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Beyond Limit: A Service Design Intervention to Enhance Sustainable Awareness in Sanyang Wetland Community

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Abstract. The Sanyang Wetland, once a vital agricultural resource, faces severe ecological challenges due to persistent reclamation efforts and local activities. Water quality has deteriorated, leading to eutrophication and a loss of wetland attributes. This paper proposes an integrated approach to address these issues, combining ecological restoration with sustainable education. We introduce two key components: an artificial wetland in a greenhouse and education for sustainability. The wetland family park setup, including artificial floating islands, serves as a practical example within the digital twin application of this approach. It engages the public, particularly teenagers, in wetland conservation through an immersive educational experience. This study addresses ecological and educational dimensions simultaneously. It emphasizes sustained research and collaboration for impactful results, offering insights applicable in various contexts. This work presents a promising path to enhance wetland ecosystems, raise awareness, and empower communities to contribute to their preservation.

Keywords. sustainable education, service design, artificial floating islands, Sanyang wetland, digital twin

1. Introduction

For centuries, the Sanyang Wetland has served as an agricultural resource. However, persistent long-term reclamation efforts, along with the influence of residents' activities and industries, have resulted in consistently subpar water quality within the wetland channels, falling short of Class V standards. Additionally, the wetland has suffered from severe eutrophication and a notable absence of naturally occurring large-scale aquatic plants, causing it to lose its original wetland attributes [1]. The wetland ecosystem traditionally plays a multifaceted role, encompassing production output, water supply, disturbance regulation, environmental purification, gas regulation, and support for biodiversity [2]. Presently, the services provided by the Sanyang Wetland, based on its current ecological state, amount to a mere 5807 yuan per hectare per year. This figure represents only 10.5% of the ecosystem's potential value, with all current

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service values falling significantly below their potential, except for production output. Notably, the environmental purification service registers a deficit, owing 7038 yuan per hectare per year due to water pollution and the absence of vascular wetland plants. While ecosystem services can guide restoration efforts and their evaluation, it is essential to initiate wetland restoration by addressing the underlying ecosystem structure. Our findings underscore the urgent need to prioritize the restoration of the environmental purification service in the Sanyang Wetland [2]. An ecological challenge of paramount importance in the Sanyang Wetland is the excessive presence of phosphorus and nitrogen. Currently, the wetland has surpassed its environmental bearing capacity. In response to these pressing challenges, this paper introduces innovative solutions that integrate ecological restoration with sustainable education. These solutions encompass the implementation of an artificial wetland in a greenhouse and the incorporation of education for sustainability.

2. State of the Art

2.1. Sustainable Education and Environmental Awareness

The importance of sustainable education, particularly environmental education (EE), in promoting sustainable practices cannot be overstated. According to Goal-setting theory, goals are defined as specific, challenging, participative, and realistic objectives that individuals strive to achieve. Research consistently demonstrates that setting such goals leads to superior task performance compared to vague "do your best" goals, easy goals, or having no goals at all [3].

EE programs aim to enhance knowledge and attitudes towards the environment, ultimately fostering eco-friendly behavior. Both environmental knowledge and attitudes are considered essential foundations for environmentally responsible actions. Numerous studies indicate that outdoor education programs play a pivotal role in positively influencing environmental attitudes. By providing firsthand experiences and enjoyable interactions with nature, these programs not only impact knowledge and attitudes but also strengthen an individual's connection to nature [4]. Additionally, in the realm of education, it is imperative to promote awareness of the health and well-being benefits associated with nature exposure [5].

2.2. Positive Human Intervention in Ecosystems

In the context of sustainable development, human intervention in ecosystems has become increasingly essential [6]. As environmental changes intensify, there is a growing need for humans to intervene in ecosystems to preserve or restore ecosystem services and biodiversity. Such interventions can be categorized as reactive, active, or proactive and may operate at local, regional, or global levels. Reactive interventions aim to maintain the current state of an ecosystem or halt processes that degrade ecosystem values. Active interventions involve deliberate steps to modify ecosystem properties in a desired direction, while proactive interventions focus on addressing the underlying human drivers of ecosystem disruption [7].

Eco-engineering plays a significant role in ecosystem intervention, emphasizing the maximization of ecological benefits through the use of natural biogenic habitats and defenses. It is advisable to resort to artificial structures only when necessary, prioritizing "soft" engineering approaches that involve working in harmony with nature [8].

Ecological interventions, as distinct from conventional ones, target the ecological context in which spillover processes occur. These interventions offer novel and actionable solutions to manage or reduce spillover events, such as enhancing natural enemies, modifying habitats, or restoring ecosystem services [9]. However, it's crucial to recognize that intense human disturbance often leads to the removal of specialist species and the proliferation of adaptable species, resulting in biotic homogenization, which can negatively impact biodiversity [10].

2.3. Digital Solutions for Environmental Sustainability

The Internet of Things (IoT) and Industrial Internet of Things (IIoT) devices, supported by cloud and Big data technologies, are becoming instrumental in linking user experiences and facilitating lean manufacturing. Cloud storage is known for its efficiency, rich features, flexibility, and stability [11].

In response to regulatory demands and the imperative for environmentally responsible operations, industries are increasingly focusing on sustainability. Industry 4.0 technologies are being harnessed to create a platform for sustainable practices, aligning business goals with environmental considerations. This transformation extends to various aspects, including IoT, cloud-based data computation, Industry 4.0 principles, and enhancements in products and processes [11].

3. Problem Statement and Motivation

The Sanyang Wetland, situated in the East China coastal zone and near the bustling center of Wenzhou city, has experienced significant urban and economic growth over the past two decades. Covering an area of 11.41 square kilometers, it comprises over 160 island patches separated by rivers and drainages. Approximately 70.9% of the total area, equivalent to 8.09 square kilometers, is land, while the remaining portion is water [2]. The accelerated economic development in Wenzhou has resulted in the eutrophication of most rivers and wetlands in the region. This eutrophication has led to the occurrence of problematic cyanobacterial blooms in the Sanyang Wetland in recent years, with notable incidents taking place in 2017. These blooms were primarily caused by Euglena viridis in April, Chroomonas acuta and Cryptomonas cvata in May, and Gonyostomum semen in July. During these events, water bodies exhibited poor transparency and pronounced discoloration [12].

Human activities have substantially degraded the Sanyang Wetland. Key issues include excessive nutrient enrichment in the water, accumulation of heavy metals, the absence of wetland vascular plants, and a significant reduction in biodiversity. The water quality of the rivers in the area displayed characteristics of excessive nutrient enrichment, particularly in nitrogen and phosphorus content, significantly exceeding national safety thresholds. Furthermore, nutrient content in river sediment was relatively high, mirroring the conditions on the land. Overall, the water quality in the three wetlands is consistently rated as poor. The primary pollutant responsible for this water quality degradation is the excessive presence of nutrient salts [13].

Of note, the dominant economic plant in these wetlands is Ou citrus, covering 387 hectares or roughly 48% of the region's land area. The cultivation of Ou mandarins involves the application of pesticides such as oxalic acid, permethrin, tolbutazin, as well as urea, potash, and various compound fertilizers. This extensive use of agrochemicals has not only resulted in high economic input but has also contributed to environmental pollution. Given this context, it is worth considering the possibility of replacing 36% of the aging Ou citrus forests with alternative vegetation types [13].

4. Conceptual Design: Beyond Limit

This paper provides a solution elaborating on the conceptual approach of employing advanced technology and plant-based solutions to reduce phosphorus and nitrogen levels.

For the conceptual framework, it culminates in a symbiotic cycle wherein human actions and environmental dynamics balance. The dynamic introduction of Artificial Floating Islands serves as a proactive measure to alleviate the ecological strain resulting from eutrophication, effectively revitalizing the wetland with renewed vitality. Simultaneously, the educational facet engages individuals as catalysts for transformation, fostering a deep-rooted commitment to environmental consciousness. This dual-pronged approach cultivates a symbiotic rapport between humanity and the environment. The insights gleaned from immersive educational experiences not only enrich present actions but also lay the groundwork for informed future interventions. Consequently, this conceptual model encapsulates a self-reinforcing loop of reciprocal influence, underscoring the intrinsic interdependence between human endeavors and the overarching well-being of the environment.

Artificial Wetland in a Greenhouse: In response to the challenge of wetland overcapacity caused by eutrophication, the conceptual model proposes the implementation of Artificial Floating Islands. These islands serve as innovative ecological interventions designed to restore the health of the wetland ecosystem. The islands utilize plants that possess the capability to absorb excess nitrogen and phosphorus from the water, thus acting as a form of natural water purification known as phytoremediation. By integrating these artificial islands into the artificial wetland in a greenhouse, the model aims to alleviate the strain on the ecosystem by improving water quality and reducing nutrient imbalances.

Sustainable Education: Recognizing the crucial role that human awareness and behavior play in environmental sustainability, the conceptual model integrates the element of sustainable education. This component focuses on empowering individuals to actively participate in addressing environmental challenges. Users are engaged in hands-on experiences where they are involved in the creation of Artificial Floating Islands. This practical engagement not only reinforces a sense of ownership and connection to the environment but also imparts valuable knowledge about ecological systems, biodiversity, and sustainable practices. Through seamless service design, participants are guided through the process of constructing these islands, fostering a deeper understanding of the mechanisms behind wetland restoration.

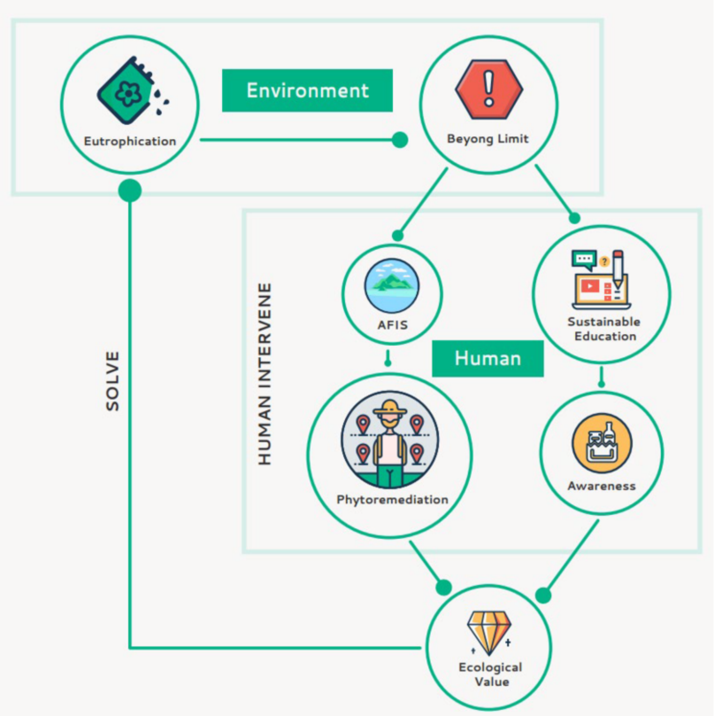

Figure 1. Conceptual Mode.

4.1. Artificial Wetland Creation and Restoration

4.1.1. Artificial Floating Islands

Floating islands occur naturally in various aquatic environments, typically consisting of a buoyant organic mat that supports plant growth. This mat has an upper layer known as the root zone, composed of interwoven plant roots, and beneath it lies a layer of decomposed peat and decaying plant matter called the peat layer. Artificial floating islands (AFIs) are designed to mimic the characteristics of natural floating islands and operate based on their principles. AFIs are constructed as soilless planting structures comprising floating mats, floating aquatic plants, sediment-rooted emergent wetland plants, and associated ecological communities, including algae, biofilms, zooplankton, and small invertebrates. The primary purpose of AFIs is water quality improvement, particularly through the substantial involvement of submerged plant sections in the treatment process.

Beyond their role in water quality improvement, AFIs have found applications in enhancing aesthetic appeal in ornamental ponds, creating or enhancing habitats, protecting littoral zones, and improving landscapes. By diversifying shapes, structures, and plant varieties, floating islands/wetlands can not only effectively treat wastewater but also enhance the visual appeal of water treatment facilities, potentially transforming them into tourist attractions. Additionally, floating wetlands provide habitat for wildlife, including birds, adding ecological benefits to their functionality.

4.1.2. Phytoremediation

Phytoremediation is the utilization of plants to remove and accumulate contaminants from the environment, encompassing the use of plants to mitigate, transfer, stabilize, or degrade pollutants in soil, sediments, and water [14]. Phytoremediation effectively removes nutrients like nitrogen (N) and phosphorus (P) from eutrophicated water and sediment. Thus, phytoremediation emerges as a valuable technology for mitigating internal pollution during the purification of eutrophicated water [15].

4.1.3. Purification capacity of aquatic plants

The water purification capabilities of various aquatic plants exhibit significant variations. The nitrogen removal rate from water quality ranged from 36.3% to 91.8% across ten aquatic plants, while the phosphorus removal rate ranged from 23.2% to 94.0%. Phosphorus removal primarily occurs through plant uptake, substrate and root adsorption, while nitrogen removal involves additional mechanisms such as ammonia volatilization, nitrification, and denitrification, in addition to plant uptake. Nitrogen uptake by aquatic plants contributed between 46.3% to 77.0%, with the remaining nitrogen removal attributed to other processes ranging from 23.0% to 53.7%. Phosphorus uptake by aquatic plants accounted for 54.3% to 92.7%, while other processes contributed 7.3% to 45.7% to phosphorus removal. Notably, nitrogen degradation rates surpassed those of phosphorus degradation because phosphorus removal relied solely on substrate and root adsorption, while nitrogen removal also encompassed ammonia volatilization, nitrification, and denitrification, facilitated by the transport of oxygen to the root zone by aquatic plants, thus enhancing nitrogen removal efficiency [16].

Mixed planting in artificial wetlands enables faster growth and more effective pollutant purification compared to single-planting systems. Some plants excel at nitrogen absorption, while others are more proficient in phosphorus enrichment. Leveraging these differences enables plants to complement each other's strengths, ensuring stable and sustained purification effectiveness. Combined experiments confirm that the judicious combination of aquatic plants enhances nitrogen and phosphorus purification [17].

4.2. Digital Twin

4.2.1. Application of Digital Twin (DT) in Wetland Management

Wetlands, renowned as the most biologically diverse ecosystems with multifaceted ecological roles, pose a considerable challenge when it comes to orchestrating the necessary resources for a widespread network of constructed wetlands. As the proliferation of constructed wetlands continues, there arises a growing concern regarding the timely maintenance of these custom-made ecosystems. Given the inherently dynamic nature of wetlands, effectively managing the ever-evolving data and responses to unique circumstances necessitates an apt technological solution.

A DT architecture description serves as a representation of the DT system, elucidating the structure, behavior, and applications that encompass subsystems and modules. The amalgamation of four pivotal Industry 4.0 technologies the Internet of Things (IoT), Augmented Reality (AR), Cloud computing, and big data.

The IoT serves as the foundation for data collection, aggregating information from sensors deployed across each individual wetland. The exponential growth of data and the intricate interplay among data entities necessitate substantial data processing to construct information models. This IoT system encompasses seven key features: real-time monitoring, remote control, visualization of historical data, locating Artificial Floating Islands (AFIs), providing both overall and individual wetland status updates, indicating wetland statuses on maps, and processing community feedback through backend systems [18]. This integration enhances the efficiency of maintenance and operations by simplifying the process of locating AFIs and acquiring nutrient data which could be checked by the users after they put their own AFIs.

4.2.2. Rapid Detection of Nutrients Using Electronic Sensors

Electronic sensors offer distinct advantages compared to their conventional counterparts. They directly transmute chemical signals into electrical signals without the need for sample pretreatment or postprocessing, simplifying sensor operation and signal acquisition [19]. In response to the escalating demand for field-deployable, rapid, sensitive, and cost-effective sensors, this project adopts electronic nutrient sensors, encompassing potentiometric sensors, voltammetric sensors, and field-effect transistor (FET) sensors to detect the concentration of N and P in the water.

5. Fast Prototyping Methodology

The users could make their own AFIs in the Artificial Wetland Green Parks. The material would be prepared by staff if they registered in advance. The AFIs has several parts that need to be assembled by users including specific aquatic plant, substrate (80% fiber and 20% soil), float made of PE and concrete anchor. With connection and combination as Jigsaw, AFIs would be put in the Artificial Wetland to absorb N and P in the water. The prototype shows the diverse methods of connection and the effect of Phytoremediation.

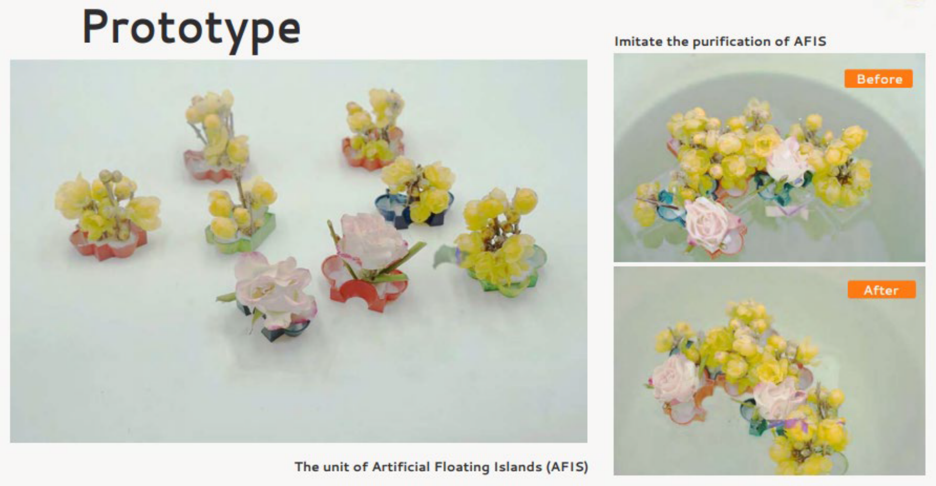

Figure 2. Prototype of AFIs.

6. Blueprint for Implementation

The service design blueprint presents an innovative approach to experiential and sustainable education tailored to teenagers. Enabling user engagement in crafting Artificial Floating Islands (AFIs) provides a distinctive learning experience that merges hands-on involvement with ecological consciousness.

- Experience Stage 1 introduces teenagers to the process by offering an app interface that empowers them to select aquatic plants and plates. This digital initiation serves as a gateway to tangible interactions. Teenagers are guided through the plant selection process, facilitated by an intuitive plant list interface. Similarly, plate selection is streamlined through a calendar display with available slots, ensuring simplicity and engagement.
- Progressing to Experience Stage 2, the transition from digital to physical is seamless. Upon reaching the greenhouse, teenagers confirm their reservations, initiating the direct communication of crucial reservation information. Frontstage personnel, represented by the reception, provide guidance, enhancing the experiential component. Simultaneously, backstage processes efficiently manage user information, underpinning the interaction's efficacy.
- Experience Stage 3 unfolds as the teenagers personally create AFIs, fostering a profound connection with sustainability. Guided by frontstage staff, they select customized AFI unit. The process is an embodiment of the educational initiative's core principles. Backstage efforts, encompassing material preparation from the warehouse, demonstrate the intricacies of resource management and the technical aspects of island construction.
- In Experience Stage 4, the teenagers embark on a journey of exploration and education. Taking a cruise allows them to navigate their creations, encouraging a deeper appreciation for the ecological impact of their efforts. This voyage is overseen by frontstage staff, who meticulously plan routes and facilitate learning through interaction. Furthermore, by visiting other users' islands within the artificial wetland, communication and shared experiences foster a community of environmentally conscious individuals.

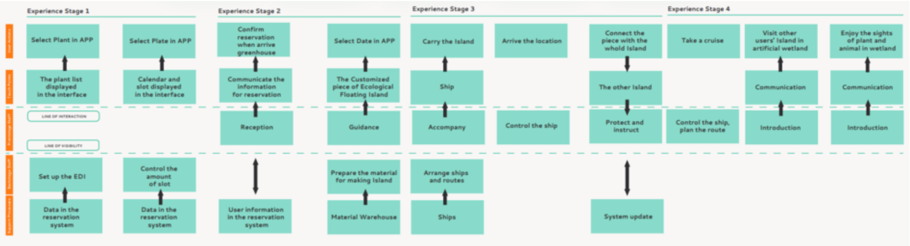

Figure 3. Blueprint.

7. Discussion and Conclusion

When applying Artificial Floating Islands (AFIs), the potential ecological impact should be considered. Some highly effective water purification plants, such as water peanuts and water hyacinth, can become harmful invasive species when introduced to areas outside their native habitats. Improperly selected and managed AFIs may inadvertently disrupt local agriculture, aquaculture, and biodiversity. Additionally, the decomposition of long-soaked floating materials can contribute to pollution concerns [20]. Furthermore, it's important to note that temperature plays a significant role in nutrient removal processes. Research has shown that the optimum temperature for these processes is around 30°C, which aligns with the average temperature during the summer and autumn seasons at the pilot-scale site [21]. The manager of the wetland should take this temperature factor into account when arranging activities and implementing AFI systems for effective nutrient removal.

In conclusion, the Sanyang Wetland faces pressing ecological challenges that demand immediate attention. The deterioration of water quality and the loss of its wetland characteristics underscore the urgency of restoration efforts. This paper has introduced an integrated approach that combines ecological rehabilitation with sustainable education to address these challenges effectively.

The implementation of an Artificial Wetland in a Greenhouse and the incorporation of Education for Sustainability offer practical solutions. The wetland family park, featuring artificial floating islands, serves as a tangible example of this approach, actively engaging the public, particularly teenagers, in immersive educational experiences focused on wetland conservation.

Our approach provides a comprehensive and synergistic solution that addresses both ecological and educational dimensions. It also provides a direction for applying a digital twin system to wetland restoration. This work not only holds great potential for enhancing the ecological health of wetland ecosystems but also for raising awareness and mobilizing communities to take an active role in their preservation.

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