in Haizhu Wetland

Experiment type	Morphological design approach		Design hypothesis		Monitoring indicator
	Prototype integration	Prototype realization	Improvement	New vision	
Mound-based orchard wetland system	1 Mound-based orchard 6 Four-season orchard 8 Natural embankment 9 Micro-wetland cluster 13 Lingnan fine fruit complex	—	· Preserving agricultural heritage	· Constructing a complete biologic chain · Enhancing stormwater retention capacity	· The growth of existing fruit trees · Diversity enhancement of aquatic plants and animals, birds, and insects · Forest birds' foraging conditions · Stormwater retention capacity
Enhanced paddy field system	3 Traditional vegetable paddy field 7 Fishway 12 Lingnan water town complex	—	· Reconnecting people with the land	· Increasing habitat for aquatic animals · Providing food sources for various species · Improving stormwater retention capacity of the wetland	· Diversity enhancement of aquatic plants and animals, birds, and insects · Forest birds' foraging conditions · Stormwater retention capacity · Co-construction and maintenance proportion
Bird island	—	4 Bird island	—	· Providing nesting, breeding, and nearby foraging places for large waterbirds	· Nesting density and quantity of waterbirds · Species and ratios of nesting waterbirds · Usage intensity and time distribution of various waterbirds for foraging on shallow beaches, wooden stakes, and rafts
High-tide habitat	—	5 High-tide habitat	—	· Offering foraging and resting areas for waterbirds unaffected by tides	· Usage intensity and time distribution of various waterbirds for deep and shallow water areas · Usage intensity and time distribution of various waterbirds for sandstone embankments
Low-maintenance resilient water system	1 Mound-based orchard 3 Orchard tidal channel composting technique 11 Purification measures for Class III water bodies 12 Lingnan water town complex	—	· Reducing maintenance costs of water systems · Improving wetland water quality	· Preserving dragon boat culture	· Annual maintenance cost · Water quality monitoring data comparison · Annual dragon boat cultural activities

NOTE
"Prototype integration" means to create new forms by integrating or modifying existing prototypes with physical forms; "prototype realization" means to form specific design forms based on the functional requirements of theoretical prototypes without concrete shapes.

fine fruit complex. Following the mound-based orchard wetland theory and construction techniques proposed by Xingzhong Yuan et al.[45], this project utilized tidal actions for low-maintenance energy supplementation and orchard production. It transformed the originally steep orchard embankments into natural ones with winding, gentle slopes entering the water, while sculpting the aquatic bed into a habitat-rich landscape for aquatic species to lay eggs, hide, and forage. In addition to preserving the existing trees in the orchard, 54 species of fruit trees were introduced, establishing a year-round food oasis with fruits and nectar, complemented by strategically placed insect houses to complete the ecological chain (Fig. 4).

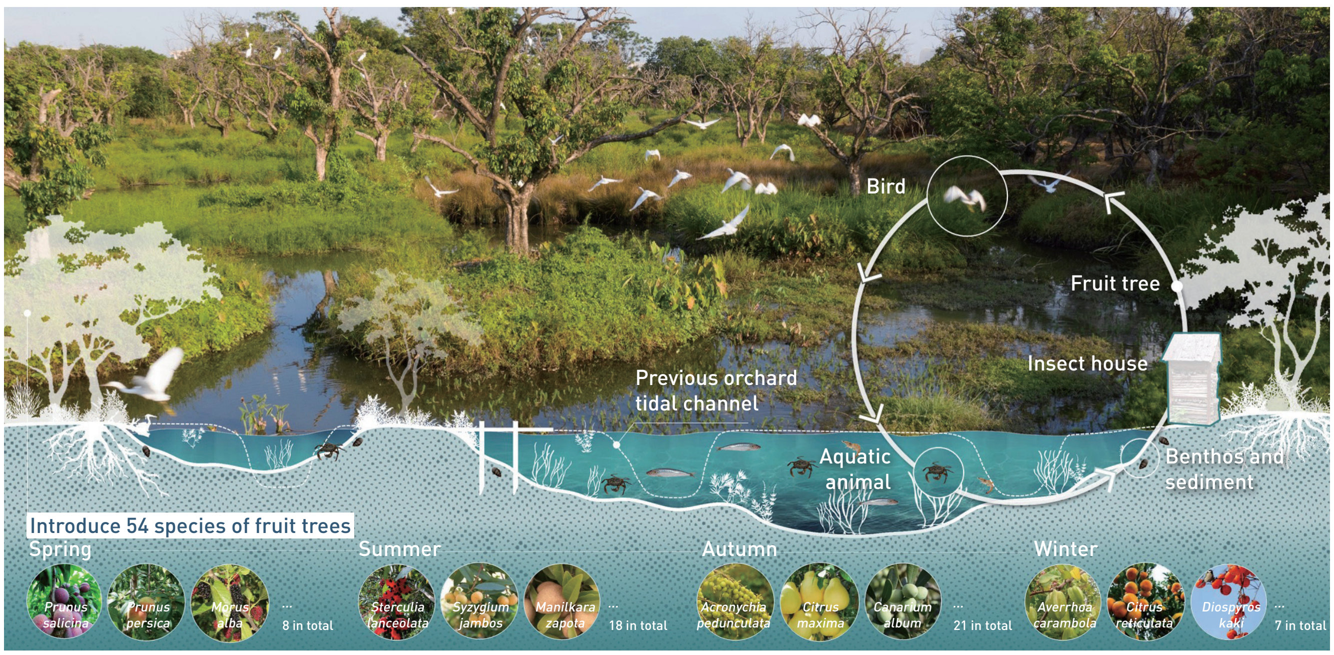
Design of the mound-based orchard wetland system planned to achieve the following 5 goals. 1) The growth of existing fruit trees in the site should maintained despite topography and hydrology modifications, thus to preserve agricultural heritage. 2) The transformation of underwater topography can effectively enrich aquatic animal species. 3) The introduction of tree species that provide fruits and nectar throughout the year can attract omnivorous songbirds such as *Pycnonotus jocosus*, *Zosterops japonicus*, and *Pycnonotus aurigaster*, which feed on plant fruits, seeds, and insects[46]. 4) An increase of insect population will attract insectivorous songbirds like *Lanius schach*, *Phoenicurus auroreus*, and *Parus major*[46]. 5) The wetland's capacity of stormwater storage and flood control can be enhanced by widening the orchard tidal channels.

In the monitoring and adjustment phase, the project established 4 assessments to reflect the above goals. 1) Compare fruit tree growth data annually, collected by multispectral drones and agricultural records from farmers, with the data from the year following project completion. This evaluation categorizes the fruit trees into three states of growth—unchanged, improved, and declined, based on which the proportion and spatial distribution of each state will be analyzed to assess whether the original fruits and vegetables can thrive in the newly created wetland. 2) Every five years, a specialized zoological team will perform detailed surveys to measure and compare the diversity of aquatic fauna and flora, birds, and insects. 3) Analyze annually the relationship between traditional and newly introduced tree species and their impact on the foraging patterns of forest birds, using data from fixed observation equipment placed in the wetland and the birdwatching groups. 4) Calculate the variance in water storage capacity between the original and transformed water systems, based on the as-built drawings to assess improvements in stormwater and flood management.

3.3.2 Enhanced Paddy Field System by Integrating Local Knowledge and Ecological Theoretical Wisdom

The enhanced paddy field system combines prototypes of the empiricism-based traditional vegetable paddy field, the positivistic fishway, and the romanticism-inspired Lingnan water town complex, aiming to increase the habitat for aquatic animals and provide food

4. The orchard before restoration (left) and the mound-based orchard wetland system (right) designed to create natural embankment, modify underwater topography, increase tree species that can provide food, and construct a complete food chain.



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5. The enhanced paddy field system: from paths in field to fishways.
6. The enhanced paddy field system co-constructed by the public becomes a paradise for wildlife.

② For participatory sites, the degree of landscape maintenance visible to the public directly impacts public participation. Drawing from past agricultural projects, the design team held that public participation will decrease when over 20% of the paddy fields are abandoned, as the agricultural landscape begins to appear neglected. Therefore, this study empirically set 80% and below as limited co-construction and maintenance sustainability, with further classification into "excellent" and "average" within this sustainable range.

sources for other animals like birds. Unlike traditional vegetable paddy fields, which were primarily for crop production with paths crisscrossing the fields, the enhanced ones can improve wetland resilience by substituting these paths with serpentine fishways ranging from 0.5 ~ 1.5 m in depth (Fig. 5). Connected to the Pearl River and leveraging its tidal influences, these fishways can draw in local aquatic species such as fish, shrimp, eels, loaches, snails, frogs, and crabs. This approach enables species traditionally confined to orchard tidal channels to migrate, forage, and hide from predators in these designed fishways. Between these fishways, wild and cultivated rice varieties are planted to serve as the primary carbohydrate source for birds, aquatic animals, and insects[46]. The system's management employs a community engagement strategy, enlisting local residents to guide volunteers and students in environmental education programs for the sowing and harvesting of rice (Fig. 6).

There are 4 design hypotheses for the enhanced paddy field system. 1) The paddy fields and fishways should attract birds for foraging, including wading birds such as *Egretta garzetta*, *Nycticorax nycticorax*, *Ardea cinerea*, *Amaurornis phoenicurus*, and *Gallinula chloropus*; swimming birds such as *Anas zonorhyncha* and *Tachybaptus ruficollis*; as well as songbirds like *Lonchura punctulata*[46][47]. 2) Increase habitats for fish and other aquatic animals to enrich the populations of native aquatic communities and benthos. 3) Construction of fishways in the paddy fields can connect to the river system, enhancing the wetland's capacity for stormwater and flood management. 4) Establish a sustainable community-involved cultivation and maintenance of paddy fields, thereby reconnecting people with the land.

In the monitoring and adjustment phase, an extra assessment in addition to those established for the mound-based orchard wetland system is the annual proportion assessment of the co-construction and maintenance paddy field area to the total paddy field area. This evaluation categorizes results into three levels of co-construction and maintenance sustainability: (90%, 100%] as excellent, (80%, 90%] as average, and [0, 80%] as limited②.

3.3.3 Bird Island Through Spatial Realization of an Ecological Theoretical Prototype

Bird island is a form prototype designed entirely grounded in the positivistic ecological principles. Ornithologists involved in

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7. The bird island before restoration and strategies to meet the nesting, breeding, and foraging needs of waterbirds.

7 © Wetland Protection and Management Office of Haizhu District in Guangzhou

the project identified 4 key functions of the island for waterbirds: nesting, foraging, perching, and roosting. Based on these functions, 5 strategies were proposed for the form design (Figs. 7, 8).
1) Increase the number and density of tree species that favor large waterbird nesting on the island, such as *Ficus concinna*, *Ficus benjamina*, and *Broussonetia papyrifera*. These species were chosen for their dense foliage, structural support, non-toxicity, and low predator attraction. 2) Create uneven foraging shallows along the perimeter of the island. At high tide, these shallows are submerged to a depth of 10 ~ 30 cm, ideal for waterbirds to forage while standing; at low tide, the shallows form flats, providing spots for waterbirds to stand, observe, and forage opportunistically. Edges of the shallows extend into the water, forming small bays for distinct standing territories of different waterbirds. 3) Install wooden stakes in the deeper surrounding area of the island, with pine stakes driven into the water and dead tree stumps from orchards placed randomly, providing perching spots for waterbirds. 4) Place floating rafts planted with hygrophytes around the island to mimic natural waterbird roosting sites.

Three design hypotheses were set for the bird island. 1) The nesting forests are expected to attract wading bird communities such as *Egretta garzetta*, *Ardea cinerea*, *Nycticorax nycticorax*, and *Phalacrocorax carbo* for nesting and breeding. 2) The shallows and wooden stakes can attract wading bird communities including *Egretta garzetta*, *Ardea cinerea*, *Nycticorax nycticorax*, *Phalacrocorax carbo*, *Amaurornis phoenicurus*, and *Gallinula chloropus* for foraging and resting. 3) The floating rafts can attract swimming birds like *Anas zonorhyncha* and *Tachybaptus ruficollis*, as well as the aforementioned wading bird communities for habitation.[46]

For monitoring and adjustment, the bird island has been equipped with monitoring devices to collect video and audio around its perimeter and inside. This enables the analysis of nesting density and quantity of waterbirds, their species diversity and proportion, and their usage intensity and time distribution of shallows, wooden stakes, and floating rafts, with the information extracted from the monitor data through image and audio recognition technologies.

3.3.4 High-tide Habitat Through Spatial Realization of an Ecological Theoretical Prototype

Similarly, the high-tide habitat is also rooted in positivistic ecological principles. The theory of high-tide habitats proposed by the ornithologists suggests that when rivers flood the tidal flat during high tide, they provide sites for waterbirds to forage in shallow water and rest along riverbanks. The theory requires creating a habitat that is at least 12 m in width and 50 m in

8. The bird island transforms the previous tourist island into a sound habitat for waterbirds.

8 © Wetland Protection and Management Office of Haizhu District in Guangzhou

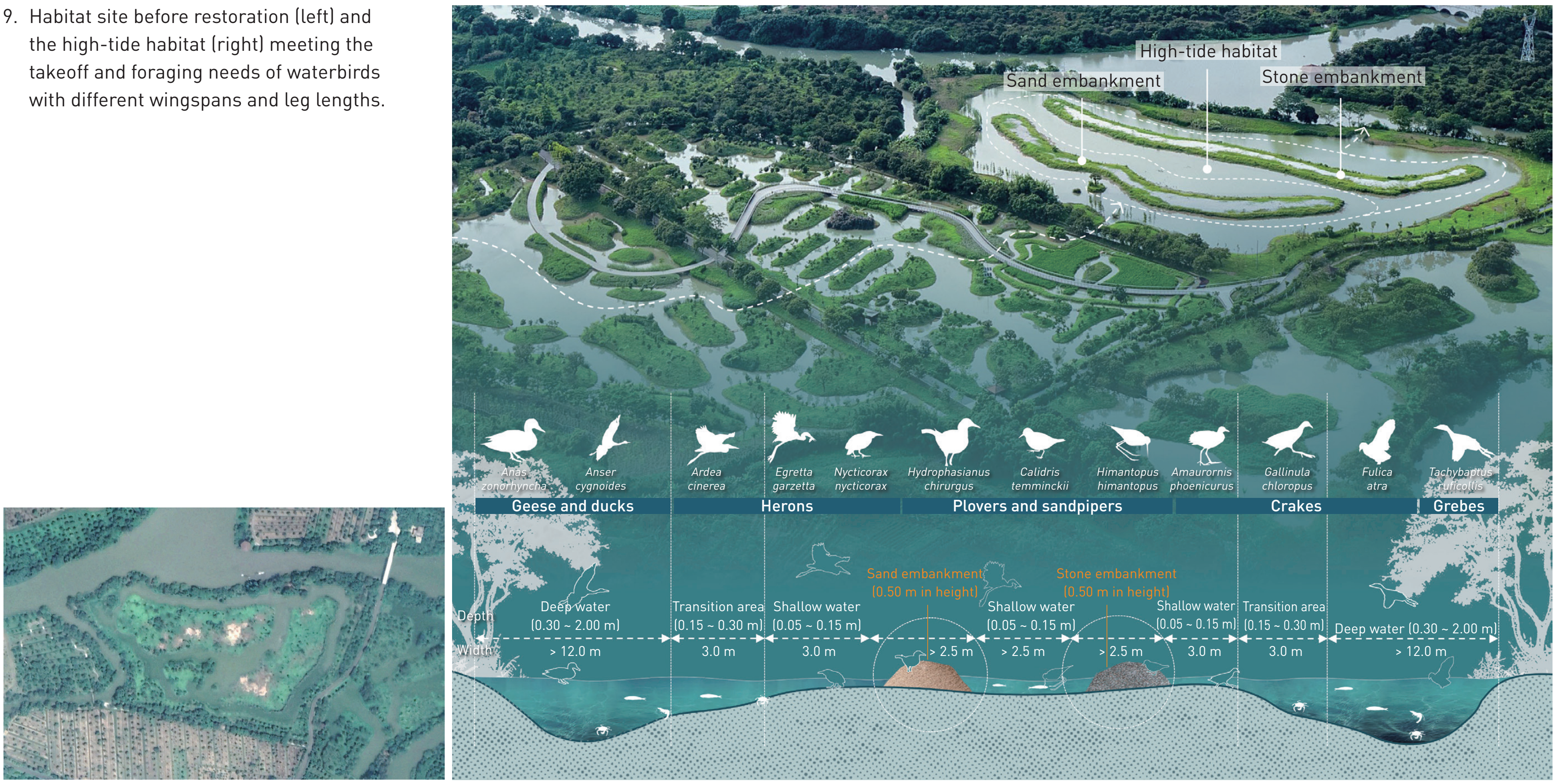
length, ensuring ample space for group takeoffs and landings. Moreover, a low sand embankment should be set at the center of the water area, providing a rest area for waterbirds free from tall vegetation that may block views of potential predators. Water levels should also be carefully managed to a certain depth to maintain a nutrient-rich environment for waterbirds. Considering all these principles, this project designed a 158-meter long sand and stone embankments and a high-tide habitat with three takeoff and landing water surfaces. The water level can be regulated by a passive sluice, allowing the depth to gently increase from the center of the embankments outward, catering to the diverse preferences of various waterbird species (Fig. 9). The upstream of this area is connected to the mound-based orchard wetland system through the sluice, ensuring an adequate food supply.

Design hypotheses for the high-tide habitat includes attracting wading birds like *Egretta garzetta*, *Ardea cinerea*, *Nycticorax nycticorax*, *Phalacrocorax carbo*, *Amaurornis phoenicurus*, and *Gallinula chloropus*, as well as swimming birds such as *Anas zonorhyncha* and *Tachybaptus ruficollis* to rest and forage during high tide[46].

For monitoring and adjustment, devices similar to those used on the bird island were installed to assess the usage intensity and time distribution of various waterbirds in both shallow and deep water areas as well as on sand embankment.

3.3.5 Low-Maintenance Resilient Water System—Integrating Novel and Traditional Technologies to Sustain Cultural Complex

By merging the empirical orchard tidal channel composting technique, positivistic water purification measures, and the romantic Lingnan water town complex, a self-purifying three-level system of wetland water network is established, consisting of a main channel, connected branch channels, and dredged orchard tidal channels. This system also serves as a critical site for dragon boat storage. The mud composting process involves layering silt from the river network atop the mound surface, facilitating dredging of the water system and soil fertilization. Employing local residents adept in this technique, this project revitalized the three-level water network and reconnected thousands of capillary-like orchard tidal channels (Fig. 10). The area and length of the water system were also increased, incorporating water purification



9. Habitat site before restoration (left) and the high-tide habitat (right) meeting the takeoff and foraging needs of waterbirds with different wingspans and leg lengths.

measures, including permeable filtration, plant purification, and algae-eating insect introduction to continuously improve wetland water quality with low maintenance costs (Fig. 11). Moreover, the system conserves a traditional pond for villagers to bury dragon boats in riverbed silt for preservation. Digging out and cleaning the boats before the Dragon Boat Festival is an important folk ceremony.

The design hypotheses for this system were to reduce wetland water system maintenance costs, improve the water quality by 1 to 2 grades, and preserve the dragon boat culture.

The monitoring and adjustment phase primarily encompasses 3 kinds of evaluation: 1) wetland maintenance costs published in the annual financial reports by the management office; 2) water quality changes monitored in collaboration with the water affairs department, to be compared with surrounding water systems; 3) documentation of annual dragon boat training, competitions, and cultural ceremonies in the wetlands.

4 Conclusions and Discussion

Haizhu Wetland Biodiversity Conservation and Restoration Project has now completed prototyping and experiment design phases. Although assessment indicators were established, the monitoring and adjustment phase has not been fully implemented, and the effectiveness of the ecological design approach remains to be further verified. However, initial monitoring data from the sites show positive trends: a significant increase in visitor number to the wetland park; an annual increase of 4 to 7 bird species observed; and the addition of 392 insect species, including 2 newly named species. The 5 designed experiments in the project have achieved various degrees of goals, with the enhanced paddy field system and bird island showing notable results, while the mound-based orchard wetland system, high-tide habitat, and low-maintenance resilient water system require further adjustments and optimization.

Specifically, in the initial stages of the bird island's development, smaller birds such as *Egretta garzetta* and *Nycticorax nycticorax* predominated, with populations reaching up to 50 individuals. A year later, larger *Ardea cinerea* also began nesting and breeding on the island, turning it into a rare breeding ground for *Ardea cinerea* in central Guangzhou. Year-round observation of waterbirds, including *Egretta garzetta*, *Phalacrocorax carbo*, *Anas zonorhyncha*, and *Anser cygnoides* on floating rafts surrounding the bird island, is possible. Shallows and wooden stakes became ideal foraging sites for waterbirds, with foraging activities primarily concentrated during low tide periods, allowing for simultaneous observation

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10. Dredging and connecting wetland water systems with the traditional mud composting technique.
11. Integrating three types of water purification technologies into the wetland water system.

of over 30 waterbirds feeding. The enhanced paddy field system also emerged as a principal foraging site for both water and forest birds, with observed flocks of *Anas zonorhyncha* and *Lonchura punctulata* feeding in the area. *Egretta garzetta*, *Nycticorax nycticorax*, and *Ardea cinerea* also scattered throughout the rice fields for foraging. The fish community, including *Squaliobarbus curriculus*, showed sound recovery, laying a foundation for the introduction of animal observation courses in Haizhu Wetland and public ecological awareness enhancement. Shallow areas created in the high-tide habitat attracted waterbirds foraging, with single observation of over 20 individuals. But given that the water area is approximately 28,000 m^2, the effect was not significant, necessitating further investigation. In the low-maintenance resilient water system, invasive species such as *Oreochromis mossambicus* and *Pomacea canaliculata* continued to damage aquatic plants, limiting water purification capabilities and requiring subsequent design adjustments to consider ecological control measures against invasive species. The growth of the 54 species of newly planted fruit trees in the mound-based orchard wetland system was favorable, providing sound food source. But there was a limited observable bird population, for which continuous observation and specific enhancement strategies are needed.

These insights partially reveal how the ecological design practice, encompassing prototyping, designed experiment, and monitoring and adjustment, showcases the feasibility of integrating ecological research with practical application to steer ecological design optimization and enhance the resilience of anthropogenic ecosystems. It is essential to emphasize that this practice framework does not dismiss existing positivistic methods but frequently incorporates certain tactics. Not inherently simpler or more straightforward than the positivistic ones, the pragmatism-based methods necessitate offering a learning-by-doing and semi-empirical paradigm and an effective process of learning during a purpose-driven practice, with the goal of enriching the ecological design approaches within the collective human knowledge. This approach requires landscape architects to sharpen their analytical skills regarding current ecological knowledge and prototypes, and prompts a shift in the design and engineering fields from believing that the completion of construction marks the end of their responsibilities. Thus, routines of monitoring and assessing the effectiveness of ecological design initiatives can be established. Such a paradigm necessitates the cooperative involvement of landscape architects, researchers, and management operators, granting landscape architects more freedom and opportunities to innovate in ecological configurations without strict adherence to existing morphology. Moving forward, the research team intends to further develop this collaborative framework among the realms of design, research, and management, persistently monitor the design performance, and provide quantitative proof of the efficacy of this ecological design method.

Competing interests | The authors declare that they have no competing interests.

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基于实践主义的生态设计实验方法
——以广州市海珠湿地改造项目为例

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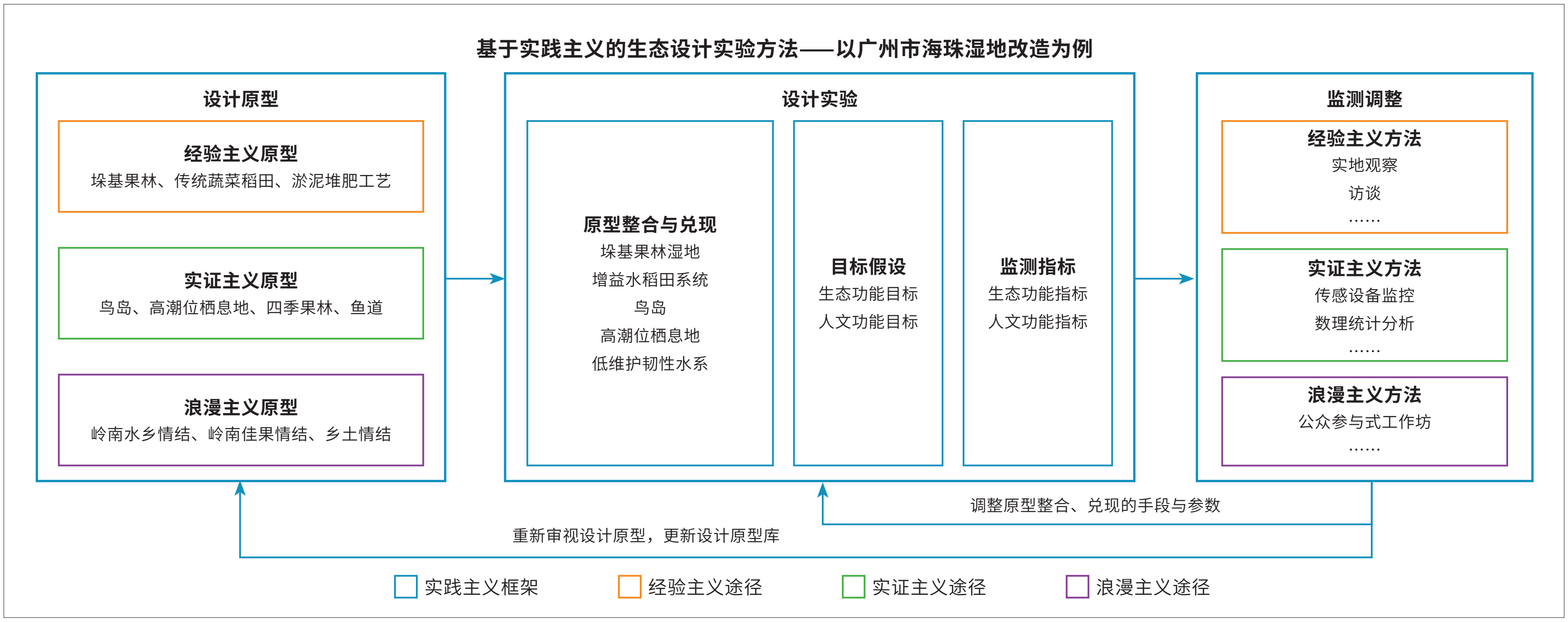
图文摘要



摘要

探索有效的生态设计方法是可持续发展的重要议题，但生态研究与景观设计的生态实践之间仍存在脱节现象。本研究以实践主义的设计实验为核心方法，融合经验主义、实证主义、浪漫主义的技术方法，提出了利用实践进行学习、以做促研的半先验式生态设计框架。框架涵盖原型设定、设计实验与监测调整三个步骤。本研究将该框架应用于广州市海珠湿地的改造实践中，在梳理了形态原型的基础上，提出垛基百果林湿地系统、增益水稻田系统、鸟岛、高潮位栖息地、和低维护韧性水系5个设计实验，并设定了相应的设计假设和监测调整评估指标。研究结果表明，由原型设定、设计实验和监测调整三个步骤组成的生态设计实践方法展现了将生态研究与生态实践相结合、指导生态设计优化、增强人类世生态系统韧性的潜力。虽然上述湿地改造项目已初步呈现生态效益和社会福祉，但该设计框架的有效性仍需进一步跟踪论证。

关键词

人类世生态系统；城市湿地；实践主义；原型设定；设计实验；监测调整

文章亮点

- 基于实践主义方法论，构建了一套有效利用实践进行学习、以做促研的半先验式生态设计框架
- 生态设计框架包括原型设定、设计实验和监测调整三个步骤
- 该方法在提升设计人员分析生态知识和原型的能力、形成跟踪评估习惯的同时，可使设计过程更具弹性

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编辑 王颖，高雨婷
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1 引言

随着城市化和全球化进程的不断推进，人类活动的影响已遍及每个角落，地球由此步入了人类世新纪元[1][2]。当前，人类已经改造了超过三分之一的生态系统（如农业用地、城市等）[3]，每年消耗陆地生态系统近一半的生物生产量[4]和可再生淡水资源[5]，改变了全球的生物地球化学循环[6]，人类世生态系统随之产生。这一受人类活动影响的生态系统具有三个特点：1）超过自然生态阈值；2）与自然生态系统相比，物种组成有显著改变；3）建立了自我维持的机制。[7][8]虽然该系统目前广泛存在，但由于演化时间较短，它同时承担的人类社会功能与自然功能仍有许多相冲突的地方。如果不能有效协调两种功能的关系，将可能对地球造成大范围的消极影响。如何界定和实现人类世生态系统平衡是当前的迫切问题。

基于上述背景，国际上自20世纪70年代开始探索现代生态设计方法[9]，我国自21世纪初开始探索城市与景观的生态设计[10][11]。尽管现代生态学发展迅速——宏观尺度出现了面向景观和生物圈的景观生态学和全球生态学，微观尺度向器官、细胞、细胞器、分子水平奋进[12]——但这类生态研究与景观设计的生态实践长期脱节[2]~[5]，生态设计理念大多停留在原则和理论层面，缺乏可操作性，难以指导形态设计[12]。

究其原因，首先，现代生态科研的解构性与生态实践的整体性不相契合[13]；其次，生态实践包含非理性的成分，无法完全沿用现代生态科研的纯理性范式。景观设计师需要运用基于非理性、想象力和神秘性的即兴创作能力[14]，将零散、晦涩、一般性的科研成果和具体需求相结合，兑现为空间形态。因此，本研究尝试跳脱主流的科学实证主义方法论，以实践主义的设计实验为核心方法，融合经验主义、实证主义、浪漫主义的技术方法，提出一种以提升生态系统韧性为目标的可操作生态设计途径，并以笔者团队主导的中国广州市海珠湿地改造项目为例进行说明。

2 基于实践主义的生态设计实验方法

广义来讲，生态设计是指对生态系统的结构和功能进行有目的的控制，以达到特定的目标[2]。设计的生态系统是对人类世生态系统进行主动管理和干预的结果[15]，两类生态系统的差别在于（图1）[8]：1）前者需要通过集中的干预措施来创造且离不开后续的维护管理，而后者不需要；2）前者因明确的人类目的而建立，后者则受无意识的人类活动影响。从人类社会的主观需求、客观的环境条件，以及现有的知识技术层面来讲，设计的生态系统均无法保持原本的自然生态系统状态。它们应当将人类影响纳为内生影响因素，在自然—人类复合生态系统中提供优化的生态系统服务，而非回到原生的自然生态系统[16]。无论是在城市还是乡村背景下，优化的生态系统服务对于生态系统韧性的提升都至关重要。[17]~[19]

设计的生态系统需要一种新的实践范式介入：将设计融入科学，让设计成为生态科学的重要组成部分，让设计师成为科学研究的主要参与者[20]。在当今的生态设计中，至少存在实证主义、经验主义、实践主义及浪漫主义 4 种不同哲学基础的方法论（表1）[9]。其中，实践主义的“适应性”理念倡导在实践中学习，通过实施多个实验方案、控制单个实验规模、监测并调整实践以实现生态设计。本研究提出的以实践主义为核心的整体框架分为原型设定、设计实验和监测调整三个部分，可将上述不同的生态设计方法和各类行动者结合在一起（图2）。

表 1：不同方法论基础的生态设计方法对比

	实证主义方法	经验主义方法	实践主义方法	浪漫主义方法
生态观	平衡态范式 复杂性范式	平衡态范式 复杂性范式	复杂性范式 人类世生态系统	开放的生态观
方法论	科学推演	经验归纳	辩证法 实践反演	艺术抽象 哲学思辨
切入点	生态科学为主 生态伦理为辅	生态伦理为主 生态科学为辅	生态伦理 生态科学	生态审美 生态伦理
典型议题	生态系统、景观生态学、城市生态学、建模评估等	生态智慧、生态实践智慧、地方知识、乡土景观、文化景观等	适应性规划、设计实验、设计生态学、公众参与、社会公平等	大地艺术、生态审美、环境感知、环境教育等

2.1 原型设定

生态设计需要选择具有明确生态意义的形态原型作为设计实验的起点。“生态意义”包括两个维度：1）具有实际的生态效用；2）可传递有益的生态观念。

具有实际生态效用的形态原型可提炼自实证主义的设计模拟和经验主义的设计协作。设计模拟指基于生态知识，利用计算机技术等方法预测某一设计形态的生态功能。这种方法通过设定不同参数产生多种设计形态，分析对比各形态的绩效指标，进而确定形态原型——例如，针对中小尺度场地的参数化设计与绩效设计[21][22]，以及针对大尺度场地的预景分析[23][24]。设计模拟能在三维场地模型上可视化展示生态绩效，是连接设计师和生态学家的重要媒介。另一方面，许多研究指出乡土实践中存在可借鉴的地方知识[13][25][26]。地方知识是指当地人与其长期居住的环境亲密互动形成的改造和管理地方景观的独特文化和特色经验，是在历史中不断试错并代代传承的生存方式。基于经验主义的乡土实践不一定拥有科学、精确的标准，但确实蕴含着生态智慧[27]~[29]。设计师可通过设计协作向当地居民学习地方知识，并将之转化为形态原型。上述两种途径能够将普遍知识和地方知识相整合，加深设计师对当地生态文化、生态意识、生态现状和生态基础数据的理解。

可传递有益生态观念的形态原型能够通过浪漫主义的设计协作获取。浪漫主义的“浪漫”指不以解决具体的环境问题为目标，而通过艺术手段激发公众的生态审美和思考，内化生态意识[30]。设计师通过与艺术家、社会公众的协作，可提取有助于公众感知和理解的表现形式，将生态过程、环境问题转化为人的直观感受，激发公众对环境的思考，从而达到环境体验和教育的功能。

2.2 设计实验

设计实验是将设计项目作为一个可重复性的生态学实验单元，在实现功能与审美的同时验证生态假设[31][32]。不少研究将设计实验应用于气候适应[33]、生物多样性[34]、基于自然的解决方案[35]等前沿议题中。设计实验主要通过三种设计形态的思路来实施：1）主观地将抽象的知识原理兑现为形态原型，以实现某一功能；2）调整单个形态原型的参数，以强化某一功能；3）整合不同形态原型，以实现复合功能。这一过程更多是依靠设计师的主观判断对原型进行修改，而非确切的生态知识①。但需要提前设想设计假设和建成后的评估方式，以便在实践中反复证伪并最终趋向合理的形态结果，即“反演法”（retroductive）[36]。

设计实验是“带有假设的生态实验”[37]，所以必然存在失败的风险。为了提升结果的可控性，设计实验需遵从以下原则：1）全过程性——研究者不只是作为项目前期的咨询顾问或者项目建成后的评估者，而要参与设计过程的讨论，特别是参与制定设计假设与建成后的评估方式[38]；2）复合性——设计实验应综合考虑城市功能、人类活动、生态功能、设计美学等多重目标[31]，保障设计实验至少能达成部分目标；3）失败的可接受性——进行适当规模的设计实验，从而将潜在的失败后果控制在可接受的范围内，避免危及到整个生态系统和生境[37]；4）适应

① 这一过程涉及经验主义，但更偏向实践主义。经验主义和实践主义的差别在于事前是否有充分的论证依据，经验主义包含经验事实依据，而实践主义则更多是主观推断。无论是要将抽象、深奥的知识原理兑现成具体形态，还是将多元原型重新拆分组合，多数情况下设计师缺少直接的现实经验依据，而更多的是非理性的“臆断”，具有实践主义“试错修正”的特点。

性——设计实验是探索“标准做法”的创新和更替过程，即使一个设计方案在某场地中被认为是正确有效的，更换场地之后，也需要根据实地情况进行适应性调整[39]。

2.3 监测调整

监测调整旨在迭代优化设计形态，是生态系统设计与管理的基石[40]。研究者根据预先设定的评估方式收集一手数据，然后验证假设，总结成功或失败的经验，再交由设计师及时调整现有设计的平面布局、形式、材料，或应用于下一轮设计中。评估方式并非固定的，需要对应场地类型和设计假设进行选择，可以参考的评估方法包括：关注于绿色节能的能源与环境先锋认证、建筑性能评估等；关注于可持续与高绩效的景观绩效系列、建成后评价、可持续场地计划等；关注于生态健康与修复的美国生态观察网络、美国河流修复科学综合项目等。

跟踪监测不仅要关注生态设计的短期效应，更要关注长期效应。以往的评估实践基本都是“一次性观察”，缺乏对景观动态的长期监测[41]。目前，越来越多的学者借助大数据、物联网等各类新型技术手段实现了长期的监测评估。[42]-[44]要实现高频次的长期监测，就需要与设计场地的运营管理者和使用者（地方政府、运营公司或管理机构、当地居民）建立常态的协作关系。可考虑将评估所需的数据收集结合到运营管理者的日常工作中，或在运营管理机构的准许下设置各类传感器，或频繁回访场地。

表 2：设计原型总览

方法论基础	原型序号	原型名称	
经验主义	1	垛基果林	
	2	传统蔬菜稻田	
	3	果林潮道淤泥堆肥工艺	
实证主义	4	鸟类栖息地营造	鸟岛
	5		高潮位栖息地
	6		四季果林
	7	鱼类栖息地营造	鱼道
	8		柔性水岸
	9		小微湿地群
	10	昆虫栖息地营造	昆虫屋
	11	水净化系统	三类水净化措施
浪漫主义	12	岭南水乡情结	
	13	岭南佳果情结	
	14	其他乡土情结	

3 海珠湿地的生态设计实验

3.1 研究区域

海珠湿地是广州市中心城区的一处湿地系统，面积达1 100hm^2（图3），是集合了珠江三角洲感潮河网自然生态系统及岭南传统农业系统、公园游憩系统、水利调蓄系统、科研教育系统等自然和人工要素的典型人类世生态系统。2019年，广州市海珠湿地生物多样性保护与修复工程项目立项，提出了建设“城央生命共同体”的总目标，以及“多样的连通河网、丰产的湿地系统、低干扰的栖息地、完整的生态链、可持续的社会支持”五项子目标，以探索多目标自然—人类复合生态系统的设计方法。

该项目修复目标多元且过程复杂，现有生态知识尚不足以支撑设计，因而采用生态设计的实践主义方法进行设计实验探索。参照设计实验的四项原则，项目设置了相应的策略：1）多主体全程参与——设计师、研究者和当地居民自项目之初便参与其中，例如邀请广东省科学院动物研究所为本项目提供专业的动物学建议并提供监测方案以评估实际成效、邀请居民分享当地的传统农业智慧；2）多元目标——综合考虑城市雨洪调蓄功能提升、关键物种栖息地恢复、农业文明传承、市民活动丰富等多项需求；3）可接受的试验规模——仅选取场地中146hm^2的范围作为试验场地，避免对整体生态系统造成不可逆的破坏；4）适应性调整——借鉴生物多样性修复及岭南传统农业的实践先例，但不拘泥于现有形态，而结合本项目的场地区位、周边环境、人口社会情况，探索未经实践验证的潜在设计方式。

3.2 原型设定

本项目的形态原型共有三种来源（表2）。

1）经验主义原型。借鉴自当地的农业传统，以垛基果林为代表。垛基果林系统是始于秦汉、兴于明清的高畦深沟农业遗产，也构成了海珠湿地的基础，包括种植果林的垛基（8~10m宽）与细密的果林潮道，能有效利用感潮河网为农业系统提供源源不断的养分和交通连接。尽管这种原型历史悠久，但只服务农业生产，功能单一。

2）实证主义原型。指依据《广州海珠国家湿地公园湿地恢复总体规划》提供的生态知识及通过广东省科学院动物研究所获取的有关水鸟、昆虫、水生动物习性的知识所构建的一系列生境场景，包括柔性水岸、鸟岛、鱼道、高潮位栖息地、小微湿地群建等。但上述原型仍停留在理

论阶段，其具体形态还未构建，功能效果有待进一步验证。

3）浪漫主义原型。参考自当地居民的乡土情结，特别是岭南水乡情结和岭南佳果情结。岭南水乡情结指由珠三角感潮河网湿地孕育出的临水而居、水上出行、龙舟节庆等生活方式与民俗节庆。岭南佳果情结源于当地百年的果林经济传统，因龙眼（*Dimocarpus longan*）、荔枝（*Litchi chinensis*）、阳桃（*Averrhoa carambola*）等佳果曾远销海外，这片土地被居民亲切地称为“万亩果园”。但由于土地价值增加、水污染加重，海珠湿地的农业功能与对应的民俗文化逐渐衰减，居民希望能够再现往日光景。

3.3 设计实验与监测方案

为实现五项子目标，本项目根据各地块的具体情况，组合不同生态效应的形态原型，最终形成5个设计实验（图3，表3），分别为垛基百果林湿地系统、增益水稻田系统、鸟岛、高潮位栖息地和低维护韧性水系，以期实现这些系统的复合社会—生态功能。

3.3.1 融合地方知识与生态理论智慧：垛基果林湿地系统

将经验主义下的垛基果林原型与实证主义下的鸟类栖息地营造、鱼类栖息地营造，以及浪漫主义下的岭南佳果情结原型相整合，构成“垛基百果林湿地系统”。依据袁兴中等提出的垛基果林湿地理论与构建方法[45]，本项目在垛基果林利用潮汐作用实现低维护能量补给与果林生产的基础上，将原本陡直的果林驳岸改造为蜿蜒曲折、缓坡入水的“柔性水岸”；水系底部设计为深浅起伏的形态，为鱼类及其他水生动物营造适合产卵、躲藏、觅食等活动的水下空间。本次工程在保护原有果林老树的基础上补充增加了54种果树，四季均可为各类生物提供果实与花蜜作为食物；林下新增昆虫屋，与湿地构成完整的生物链（图4）。

垛基果林湿地系统的设计假设包括：1）场地中原有的果树生长不受地形或水文条件改变的影响，有效传承农业遗产；2）水下地形的改造能够有效提升水生动物种群数量；3）新增全年提供果源与蜜源食物的树种，吸引红耳鹎（*Pycnonotus jocosus*）、暗绿绣眼鸟（*Zosterops japonicus*）、白喉红臀鹎（*Pycnonotus aurigaster*）等以植物果实、种子和昆虫为食的杂食性鸣禽[46]；4）昆虫数量增加，吸引棕背伯劳（*Lanius schach*）、北红尾鸲（*Phoenicurus auroreus*）、大山雀（*Parus major*）等以昆虫为食的肉食性鸣禽[46]；5）通过扩宽果林潮道增强湿地的雨洪调蓄能力。

在监测调整阶段，项目针对上述假设制定了4项评估：1）根据多光谱无人机采集的果树生长数据和果农统计的瓜果数据，每年与项目建设完成后首年进行对比，将果树分为保持现状、繁茂与凋敝三类生长状态，并统计各状态的占比与位置分布，以验证场地原有果蔬能否适应新的湿地环境；2）由专业的动物学团队对水生动植物、鸟类、昆虫的多样性进行样方调查，每五年一次进行对比；3）根据湿地内布设的固定观测仪器和观鸟协会的观测记录，分析新旧食源树种与林鸟觅食的相关性，每年一次；4）依据竣工图计算原湿地水系与改造后水系的调蓄容积差值，评估雨洪调蓄能力的变化。

3.3.2 融合地方知识与生态理论智慧：增益水稻田系统

增益水稻田系统是由经验主义的传统蔬菜稻田原型、实证主义的鱼道及浪漫主义的岭南水乡生活情结原型相整合而成，拟以增加水生动物栖息地为基础为包括鸟类在内的多种动物提供食物来源。传统的蔬菜稻田以农业生产为主，阡陌交通。为提升湿地韧性，“增益水稻田”不再保留耕作道路，而新增深度0.5~1.5m不等的蜿蜒鱼道（图5）。鱼道与珠江潮汐水系连通，利用潮汐带来的营养吸引鱼、虾、黄鳝、泥鳅、田螺、蛙、蟹等地方物种，让原本只能生存在果林潮道的水生动物可以在鱼道中洄游、觅食和躲避天敌。鱼道之间种植野生稻、水稻等稻谷作物，作为鸟类、水生动物、昆虫主要的碳水化合物来源。[46]在水稻田的管养过程中，采取全民共建的模式，聘请本土村民带领市民志愿者或自然教育学员参与水稻田的种植与收割（图6）。

增益水稻田系统的设计假设包括：1）水稻田及鱼道能吸引鸟类觅食，包括以白鹭（*Egretta garzetta*）、夜鹭（*Nycticorax nycticorax*）、苍鹭（*Ardea cinerea*）、白胸苦恶鸟（*Amaurornis phoenicurus*）和黑水鸡（*Gallinula chloropus*）为代表的涉禽，以斑嘴鸭（*Anas zonorhyncha*）和小䴙䴘（*Tachybaptus ruficollis*）为代表的游禽，以及以斑文鸟（*Lonchura punctulata*）为代表的鸣禽[46][47]；2）增加鱼类及其他水生动物栖息地，丰富本土水生及底栖生物的种群数量；3）水稻田中鱼道的建设可以连通河道系统，提升湿地的雨洪调蓄能力；4）形成全民参与水稻田耕作维护的可持续共建模式，重新连接人与土地的关系。

进入监测调整阶段，在“垛基果林湿地系统”后四项评估指标的基础上，增加共建维护比例评估，即将共建稻田面积占总增益水稻田面积的比例作为表征指标，每年评估一次，结果达90%~100%为优秀可持续，80%~90%为一般可持续，低于80%为较不可持续②。

3.3.3 生态理论原型的空间实现：鸟岛

鸟岛是完全基于实证主义生态原理的形态原型。参与本项目的鸟类学家指出，鸟岛应具备水鸟林上筑巢、临岛觅食、水上站立、临

② 对于参与式的场地，公众视觉所见的景观维护程度会直接影响其参与意愿。基于农田相关的项目经验，设计团队认为当抛荒率超过 20%，农田景观会呈现比较明显的颓势，进一步降低公众参与稻田共建的意愿。因此，本研究将经验性的 80% 作为共建维护可持续与不可持续的分割线，并在可持续的范围中对半划分了“优秀可持续”和“良好可持续”。

表 3：海珠湿地设计实验总览

实验名称	形态设计方式		设计假设		监测指标
	原型整合	原型兑现	改善现状	新设愿景	
垛基百果林湿地系统	1 垛基果林 6 四季果林 8 柔性水岸 9 小微湿地群 13 岭南佳果情结	—	· 传承农业遗产	· 构建完整生物链 · 增强雨洪调蓄能力	· 原有果树的生长情况 · 水生动植物、鸟类、昆虫多样性提升情况 · 林鸟觅食情况 · 雨洪调蓄能力
增益水稻田系统	3 传统蔬菜稻田 7 鱼道 12 岭南水乡情结	—	· 重新连接人与土地	· 增加水生动物栖息地 · 为各类生物提供食物来源 · 提升湿地的雨洪调蓄能力	· 水生动植物、鸟类、昆虫多样性提升情况 · 林鸟觅食情况 · 雨洪调蓄能力 · 共建维护比例
鸟岛	—	4 鸟岛	—	· 为大型水鸟提供筑巢、繁衍与就近觅食的场所	· 水鸟的筑巢密度与数量 · 筑巢水鸟的种类及占比 · 各类水鸟对觅食浅滩、木桩、浮排的使用强度与时间分布
高潮位栖息地	—	5 高潮位栖息地	—	· 为水鸟提供不受潮汐影响的觅食地与停歇地	· 各类水鸟对深浅水域的使用强度与时间分布 · 各类水鸟对沙石堤的使用强度与时间分布
低维护韧性水系	1 垛基果林 3 果林潮道淤泥堆肥工艺 11 三类水净化措施 12 岭南水乡情结	—	· 降低水系维护费用 · 提升湿地水质	· 传承龙舟文化	· 年度维护费用 · 水质监测数据对比 · 年度龙舟文化活动

注

“原型整合”指整合或修改具有现实形态的原型形成新形态；“原型兑现”指根据无具体形态的理论原型的功能要求，形成具体的设计形态。

水栖息四种功能。以此为依据，形态设计的策略包括（图7，8）：1）增加湖中央岛屿上适合大型水鸟筑巢树种的数量与密度，如雅榕（*Ficus concinna*）、垂叶榕（*Ficus benjamina*）与构树（*Broussonetia papyrifera*）等，其枝叶密度大，支撑力强，无毒无害且较难吸引水鸟天敌。2）湖中央岛屿沿岸增设不规则的觅食浅滩——高潮位时水面淹没浅滩10~30cm的深度，水鸟可以站立觅食；低潮位时浅滩露出水面形成若干滩地，供水鸟伫立观察水面、伺机觅食。浅滩边缘伸向水中形成多个小湾，供不同水鸟划分各自的站立领域。3）沿鸟岛外围深水区布置木桩，部分使用松木桩打入深水区，部分直接放置果林的枯树桩，供水鸟停留。4）在岛屿周边布置种植了湿生植物的浮排，模拟水鸟临水栖息场地。

鸟岛的设计假设包括：1）筑巢林能吸引白鹭（*Egretta garzetta*）、苍鹭（*Ardea cinerea*）、夜鹭（*Nycticorax nycticorax*）和普通鸬鹚（*Phalacrocorax carbo*）等涉禽群落筑巢繁衍；2）浅滩与木桩可吸引以白鹭（*Egretta garzetta*）、苍鹭（*Ardea cinerea*）、夜鹭（*Nycticorax nycticorax*）、普通鸬鹚（*Phalacrocorax carbo*）、白胸

苦恶鸟（*Amaurornis phoenicurus*）、黑水鸡（*Gallinula chloropus*）为代表的涉禽群落觅食休憩；3）浮排能吸引包括以斑嘴鸭（*Anas zonorhyncha*）、小䴙䴘（*Tachybaptus ruficollis*）为代表的游禽及上述涉禽群落栖息。[46]

在监测调整方面，鸟岛外围及内部安装了可采集视频和声音的监控设备，可通过图像识别和音频识别技术从监控数据中提取鸟类信息，监测水鸟的筑巢密度与数量，筑巢水鸟的种类及占比，各类水鸟对浅滩、木桩、浮排的使用强度与时间分布等信息。

3.3.4 生态理论原型的空间实现：高潮位栖息地

高潮位栖息地同样是基于实证主义生态原理的形态原型。鸟类学家的高潮位栖息地理论指出，河流涨潮淹没滩涂地时能为水鸟提供浅水觅食、水岸停歇的场地。该理论要求：为保障大型水鸟成群起降，高潮位栖息地水面宽度不小于12m，长度不小于50m；水中央设置矮堤供水鸟停歇，堤上不能有遮挡水鸟观察天敌视线的高大植物；水位需保持一定的深度，以提供丰富的水鸟食源。基于上述知识，项目设计了长达158m的沙石双堤和包含三片起降水面的高潮位栖息地，水位由无动力的水梪调控，水深由双堤向两侧逐渐加深以适应不同水鸟的习性（图9）。该区域水系上游通过水梪与垛基果林湿地连通，保障充足的食物来源。

高潮位栖息地的设计假设为：在涨潮时能吸引以白鹭（*Egretta garzetta*）、苍鹭（*Ardea cinerea*）、夜鹭（*Nycticorax nycticorax*）、普通鸬鹚（*Phalacrocorax carbo*）、白胸苦恶鸟（*Amaurornis phoenicurus*）、黑水鸡（*Gallinula chloropus*）为代表的涉禽和以斑嘴鸭（*Anas zonorhyncha*）、小䴙䴘（*Tachybaptus ruficollis*）为代表的游禽来此停歇、觅食[46]。

在监测调整阶段，设置与鸟岛相同的监控设备，评估各类水鸟对深浅水域及沙石堤的使用强度与时间分布。

3.3.5 新旧技术融合延续文化情结：低维护韧性水系

将经验主义下果林潮道淤泥堆肥工艺、实证主义的三类水净化技术与浪漫主义的岭南水乡情结相结合，构建具有自净化能力的“主涌—连通支涌—疏浚果林潮道”三级湿地水网系统，同时作为保管龙舟的重要场地。淤泥堆肥工艺指将河网淤积的底泥堆叠到垛面，可起到疏浚水系和土壤增肥的效果。项目聘请熟练掌握该工艺的当地农民实施淤泥堆肥，疏浚打通三级河网水系，重新连接“毛细血管”般的上千条果林潮道（图10）。增加水系面积与长度，沿线结合渗透过滤、植物净化、食藻虫引入三项水净化措施，以较低维护成本持续提升湿地水质（图11）。湿地水系保留了村民埋藏龙舟的“藏龙潭”，将龙舟埋于河床的淤泥之中，可起到防腐作用。每年端午前挖出洗净、上龙头都是重要的民俗仪式。

低维护韧性水系的设计假设包括降低湿地水系维护成本、将湿地水质提升1~2个等级，以及传承龙舟文化。

监测调整阶段主要评估3项指标：1）湿地管理处每年公示的财务报表中的湿地维护费用；2）联动水务部门监测水质变化，并与湿地周边水系的水质进行对比；3）记录每年湿地中的龙舟训练、比赛及文化仪式情况。

4 总结与讨论

截至目前，海珠湿地生物多样性保护与修复工程已完成了原型设定、设计实验环节。虽然设置了评估指标，但尚未能完整实施监测调整环节，上述生态设计途径有待进一步验证其有效性。但就已掌握的部分湿地监测数据来看，设计实验初步呈现向好的趋势：湿地公园人流量明显上升；鸟类种类每年增加4~7种；新增了392种昆虫，其中包括2个新命名昆虫物种。项目中的5个设计实验均不同程度地实现了部分设计目标，其中增益水稻田系统、鸟岛成效较为明显，垛基百果林湿地系统、高潮位栖息地、低维护韧性水系有待进一步调整优化。

具体而言，在鸟岛营造初期，树顶筑巢繁衍的多是体型较小的白鹭（*Egretta garzetta*）、夜鹭（*Nycticorax nycticorax*），数量多达50只；一年后体型更大的苍鹭（*Ardea cinerea*）也开始在此筑巢繁衍，成为广州市中心区难得一见的苍鹭繁殖地。鸟岛周边的浮排上可常年观察到有白鹭（*Egretta garzetta*）、普通鸬鹚（*Phalacrocorax carbo*）、斑嘴鸭（*Anas zonorhyncha*）、鸿雁（*Anser cygnoides*）等水鸟栖息。浅滩与木桩成为水鸟觅食的理想场所，受潮汐水位的影响，觅食活动主要集中在低潮位时段，可以同时观测到超过30只水鸟觅食。增益水稻田系统成为水鸟、林鸟的主要觅食地，已监测到成群的斑嘴鸭（*Anas zonorhyncha*）、斑文鸟（*Lonchura punctulata*）等鸟群在此觅食，白鹭（*Egretta garzetta*）、夜鹭（*Nycticorax nycticorax*）、苍鹭（*Ardea cinerea*）也会散布在稻田各处觅食。水系中的赤眼鳟（*Squaliobarbus curriculus*）群落恢复良好，为开设海珠湿地动物观察课程、提升公众生态认知奠定了基础。高潮位栖息地营造的浅水区域吸引了水鸟觅食，单次观测数量可达到20只以上，但该水域面积达28 000m^2左右，因而成效并不明显，需要进一步探究其中的原因。在低维护韧性水系中，外来入侵物种罗非鱼（*Oreochromis mossambicus*）与福寿螺（*Pomacea canaliculata*）持续破坏水生植物，限制了水质净化能力，后续的设计调整需要考虑针对入侵物种的生态防治措施。垛基百果林湿地中54种新栽果树的生长态势良好，挂果良好，提供了生物食源，但因可观察到的鸟类数量有限，仍需要持续观察恢复效果，提出针对性的提升策略。

上述迹象部分表明，由原型设定、设计实验和监测调整三个步骤组成的生态设计实践方法展现了将生态研究与生态实践相结合、指导生

态设计优化、增强人类世生态系统韧性的潜力。需要强调的是，上述实践框架并不否定现有实证主义方法，甚至常要借助各种具体的实证主义方法。实践主义方法也不比实证主义方法更为简单或更易施行。实践主义方法的核心价值是提供一种“以做促研”的半先验范式，以及在目的明确的实践过程中进行学习的有效流程，旨在加速积累人类知识库中的生态设计工具。该方法既要求设计人员提升分析已有生态知识和生态原型的能力，也要求设计、工程界改变“建设结束即工作结束”的既有观念，形成跟踪评估生态设计手段绩效的习惯。这需要设计师、研究者和管理运营者的协同参与。上述改变能够赋予设计师更多塑造生态形态的权利与机会，使其不必过分拘束于既有形态。未来，研究团队将继续推进设计单位、科研单位与管理单位的三方协作框架，持续跟踪监测指标，并定量论证该生态设计途径的有效性。

图 1. 不同类型生态系统之间的转化（改绘自参考文献 [8]）
图 2. 生态设计的实践主义方法框架
图 3. 5 个设计实验的分布总图
图 4. 修复前的果林（左图）和修复后的垛基果林湿地系统（右图）。湿地系统旨在打造柔性水岸、改造水下地形、增加食源树种和构建完整的生物链。
图 5. 增益水稻田系统改造：“耕道”变“鱼道”
图 6. 全民共建的增益水稻田系统成为野生动物的乐园
图 7. 修复前的小岛和修复后的鸟岛。鸟岛种植筑巢林、增加觅食浅滩及浮排与木桩，以满足水鸟栖息繁殖觅食需求。
图 8. 在海珠湖中定制的水鸟栖息地，把不适宜鸟类居住的游人岛改造为鸟岛。
图 9. 修复前的场地（左图）和改造后的高潮位栖息地（右图）。栖息地可适应不同翅长、脚长水鸟的起降与觅食需求。
图 10. 通过传统的淤泥堆肥工艺疏浚连通湿地水系
图 11. 在湿地水系融入三种水净化技术