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# Application Research of Waterborne Plastic Waste Recycling Device Based on Green Design Principles

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**Abstract.** In light of the severe plastic pollution in water bodies, this paper designs a plastic waste recycling device based on the "green design principles" to address the issue of plastic debris in inland waterways. This approach aims to tackle the problem of plastic waste entering the oceans at its source. The overall structure of the device incorporates an environmental recognition system, a green product system, and an interactive system. These systems encompass regional environmental awareness, integrated product design awareness, modularization awareness, and more to adhere to the "3R" principles of green design, effectively addressing the problem of plastic pollution in water bodies.

**Keywords.** Green design, plastic waste, device design, recycling system

## 1.Introduction

The economic development and convenience brought about by plastic production are widely recognized. However, certain literature extensively discusses the impacts of plastic production and its lifecycle on human growth, endocrine disruption, and immune-related cancers [1]. Furthermore, the recycling and reuse of plastic waste have garnered increasing attention. Currently, plastic waste is primarily disposed of in landfills and eventually finds its way into the environment, flowing into rivers and oceans, posing a severe threat to marine ecosystems [2]. This is an urgent problem that needs to be addressed.

Existing research has summarized various methods for plastic waste recycling, including optional sorting, density separation, flotation, and Tribo-electrostatic separation [3]. In practical terms, there are mechanical recycling methods such as the floating salvage vessel developed by the Shanghai Municipal Waste Disposal Company and the Seabin marine garbage bin in Australia, which have proven effective in recovering plastic waste from water bodies [4]. However, these devices often suffer from issues such as high energy consumption, unsuitability for use in inland waterways or fast-flowing rivers where they may struggle to efficiently capture surface plastic waste.

In light of these challenges, this paper employs the "green design principles" to develop an innovative solution for plastic waste retrieval in inland waterways, akin to the capillary-like network of blood vessels. The objective is to reduce the volume of plastic waste entering the sea at its source.

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## 2. Understanding Green Design

"Green" products or services possess several key characteristics. For instance, they emphasize factors such as reducing energy consumption, reusing resources, and protecting the ecological environment during the product design phase, all while ensuring the functionality of the product is maintained as a paramount goal [5] . In today's green economy ， the ease of disassembly in a product significantly influences its overall value and sustainability[6]. Partial disassembly, based on cost-effectiveness, can lead to the recovery of discarded components. This approach aligns with a systems theory perspective where resources become a basis for competition in businesses. Ghisellini P and others propose that future considerations should balance the interaction between environmental and economic systems, focusing on aspects such as recycled materials, reuse, and technological integration [7].

Scholars introduce environmental awareness into product modular analysis by considering eight environmental factor criteria. They utilize a fully hierarchical analysis method to determine the priority of these criteria, establishing a semi-quantitative environmental factor modular analysis model [8]. Furthermore, LI Zhongkai emphasize that modular design should meet product functionality, enhance the green performance of modular products, and prioritize considerations such as downsizing, reusability, and recyclability [9]. Based on these principles, the overall structural design is derived.

## 3. Overall Structural Design and Working Principles

### *3.1 Overall Structural Design*

The core of green design is environmental consciousness. In green design, the system's overall structure incorporates an environmental recognition system, which encompasses awareness of the specific usage environment of the device; a green product system, which includes integrated product design awareness, modularization awareness, and awareness of using green materials; and an application system, which ensures the effective transmission of environmental awareness, low learning and usage costs, and clear recognition of the device's value.

### *3.2 Working Principles*

#### *3.2.1 Environmental Recognition System: Regional Environmental Awareness*

In green design, environmental awareness is crucial, and it requires a deep understanding of the product's lifecycle and its relationship with the surrounding environment [10]. When it comes to plastic waste entering the ocean, it initially accumulates in small waterways within densely populated areas and areas with dense river networks. Approximately 90% of marine plastic pollution originates from rivers [11]. To enhance collection and recycling rates, the challenge is to optimize collection and transportation methods. Therefore, it is essential to have a thorough understanding of the conditions in the regional waterways and strategically place interception points.

In this section, existing GIS (Geographic Information System) technology can be employed. GIS's core functionality is to integrate various datasets and perform location-based analysis, storage, and display in the form of maps. This approach enables a comprehensive understanding of the characteristics of population distribution and river density in the region.

In November 2017, hydrogeologist Christian Schmidt conducted research on plastic waste carried by the Pearl River Basin in the Guangzhou region of China, ranking it 7th

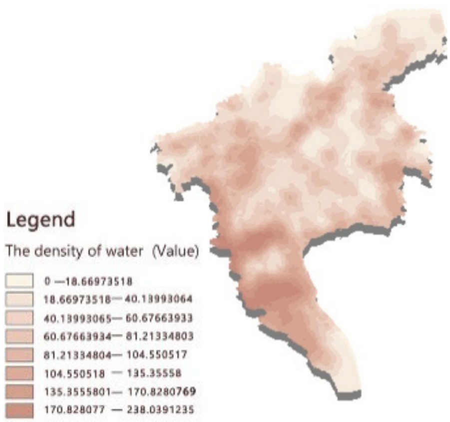


**Figure 1.** Kernel Density Analysis of River Quantity

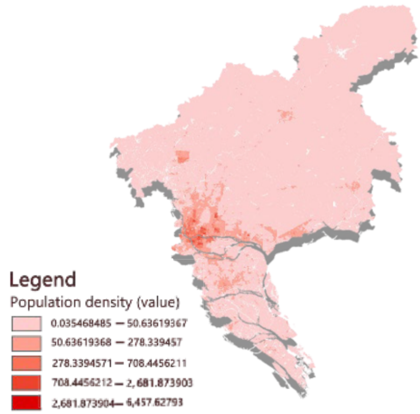


**Figure 2.** Kernel Density Analysis of Population Distribution

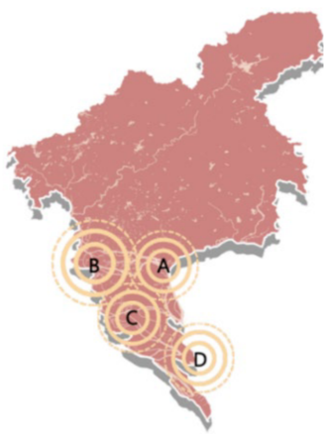


**Figure 3**. Analysis of Regional Interception Points

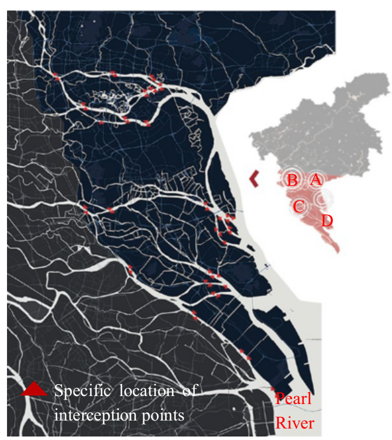


**Figure 4.** Analysis of Specific Interception Points

in terms of plastic waste load among global rivers[12]. Therefore, this paper selects Guangzhou as the environmental research area. It uses ArcGIS kernel density analysis to analyze relevant population and river distribution data (as shown in Figures 1 and 2). Kernel density analysis is a vital data visualization technique that reveals the density distribution of data in a region through varying colors. Based on the density overlay of river quantity and population distribution maps, interception points (A, B, C, and D in Figure 3) are selected.

Points A, B, and C are located in areas with high population density in the city center, coinciding with high river density regions. Point D represents the primary waterway where the Pearl River flows into the sea. Intercept points are strategically placed based on regional environmental data to minimize environmental impact and enhance collection rates. Further specific interception points are determined based on this analysis (as seen in Figure 4 red triangle). Identifying hotspots with a significant source of plastic waste is key to addressing the plastic waste problem and is the first step in planning interception points. Plastic waste tends to accumulate in specific areas due to urbanization and population density factors. Utilizing existing data helps guide future actions effectively.

### *3.2.2 Green Product System*

*(1) Integrated Product Design Awareness*

Integrated product design awareness consists of three interconnected modes: power integration, collection integration, and transportation integration (as shown in Figure 5).

**Power Integration**: This mode focuses primarily on reducing material and energy consumption. It utilizes the resources available in the waterway environment where the device is located, harnessing tidal energy, hydropower, and solar energy as the primary sources of power for the device. It enhances interactive features to engage the public in the device's energy generation process. To adapt to varying water currents and tidal energy intensities in different rivers, multiple compact gears are placed within the device, allowing turbines to generate power under different water flow conditions. Solar panels on the device's surface absorb additional power for daily needs. A part of the electricity also comes from public interaction through kinetic energy, as demonstrated at point E with exercise bikes (At the red dashed line in Figure 6). These bikes are equipped with power-generating mechanisms, encouraging the public to participate in plastic waste recycling activities.

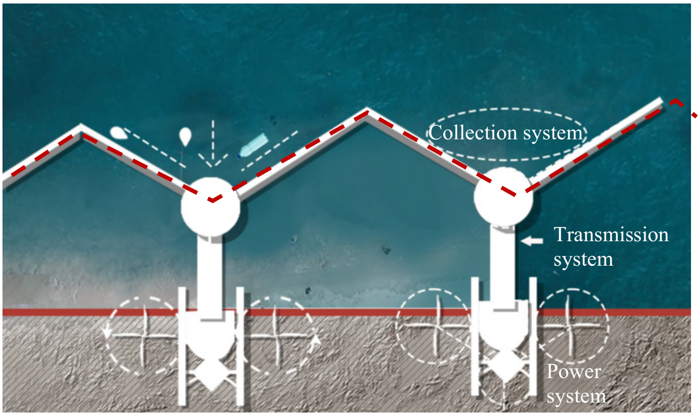


**Figure 5.** Analysis of Integrated Design Awareness

**Collection Integration:** This mode leverages the characteristics of water flow to collect plastic waste efficiently. It uses a cascading baffle system configured in a "V" shape to align with the water's direction and guide plastic waste towards collection points. The angle between the baffles can be adjusted based on the width of the waterway to accommodate potential navigational requirements. The baffles can also be interconnected to enhance their barrier effect, especially in situations like heavy rain when increased land-based plastic waste might enter the waterway. In such cases, the baffles can be connected to create a barrier between the land and the river, preventing plastic waste from flowing into the waterway, as illustrated in the collection system in the plan view (At the red fold line in Figure 5).

**Transportation Integration:** In the transportation integration mode, the design optimizes the use of potential energy and the movement of the paddle conveyor to enhance plastic waste transportation efficiency. As the paddle conveyor moves, it generates a flow of water from point F to point B. This movement increases the suction force at point B, further attracting water from around the device to converge along the "V-shaped baffles." This, in turn, propels more plastic waste in the water to filter towards the collection point. Below point D, there is a perforated aluminum plate with dense circular holes of 3-5mm in diameter. This plate serves to separate plastic waste from the water source. The water flows back into the river, while the plastic waste is lifted by the paddles and directed upwards into the storage compartment located above. These three integrated modes collectively achieve the low consumption of materials and energy within the collection device.

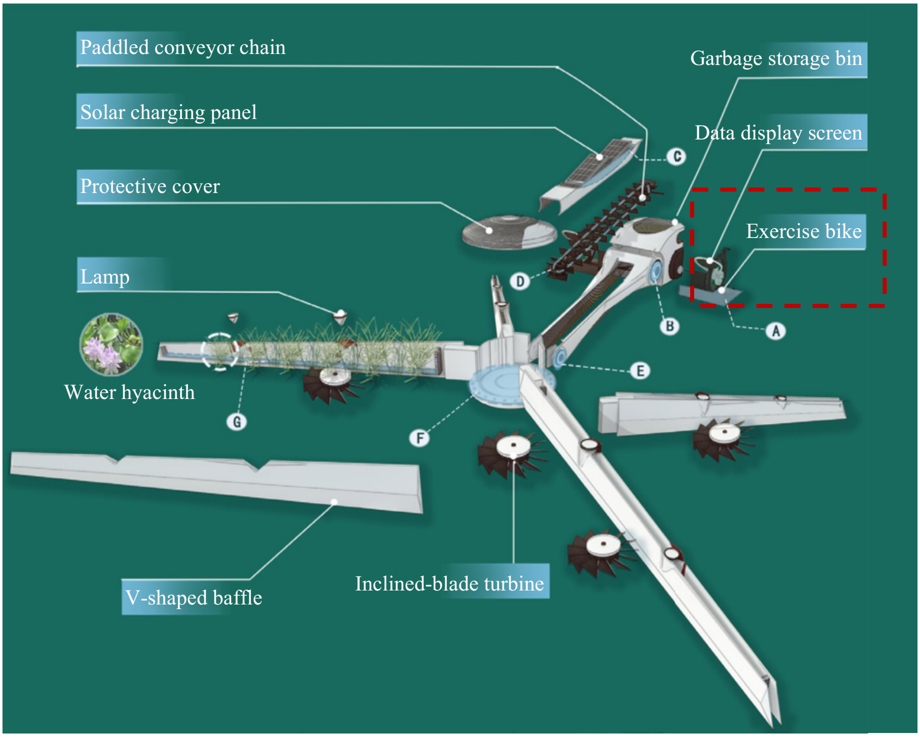


**Figure 6.** Design Explosion Analysis Diagram

*(2) Modularization Awareness*

Modularization awareness in the design of the plastic waste collection device involves creating components that can be easily assembled and disassembled. This approach reduces the design and manufacturing cycle of the collection device and promotes resource efficiency through modular and standardized designs. Universal design of components increases their versatility and utilization, simplifies the production process, reduces product recycling and maintenance costs, and minimizes repetitive labor.

In this study, modularized structural components were investigated. For example, to

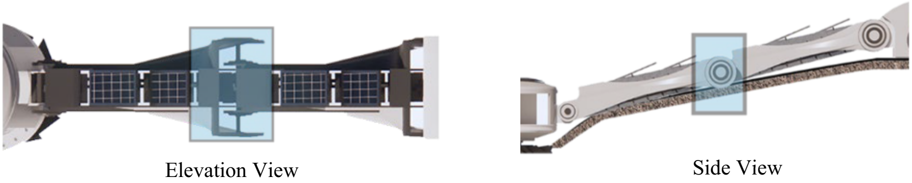


**Figure 7.** Connection Structure Diagram

accommodate variations in the slope of different riverbanks, a rod-like connecting mechanism was employed to allow the continuous extension of the paddle conveyor in the central part of the device,(At the blue box section in Figure 7), preventing it from getting stuck.

Furthermore, the "V-shaped baffles" inside the device are constructed using individual square wooden grids. (See blue box in Figure 7). These grids serve to adapt to the required length of the river to be intercepted and provide habitats for seabirds. The length of the baffles is determined based on the curvature of the coastline. If the coastline is straight and long, a single wooden grid is used to form a long and straight baffle. If the coastline is curved, modular wooden grids are combined to create a more flexible, segmented baffle that conforms to the curve of the coastline.

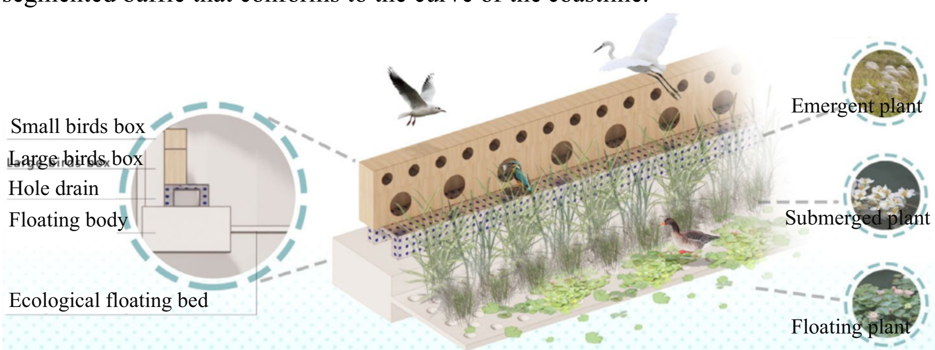


**Figure 8**

Moreover, the spatial layout of the modular wooden grids on the baffles can accommodate the resting needs of seabirds. Each individual bird nesting box is designed to accommodate different bird species with varying sizes of holes, and drainage holes are provided for excreta and tidal water drainage. Additionally, 500mm by 500mm individual ecological floating beds are connected for water purification through floating, water retention, and submerged plants. These floating beds purify the water quality by growing plants, providing shelter, food, and breeding spaces away from human activity for seabirds through a combination of three types of plants. (At Figure 8).

*(3) Green Material Awareness*

Due to the device's prolonged exposure to water, material selection prioritizes wood to avoid the generation of microplastics resulting from prolonged water contact. In this regard, researchers in relevant fields have explored the synthesis of organic silicon polymers and the use of materials like linseed oil-based emulsions to enhance the waterproof properties of wood [13-14].

### 3.2.3 Application System: Green Value Perception Transmission

Marshall McLuhan once asserted that "the medium is the message" to reveal the essential nature of communication. In the context of the plastic waste collection device, it is crucial to effectively communicate its green values to the public, convert information, and achieve interaction awareness. This involves going beyond basic visual effects and focusing on emotional design, including behavioral and reflective design, emphasizing values beyond aesthetics [15]. Green design should release additional value beyond the product itself, emphasizing the way information is conveyed. This approach ensures that the device's purpose of plastic recycling garners more support and enhances its intrinsic value. Utilizing various interactive branches and detailed experiences, the product tells the story of reducing plastic pollution, aiming to achieve green psychological goals.

In the nearshore part of the device, specifically at point E, (At the red dashed line in Figure 6), an exercise bike mechanism is installed. This serves the dual purpose of allowing exercisers to convert kinetic energy into electrical power for the device while providing an interactive display screen on the bike. The screen conveys ecological information stories, recording data such as energy supply, calorie consumption, and exercise duration, transforming them into personal data records. This approach turns plastic waste collection into a data-driven topic in personal social networks. By simplifying the learning and operation costs for the audience and facilitating the transition from individual to societal awareness, it fosters the formation of an


**Figure 9.** Interactive Information Chart

environmentally friendly social network. (At Figure 9). The device establishes an implicit interactive field of green environmental values, enhancing recognition of the device's value within society.

## 4. Conclusion

This design is specifically tailored to address the issue of plastic waste pollution in waterways, considering the current state of plastic pollution in water sources. Throughout the entire process, the design adheres to the "3R" principle of green design, incorporating environmental awareness, integrated design, modular design, green materials awareness, and information interaction awareness to form a systematic approach to green design for tackling plastic waste collection in specific regions.

The analysis of the unique characteristics of the distribution density of waterways and population density in the Guangzhou region was conducted to strategically select interception points along the rivers, enhancing the efficiency of plastic waste collection in the Pearl River. The design of the device fully reflects the diversity of river conditions, employing modular and integrated approaches, and utilizing green materials to minimize the potential for secondary pollution from the equipment.

Additionally, the device facilitates the transmission of green value information through interaction with users, increasing public awareness and engagement in green actions. This, in turn, expands its influence and enhances the devices efficiency in addressing plastic pollution.

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